SOIL SURVEY SCALE AND ITS EFFECT ON LAND USE PLANNING[1]

J. A. M. Demattê
University of São Paulo, ESALQ,
Department of Soil and Plant Nutrition,
Piracicaba, SP, Brazil

Peterson R. Fiorio and Rogério Costa Campos
Institute of Technological Research (INPE),
São José dos Campos, SP, Brazil

Marcos R. Nanni
Department of Agronomy, University of Maringá,
Maringá, PR, Brazil

Jane Costa Lima and Walmiqui Costa Lima
Department of Agronomy, University of Curitiba,
Curitiba, PR, Brazil

Abstract: Soil survey maps compiled at a variety of scales (1:5,000; 1:100,000; 1:500,000) were incorporated into a GIS and compared in terms of the number of soil classes (and discrete soil units belonging to these classes) that could be identified on the basis of the System of Analysis for Agricultural Planning (SAMPA). Significant differences in the number of soil classes were observed between the detailed (1:5,000) survey and the two others. The semi-detailed (1:100,000) and the recognition (1:500,000) maps did not differ in terms of the number of soil classes depicted, but there were nonetheless differences in soil classification, which has a direct bearing on their utility for land use planning.

INTRODUCTION

Awareness of environmental degradation has expanded in recent years and several recent studies in Brazil have demonstrated the efficacy of planning to reduce the impact of human activity (Koffler, 1996, Fiorio et al., 2000). Planning decisions, in turn, usually are based on maps of land use, relief, and soils, employing different scales of mapping according to the objectives of the work.

In Brazil, as in many other parts of the world, most soil maps are compiled at what can be described as the "recognition level," featuring general coverage at a rather small scale. In the United States, in contrast, detailed soil maps based on sur-

Mapping Sciences and Remote Sensing, 2002, **39**, No. 4, pp. 258-272.

veys are conducted at a rate of 120 to 240 ha per day, or 288,000 ha of land surveyed per year (Morse, 1999). In Brazil, the most recent material is a recognition soil map of São Paulo state, published by Oliveira et al. (1999), which consists of a compilation and re-evaluation of previously mapped data adapted to the new soil classification system (Embrapa, 1999).

Dalmolin (1999) emphasized the need for more critical research in soil mapping and its application to the practice of soil management in Brazil. Research is especially lacking on the implications of different levels of soil surveys on the practice of soil management and land use planning. In regions of the country where the economy is predominantly based on agriculture, an intimate knowledge of the soils, their character, spatial distribution, and physico-chemical properties is a prerequisite for a good land use planning. Consequently, the working scale may influence the results obtained from studies based on soil maps, indicating the need for comparative evaluations of their basic properties at a variety of scales.

The concept of "precision agriculture" has been advanced in land use planning as a means of optimizing farm profit and minimizing the disruption involved in changing methods of agricultural production (Schueller, 2000). As determined by Thomasson et al. (2002), new farm technologies should be developed with consideration of soil quality. Furthermore, since accurate data are quite important for precision agriculture, soil maps at a variety of scales form the basis for the system.

Researchers have tested a variety of methods to generate data for land use planning. However, according to Assad (1995), the basis of the systems most widely used in Brazil to evaluate the farming potential of land are the Land Suitability Classification system established by Ramalho et al. (1978) and the Land Capacity Classification (Lepsch et al., 1991). These systems incorporate elements of judgment that are often subjective. Formaggio et al. (1992) observed that the most realistic method for promoting adequate land use would be a semi-automated system rather than a subjective one, in which the definition of the land's agricultural suitability is determined through periodic verifications of current land use and comparisons with its suitability for that use.

For adequate land use planning, therefore, it is necessary to have a soil map that is compatible with the area to be worked in terms of the map scale and with the planning objective (Lepsch et al., 1991). Sometimes this is not possible because of the scarcity of maps or the user's lack of information about the risks of using soil maps at improper scales. On the other hand, in areas with homogeneous soils and topography, semi-detailed survey levels are often very similar to detailed ones as far as the mapping units are concerned. In such cases, the use of semi-detailed maps (e.g., 1:100,000) instead of detailed ones is perfectly appropriate for agricultural planning purposes; indeed, this has been done in many sugar cane-growing areas in the State of São Paulo (Joaquim et. al., 1994).

In Brazil, moreover, there are extensive tracts of flat land ranging from 300 to 500 ha with homogeneous soils and topography. In such cases, even recognition maps (e.g., 1:500,000) of low spatial resolution can be used for agricultural planning purposes. However, in actual practice, have the soil surveys carried out thus far achieved the intended levels? To what extent are there differences among them? And how do they relate to the actual land use? These issues are quite theoretical and, because they are apparently so "obvious," have been largely unexplored. Thus, there is a clear need for these theoretical parameters to be tested by non-subjective systems. Based on computerized techniques, therefore, we formulated two related objectives: (1) to evaluate the variation among soil surveys of differing levels of detail (scale) in land use planning and in determining preferential land uses; (2) to test the digital mapping system using geographic information systems (GIS).

MATERIALS AND METHODS

The 345 ha area of this study is located in the region of Piracicaba, State of São Paulo, Brazil, at 47°35′00″W. Long. and 22°40′00″S. Lat. and an elevation varying from 500 to 590 m. According to Koppen's classification, the climate is Cwa, characterizing it as subtropical, with dry winters and rainy summers. The region's average annual rainfall and temperature are 1,200 mm and 21°C, respectively. The lithology is represented by the clayish flaky rock of the Corumbataí and the diabase of the Serra Geral Formation (IPT, 1981).

Several maps were used in this study. A geological relief map at 1:5,000 scale was digitized with a 5 m contour interval, in addition to main and secondary roads and the drainage network. Based on these digitized contours, a digital terrain model was produced and sliced using the Spring Georeferenced Information Processing System (INPE, 1999). This generated a clinographic map at 1:5,000 scale. The land relief map was also used as the basis for a detailed soil survey. A semi-detailed pedological map of the Piracicaba region, at 1:100,000 scale (Oliveira and Prado, 1989) and a recognition map at 1:500,000 scale (Brasil, 1960) scale also were digitized using the vector editing module of the Spring Georeferenced Information Processing System (INPE, 1999). The IDRISI GIS (Eastman, 1992) was used to crosstabulate the information and export the data to System of Analysis for Agricultural Planning (SAMPA) (Koffler, 1992, 1996). The land use capacity class map was plotted by combining information from the detailed soil survey and the clinographic map.

The detailed soil survey of the area (Embrapa, 1995) was performed by boring holes distributed in toposequences at 200 meter intervals, with a total of 39 sampled points that resulted in 0.2 observations being made per minimum mappable area. Soil samples were collected from the boreholes at fixed depths of 0–20, 40–60, and 80–100 cm, and its location georeferenced by the Global Positioning System. The mapping units were characterized by a profile evaluation. Chemical (Raij et al., 1987) and physical (Camargo et al., 1987) analyses were performed on soil samples. The soil classification of the detailed map was based on Embrapa (1999) and correlated with *Keys to Soil Taxonomy* (Soil Survey Staff, 1998).

The land use was established based on remote sensing imagery from the Landsat-5 Thematic Mapper in bands 3, 4, and 5. Land use categories were demarcated by the Spring software program based on supervised classification using the Maximum Likelihood, MAXVER procedure (INPE, 1999).

After preliminary analyses of the physical and chemical limitations of the soils and of the area's slope, the SAMPA program organizes the data into areas of suitability for four groups of crop agriculture (short-cycle, long-cycle, pasture, and silviculture), thus providing a semi-automated rather than subjective definition of the proper land use, or preferential use (Fiorio et al., 1999). For a quantitative evaluation

Table 1. Cross Tabulation of Soil Maps Obtained at Different Scales

Detailed soil survey 1:5,000[a]	Semi-detailed soil survey 1:100,000 [a]		Recognition soil survey 1:500,000 [a]	
	LR	PE	LR	LE
LR[b]	118.08[c] (34.2)[d]	2.19[c] (0.6)[d]	120.27[c] (34.8)[d]	0.00[c] (0.0)[d]
LE	54.98 (15.9)	45.31 (13.1)	97.54 (28.2)	2.75 (0.8)
LV	2.11 (0.6)	0.00 (0.0)	2.11 (0.6)	0.00 (0.0)
PE	9.13 (2.6)	40.06 (11.6)	29.66 (8.6)	19.53 (5.6)
PV	0.71 (0.2)	40.95 (11.8)	5.33 (1.5)	36.33 (10.5)
Al	0.00 (0.0)	5.90 (1.7)	0.00 (0.0)	5.9 (1.7)
R	0.00 (0.0)	20.98 (6.1)	0.54 (0.1)	20.44 (5.9)
C	0.00 (0.0)	4.99 (1.4)	0.00 (0.0)	4.99 (1.4)

[a]Scale of publication.

[b]Abbreviations: LR = Latossolo Vermelho Distroférrico típico (Typic Haplorthox); LE = Latossolo Vermelho (Typic Haplorthox); C = Cambissolo Háplico (Typic Disctochrept); R = Neossolo Litólico (Lithic Distrochrept); Al = Neossolo Flúvico (Typic Fluvent); PE = Argissolo Vermelho distrófico típico (Rhodic Paleudult); PV = Argissolo Vermelho-Amarelo distrófico típico (Rhodic Paleudult); LV = Vermelho Amarelo (Typic Haplorthox).

[c]Area in hectares of coincidence of detailed soil map with semi-detailed and recognition maps.

[d]Percentage of coincidence of detailed soil map with semi-detailed and recognition maps.

of the soil and land use maps, a cross tabulation was made using the Spring program (INPE, 1999).

RESULTS AND DISCUSSION

Comparison of Soil Survey Levels

The detailed soil map (Fig. 1) revealed the occurrence of eight mapping units: LR[2], Latossolo Vermelho Distroférrico típico (Typic Haplorthox); LE, Latossolo Vermelho and LV, Vermelho Amarelo (both Typic Haplorthox); C, Cambissolo Háplico (Typic Disctochrept); R, Neossolo Litólico (Lithic Distrochrept); Al, Neossolo Flúvico (Typic Fluvent); PE, Argissolo Vermelho distrófico típico (Rhodic Paleudult); PV, Argissolo Vermelho-Amarelo distrófico típico (Rhodic Paleudult).

A comparison of the detailed survey with the semi-detailed one (Fig. 1) shows that the LR mapping unit, on both maps, exhibited 34.2% coincidence (Table 1). The PE unit showed only 11.6% coincidence. This means that compatible (identical-unit) areas were depicted 45.8% of the time on the two maps and areas of different (non-identical) soil units 54.2% of the time. This variation is distributed among the remaining mapping units of the detailed survey.

Comparing the detailed survey and the reconnaissance survey (Fig. 1), in which two mapping units (LR and LE) were identified, it was found that the coincident areas accounted for 39.6% of the map area, of which 34.8 % represented LR and only 0.8% the LE, and that the error between the maps (60.4%) was distributed among the remaining units of the detailed survey (Table 1).

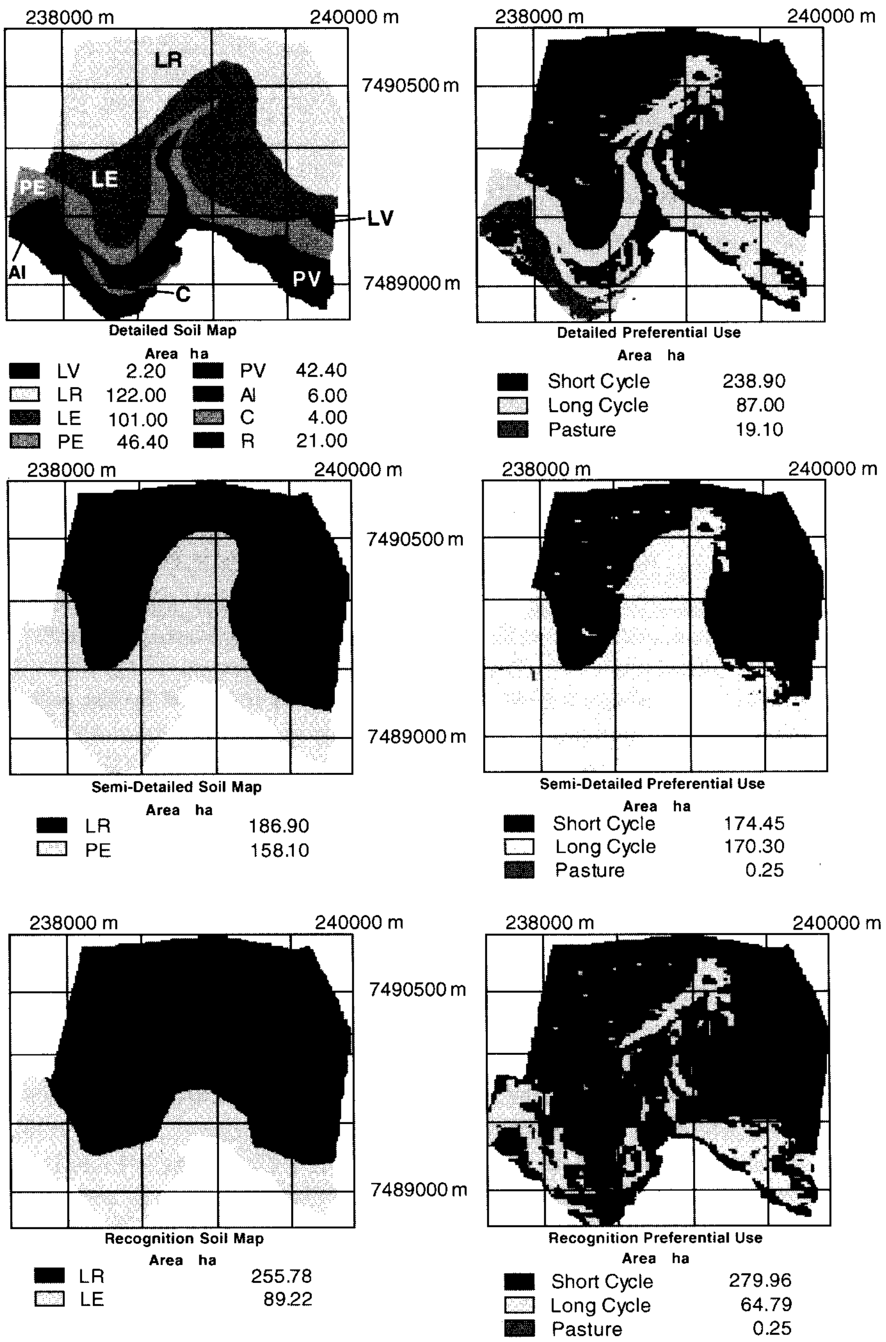

Fig. 1. Identification of soil classes and preferential use—determined by the SAMPA (System of Analysis for Agricultural Planning) software—for different levels of soil surveys.

Table 2. Comparison between the Different Levels of Soil Survey

Level of soil maps	Number of boreholes	Number of profiles	m.m.a. (m^2) [a]	Scale of base map	Scale of publication map	Number of soil classes detected
Detailed soil map	39	8	0.1	1:5,000	1:5,000	8
Semi-detailed soil map	2[b]	2	40.0	1:50,000	1:100,000	2
Recognition soil map	2[b]	2	1,000.0	1:100,000	1:500,000	2

[a]Minimum mapable area (m.m.a.) = [Publication scale × 0.4]/10^8; the result is reported in ha after-Emprapa, 1995.

[b]Supposed values realized in the area considering the information of the original soil maps.

The differences found in the cross tabulations can be better explained via the methodology that was used, which is expressed by the following: number of field observations, number of profiles observed, minimum mappable area (m.m.a.), scale of publication, and number of classes (Table 2). In compiling the detailed soil map, 39 boreholes were excavated in an area of 345 ha—i.e., 1.3 observations per hectare. Profiles were analyzed for each delimited mapping unit, which confirmed the presence of eight soil classes. On the other hand, during the semi-detailed and reconnaissance surveys two observations each were made in the study area, resulting in the two soil mapping units identified for both (Fig. 1).

A comparison of the detailed soil map and the semi-detailed one revealed that the latter was more homogeneous, a fact that was attributed to its scale of publication (i.e., 1:100,000), indicating a possible loss of some soil limits, since the base map used was at a scale of 1:50.000. This loss is also due to the methodology used in compiling the map—i.e., a minimum mappable area (m.m.a.) of less than 40 ha and observation intensities of 0.3 to 0.4 (Embrapa, 1995). The same trends were observed in the low-intensity reconnaissance surveys (Brasil, 1960) which, because their generic nature focused on the planning of large areas, are published at a small scale (1:500,000) (Embrapa, 1995), corresponding, in terms of minimum mappable area, to areas of 2.5 km^2 to 22.5 km^2 and observation intensities of 0.8 to 1.0 per m.m.a. However, according to Embrapa (1995) the same number of soil units is not to be expected in both semi-detailed and recognnaissance levels, showing the necessity of each level of research in agreement with Dalmolin (1999).

On the other hand, considering the number of samples proposed by Embrapa (1995), in practice it is possible to rationalize the number of field observations with the proper use of remote sensing products related to mapping units. Hence, it is entirely possible to reduce the number of boreholes that are representative of these mapping units without affecting the quality of soil mapping (Prado, 1997). Besides, this author enphazises that the tables listing the number of samples per minimum map area cannot be evaluated only in theoretical terms, which corresponds with our view of the differences of soil surveys.

According to Embrapa (1995), the main objective of low-intensity recognition surveys is for the planning of large areas for general purposes, which is used in the evaluation of potential soil resources. Semi-detailed surveys should meet the needs of settlement projects for rural lots, integrated studies of microbasins, or projects that do not include high-intensity land use. Detailed surveys are used in the execution phase of soil conservation projects, and irrigation and drainage projects, and are particularly useful in support of recommendations on soil working and land use.

It should be noted that semi-detailed and reconnaissance surveys involve two mapping units that differ from the standpoint of soil management. This was better observed in the detailed survey, in which eight classes of soils were reported and their correct management is extremely important to avoid problems of erosion that can damage the environment. Fiorio et al. (1999) found improper handling of the soils of a hydrographic microbasin with an argillic B horizon and lithologic soils led to the siltation of a large reservoir, which produced a not inconsequential environmental impact in the area.

Here, it was expected that the semi-detailed map would discriminate a greater number of mapping units than the reconnaissance map, but that was not the case. This illustrates the variations that may occur between theory and practice, although it should be noted that the level of the soil map depends on the objectives and conditions for their development.

Preferential Use of Soils and Levels of Pedological Surveys

For the purpose of defining land uses that would take into account the soil's qualities and limitations, thus keeping them productive, a map was generated by the SAMPA system that was to indicate the best allocation and distribution of land uses of the study area at each of the three survey levels (Fig. 1). Authors such as Lepsch et al. (1991) support the idea that adequate land use is one of the first and most basic steps toward achieving sustainable agriculture. The program rapidly and automatically determined preferential uses for each level of the soil survey, analyzing the data spatially, which permitted the integration of various aspects of the area and their updating at any time, in agreement with the recommendations of Formaggio et al. (1992).

A comparison of the pedological surveys and their respective preferential uses (Fig. 1) reveals that differences exist in these uses in the study area due to the level of detail and scales of these maps. The preferential use indicated on the detailed survey (larger scale) exhibited a more coherent distribution, whereas in contrast, the preferential uses found through the semi-detailed and reconnaissance surveys (smaller scale) showed a distribution that was, to a large extent, inconsistent with the reality of the area, even though the results obtained by Joaquim et al. (1994) indicated that detailed surveys for agricultural planning were unnecessary. Regarding the reconnaissance survey of the latosols, their favorable physical and chemical characteristics and their location presented no limitations for most crops according to SAMPA and, therefore, the program considered most of the area (i.e., 279.96 ha), appropriate for short–cycle crops (Fig. 1). The areas indicated as appropriate for long-cycle cultures (64.79 ha) are areas with slopes of 10–25% (Fig. 2); in other words, they are inappropriate for short cycles, since they present greater risk of erosion. However, they can be used for long-cycle crops with lower risk of degradation due to the good physical characteristics of their soils. The areas with slopes of 25–45%, 0.25 ha, were found to be appropriate for pastures. According to Lepsch et al. (1991), it is often a land's topography, especially slopes, that is the decisive factor in determining its preferential use (Fig. 2).

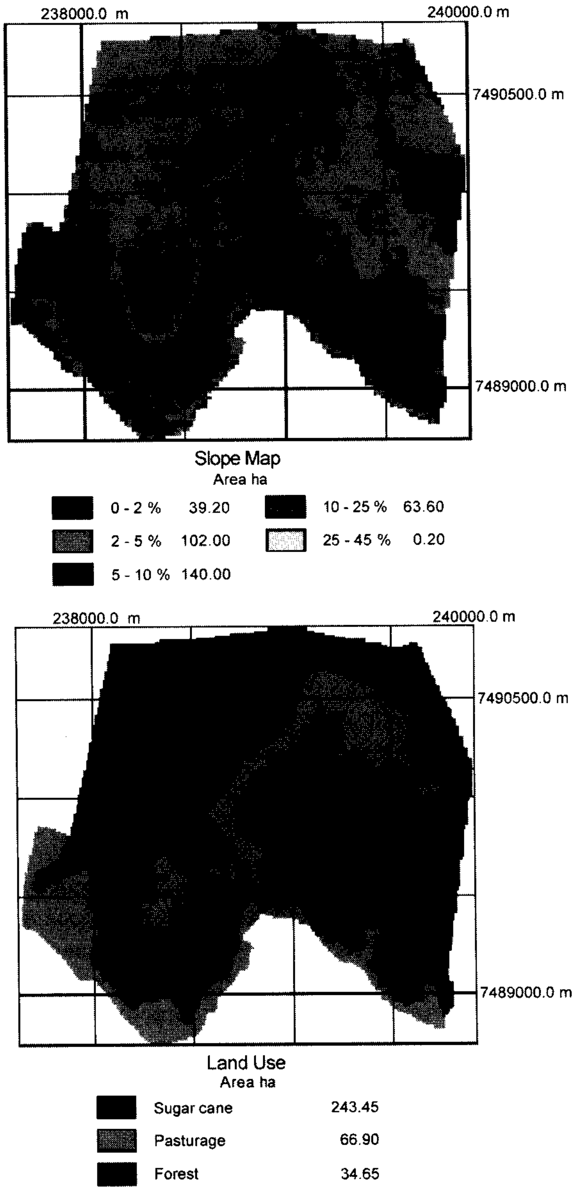

Fig. 2. Slope and actual land use of the study area.

The semi-detailed survey also presented two classes of soils (LR and PE), although two that showed greater differences in their characteristics, mainly physical and morphological (Embrapa, 1999). The PE soils showed greater susceptibility to erosion owing to the differences in texture of its horizons and the presence of an argillic B horizon with lower drainage, as already stated by Prado (1997).

As a result, the SAMPA program presented as preferential for short-cycle crops approximately 174.45 ha, while the pedological map showed the LR soil occupying an area of 186.90 ha (Fig. 1). For long-cycle crops there are 170.3 ha mostly with PE soil. An analysis of the spatial distribution of both maps (soil map and preferential use map) shows that they are quite similar, and the differences between the areas (in hectares) on the pedological and preferential use maps are mainly due to the 10–25% slope in the LR, which the program considers as an area of risk for short-cycle crops, but appropriate for long cycles. This is in agreement with Lepsch et al. (1991), who found that the degree of slope was the main factor affecting land use. According to Flores (1995), long-cycle crops and pastures are appropriate for podzolic and shallow soils, provided they have compatible slopes. The area indicated as appropriate for pastures has a slope of 25–45%, occupying 0.25 ha of the study area (Fig. 1), and is located in the same position as that found on the reconnaissance survey (Fig. 1), which again is in agreement with the findings of Lepsch et al. (1991).

In the detailed survey, LR and LE predominate in area, with a total of 223 ha, and are not differentiated in terms of cultivation. The Paleudult soils rank second, covering an area of 88.8 ha and, due to the differences in texture among horizons, these soils are more susceptible to erosion, particularly the PV soil (Fig 1). According to Prado (1997), these soils exhibit greater drainage on the superficial horizon and slower drainage on the subsuperficial one (argillic B horizon). The remainder of the area consists on shallow soils, as follows: R (21 ha), an association of hydromorphic and alluvial soils (6 ha), and C (4 ha) (Fig. 1).

For agricultural use, most of the area, i.e., 238.9 ha, appears best suited to short-cycle crops, which are predominant in the areas with latosols, although parts of this area with more pronounced slopes (10–25%) are used for long-cycle crops. The areas with Paleudult soils have predominantly long-cycle crops. It is interesting to note that the PV soil, which is generally highly susceptible to erosion, appeared to be preferential for short-cycle cultures, which is principally attributable to its gentler slope (5–10%).

In areas the SAMPA program allocated to pastures, a significant difference was found between the detailed survey and the others; under the detailed survey 19.10 ha are assigned to this use, whereas on each of the semi-detailed and the recognition surveys, only 0. 25 ha are. According to Vieira (1987), soils most preferential for pastures and/or reforestation are those that are highly susceptibile to erosion.

Assignment of the preferential use indicated by the reconnaissance survey would result in inappropriate planning, posing a serious risk for environmental degradation, decreased productivity, etc. due to the improper use of the natural resources, principally in the areas with shallow soil, as pointed out by Fiorio et al. (1999). Consequently, for studies of potential land use, it would be more relevant to use cartographic data at larger scales, detailed or semi-detailed surveys made with a higher density of observation points that offer more information about the area (Bouma, 1989). However, this is not always possible owing to the lack of detailed maps.

Comparison among Preferential Uses and Classes of Use Capacity

The map of Land Capability Use Classification (LCUC; Fig. 3) was generated following the methodology described by Lepsch et al. (1991), by cross tabulating and interpreting the data obtained from the detailed soil map, using the relief chart at 1:5,000 scale as a base map (Fig. 3). The map thus generated presented the following

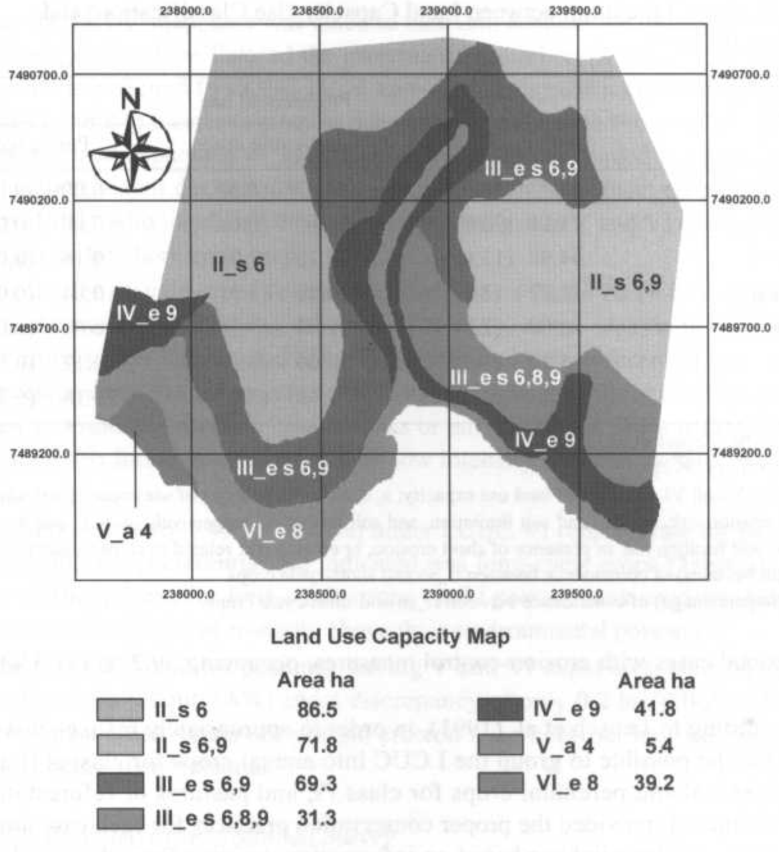

Fig. 3. Land use capacity map of the study area. For an explanation of the symbols see the subsection of the paper on Comparison among Preferential Uses and Classes of Use Capacity.

classes of use capacity (Lepsch et al., 1991): II_s6 = farmable land with simple problems of conservation and/or maintenance of improvements, with limitations of soil fertility, occupying 86.5 ha (25%) of the area; II_s6,9 = farmable land with simple problems of conservation and/or maintenance of improvements, with limitations in terms of soil fertility and slope, occupying 71.8 ha (20.7%) of the area; II_es6,9 = farmable land with complex problems of conservation and/or maintenance of improvements, with limitations involving erosion and/or risk of erosion and soil fertility and slope, occupying 69.3 ha (20%) of the area; III_es6,8,9 = farmable land with complex problems of conservation and/or maintenance of improvements, with limitations involving sheet erosion and/or risk of erosion as well as soil fertility and slope, occupying 31.3 ha (9%) of the area; IV_e9 = land only partially farmable and/or farmable to a limited extent, limited by serious erosion and/or risk of erosion and slope, occupying 41.8 ha (12.1%) of the area; V_a4 = land adapted mostly to pastures and, in some cases, to reforestation, without need for special conservation practices, farmable only in very special cases, with limitations involving excess water and risk of flooding, occupying 5.4 ha (1.6%) of the area; VI_e8 = land generally adapted to pastures and/or reforestation, with simple problems of conservation, farmable only in

Table 3. Cross Tabulation between Land Capacity Use Classification[a] and Preferential Use[b]

LCUC [c]	Preferential use		
	Short-cycle crops	Long-cycle crops	Pasturage
II_s6	84.53[d] (24.5)[e]	1.87[d] (0.5)[e]	0.00[d] (0.00)[e]
II_s6,9	71.85 (20.8)	0.00 (0.0)	0.00 (0.00)
III_es6,9	44.98 (13.0)	24.15 (7.0)	0.16 (0.046)
III_es6,8,9	12.27 (3.5)	19.03 (5.5)	0.04 (0.012)
IV_e9	10.09 (2.9)	31.84 (9.2)	0.00 (0.00)
V_a4	5.17 (1.5)	0.00 (0.0)	0.17 (0.047)
VI_e8	9.55 (2.8)	9.49 (2.7)	20.16 (5.80)

[a]LCUC (after Lepsch et al., 1991).
[b]After Koffler (1992).
[c]II, III, IV, V, and VI = classes of land use capacity; a, e, es, s = subclasses of use capacity for water limitation, erosion risk, erosion and soil limitation, and soil limitation, respectively; 4, 6, 8, and 9 = flooding risk, soil fertility, risk or presence of sheet erosion, or erosion risk related to slope, respectively.
[d]Area (in hectares) of coincidence between II_s6 and short-cycle crops.
[e]Area (in percentage) of coincidence between II_s6 and short-cycle crops.

very special cases with erosion-control measures, occupying 39.2 ha (11.3%) of the area.

According to Lepsch et al. (1991), in order to appropriately manage this area it would also be possible to group the LCUC into annual crops for classes II and III, semi-perennial and perennial crops for class IV, and pastures or reforestation for classes V and VI, provided the proper conservation practices for each case are maintained. Thus, preferential use based on information deriving from the detailed pedological survey considers that 238.90 ha (69.2%) of the area can be farmed with short-cycle crops, corresponding to classes of use capacity II and III. For long-cycle crops, 87.0 ha (25.2%) are available, corresponding to class IV, and 19.1 ha (5.5%) for pastures, corresponding to classes V and VI, in agreement with Koffler and Moretti (1991). Based on these data, a cross tabulation was performed using the SPRING program to quantify the similarity of these two maps, thus allowing for a comparison of the methods employed—SAMPA (Koffler, 1992) and Classes of Land Use Capacity (Lepsch et al., 1991)—in the management of small tracts of land (Table 3).

Considering the correspondences between the classes of use capacity and preferential use, it was found that 76.8 % of the study area was preferential in some degree for crops, with only 23% of the area showing discrepancies (Table 3). The most significant coincidence between the maps was in the areas designated for short-cycle crops (classes II and III), with 213.6 ha, i.e., about 61.8 % of the total area. Only 24.8 ha (7.2% of the area appropriate for short-cycle crops) was mixed with classes IV, V, and VI, since this land was used for semi-perennial and perennial crops and pastures (Table 3).

Discrepancies such this occur mainly in the areas destined for pastures and reforestation of the natural drainage systems, since SAMPA does not identify such areas as preservation by means of riverine reforestation, a fact noted by Fiorio et al. (1999). In charting the LCUC map, care was taken to take into account the drainage areas, even where the (gentle) slope favored the growing of annual crops (Fig. 1). It was found that the areas assigned to LCUC IV, V, and VI, yet farmed with short-cycle crops, were susceptible to a serious erosion risk, in agreement with Fiorio et al. (2000), as the disorganized expansion of sugar cane cultivation has tended to invade pasturelands, leading to soil degradation. The same situation was observed by Koffler and Palanca (1997), who identified the areas assigned to group V and VI classes that were inappropriate for short-cycle crops.

For the long-cycle crops (class IV), there was a 31.84 ha (9.2%) coincidence between the two maps (Table 3), whereas 45 ha (13% of the area) with a capacity for annual crops (class III) showed long-cycle crops as the preferential use—i.e., the maps present divergent information. Short-cycle crops apparently could be grown in these areas without generating erosion risks or environmental impacts (Table 3). Fiorio et al. (1999) found that the areas with low intensity land use showed low risks of erosion.

On approximately 9.49 ha (2.75%) under LCUC VI (appropriate for pastures or reforestation), the preferential use indicated was long-cycle crops (Table 3). Hence, the use of these areas for long-cycle crops could present erosion risks, since they would be used at a level of intensity above their environmental potential.

The areas destined for pastures, having V and VI capacities, showed a coincidence of 20.3 ha (about 5.8%) and a discrepancy of only 0.2 ha (0.06%) (Table 3). The discrepant areas would not present erosion risks because they are used as pastures, i.e., below their potential.

Land Use Revealed by the Detailed Survey

Sugar cane predominates in most of the study area, especially on slopes of 0–10%. However, this crop also was found growing in areas with slopes of 10 to 25% having shallow soils or soils with variable texture, which usually are more appropriate for pastures or reforestation because of their heightened susceptibility to erosion (Fiorio et al., 1999) (Fig. 2). Of the total area studied, sugar cane occupies 243.45 ha, whereas 66.90 ha consist of pastures and 34.65 is occupied by riverine (galleria) forest (Fig. 2). The determining factor for this land use pattern is economic, since there is high demand for sugar cane. Fiorio et al. (2000) noted that this crop has expanded in a disorganized manner, based on economic considerations rather than the aptitude of the land. This factor has determined that areas with better soils and more favorable relief are being occupied by sugar cane, although sugar cane is not restricted to these areas (Fiorio et al., 2000).

The areas occupied by pastures were found to be mostly those with greater slope (10–25%)—in other words, appropriate in terms of conservation practices, in view of the area's susceptibility to erosion, according to Flores (1995) (Fig. 2). The presence of riverine forests in most of the area is spatially coincident with the drainage system, regardless of slope and soil type, in accordance with Law No. 4171/BR of September 15, 1965, article 20, which stipulates the permanent preservation of forests and other types of natural vegetation along rivers or other bodies of water.

CONCLUSIONS

The analysis presented in this study demonstrates that variations in the scale of soil surveys influence the final results of land use planning. Detailed soil surveys are the most important for decision-making in agriculture, and are far superior to smaller-scale maps. Semi-detailed and recognition maps may depict different soil classes than are actually in place on the ground, which interferes with determination of the appropriate land use.

Preferential Use and Land Capacity Use Classification systems did not show major differences with respect to allocating land uses within the study area. The software used for the preferential use system was non-subjective and allowed for repeated and easy updating.

Lands best suited for pasture in areas with pronounced slopes were best detected using the detailed soil survey, and it was found that planning based on the recognition level presents serious risks of erosion, particularly for shallow soils. For land use planning and management, it would be more relevant to use cartographic data at larger scales, detailed or semi-detailed surveys made with a higher density of observation points.

NOTES

[1]The authors wish to acknowledge the support from the National Research Organization (CNPq), which provided funding for the first author's research (Process No. 98/01059-7).

[2]Soil class abbreviations are from Oliveira and Do Prado (1989).

REFERENCES

Assad, M. L. L. "Uso de uma sistema de informações geográficas na determinação da aptidão agrícola de terras [Use of a Geographic Information System for Determining the Potential of Agricultural Land]," *Revista Brasileira de Ciência do Solo*, Vol. 19, No. 1, 1995, pp. 133-139.

Bouma, J. "Using soil survey data for quantitative land evaluation," in: B. A. Stewart, ed., *Advances in Soil Science*, Vol. 9, 1989, pp. 177-213.

Brasil. Comissão de Solos (Brazilian Soil Comission). Centro Nacional de Ensino e Pesquisa Agronômica. *Levantamento de reconhecimento de solos do Estado de São Paulo* [Soil Survey of São Paulo State]. Rio de Janeiro, Brazil: Brasil. Comissão de Solos (Brazilian Soil Comission). Centro Nacional de Ensino e Pesquisa Agronômica, Bulletin No. 12, 1960, 634 p.

Camargo, A. O. de, A. C. Moniz, J. A. Jorge, and J. M. Valadares. *Métodos de análise química, mineralógica e física de solos do IAC* [IAC Methods of Chemical, Mineralogical, and Physical Analysis of Soils]. Campinas, Brazil: Agronomic Institute, Technical Bulletin, No. 106, 1986.

Dalmolin, R. S. D. "Faltam pedólogos no Brasil [Absence of pedologists in Brazil]," *Boletim Informativo SBCS*, Vol. 24, No. 4, 1999, pp. 13-15.

Eastman, J. R. *IDRISI: User Guide*. Worcester, MA: Clark University, 1992, 384 pp.

Embrapa SNLCS (Brazilian Agricultural Research Organization). *Procedimentos normativos de levantamentos pedológicos: Normas em uso pelo SNLCS* [Criteria for Soil Survey: Norms for Use by SNLCS). Brasília, Brazil: Embrapa, 1995, 101 p.

Embrapa SNLCS (Brazilian Agricultural Research Organization). *Sistema brasileiro de classificação de solos* [Brazilian System of Soil Classification]. Brasília, Brazil: Embrapa, Serviço de Produção de Informação, 1999, 412 pp.

Fiorio, P. R., J. A. M. Demattê, N. J. Mélem Junior, and J. A. Mazza. "Potencialidade do uso da terra na microbacia hidrográfica do Córrego do Ceveiro na região de Piracicaba [Land use potential in the Ceveiro Stream, watershed Piracicaba]," *Scientia Agricola*, Vol. 56, No. 4, 1999, p. 1273-1280.

Fiorio, P. R., J. A. M. Demattê, and G. Sparovek. "Cronologia do uso da terra e seu impacto ambiental na microbacią hidrográfica do Córrego do Ceveiro, Piracicaba (SP) [Chronology of land use and its environmental impact in the Ceveiro microbasin in Piracicaba region]," *Pesquisa Agropecuária Brasileira*, Vol. 35, No. 4, 2000, pp. 671-679.

Flores, M. X. "Uso agrícola do solo: Principais tipos de solo, potencial de utilização e impactos ambientais [Agricultural Soils: Main soil types, their potential and environment impacts]," in: S. M. Tauk-Tornisielo, N. Gobbi, C. Foresti, and T. M. Lima, eds., *Análise ambiental: Estratégias e ações* [Environment Analysis: Strategies and Actions]. Piracicaba, Brazil, 1995, pp. 280-290.

Formaggio, A. R., D. S. Alves, and J. C. N. Epiphanio. "Sistemas de informação geográficas na obtenção de mapa de aptidão agrícola e taxa de adequação de uso das terras [Geographic information systems in the determination of land use potential]," *Revista Brasileira de Ciência do Solo*, Vol. 16, No. 2, 1992, pp. 249-256.

IPT (Institute of Technological Research). *Mapa geomorfológico do Estado de São Paulo* [Geomorphological Map of São Paulo State]. São Paulo, Brazil: Institute of Technological Research, 1981, scale 1:100,000.

INPE (National Institute of Space Research). *Software Spring versão 3.5* [Spring Software Version 3.5]. São José dos Campos, SP, Brazil: National Institute of Space Research 2000 [http/www.inpe.br/].

Joaquim, A. C., I. F. Bellinaso, and J. L. Donzelli. "Potencial e manejo de solos cultivados com cana-de-açúcar [Management and potential of soils for sugar cane]," in: *VI Seminário de Tecnologia Agronômica, Centro de Tecnologia Copersucar* [Center of Sugar Cane Technology]. Piracicaba, Brazil: Coperativa dos Produtores de cana, açúcar e álcool do Estado de São Paulo, 1994, pp. 1-9.

Koffler, N. F. *Sistema de análise ambiental para planejamento agrícola: versão 1.0* [Environment System on Land Use Planning: Version 1.0]. Rio Claro, Brazil: Environment Sciences and Planning Center, 1992. 41 p.

Koffler, N. F. "Uso das terras da Bacia do Rio Bauru (SP): Situação atual e potencialidade agrícola [Use of Bauru basin lands: Situation and agricultural potential]," *Mimesis*, 1996, Vol. 17, No. 1, pp. 99-125.

Koffler, N. F. and E. Moretti. "Diagnóstico do uso agrícola das terras do município de Rio Claro, SP [Rio Claro, SP, Brasil, Agricultural land use diagnosis]," *Geografia*, 1991, Vol. 16, No. 2, pp. 1-76.

Koffler, N. F. and R. T. S. Palanca. "Avaliação agrícola da terra da Bacia do Rio Jaú (SP) através de técnicas de geoprocessamento [Geoprocessing in the agricultural evaluation of Jaú River basin]," *Ciência Geográfica*, 1997, No. 6, pp. 18-27.

Lepsch, I. F., J. R. Bellinazzi, D. Bertolini, and C. R. Espindola. *Manual para levantamento utilitário do meio físico e classificação de terras no sistema de capacidade de uso* [Handbook for Land Capability Use System]. Campinas, Brazil: Sociedade Brasileira de Ciência do Solo, 1991, 175 pp.

Morse, D. "100 years old," *Resource Engineering & Technology for a Sustainable World*, Vol. 6, No. 8, 1999, pp. 11-12.

Oliveira, J. B and H. do Prado. *Carta Pedológica Semidetalhada do Estado de São Paulo: Quadrícula de Piracicaba* [Pedological Soil Survey of São Paulo State at a Semi-detailed Level: Piracicaba Quadrangle]. São Paulo, Brazil: IAC, 1989, 1:100,000 scale.

Oliveira, J. B., M. N. de Camargo, M. Rossi, and B. C. Filho. *Mapa pedológico do estado de São Paulo* [Pedological Map of São Paulo State]. São Paulo, Brazil: IAC, 1999, recognition level, 1:500,000 scale.

Prado, H. do. *Os solos do Estado de São Paulo: Mapas Pedológicos* [Soils of the State of São Paulo: Pedological Maps]. Piracicaba, Brazil: ESALQ-USP, 1997, 205 pp.

Raij, B. van, J. A. Quaggio, H. Cantarella, M. E. Ferreira, A. S. Lopes, and C. O. Bataglia. *Análise química do solo para fins de fertilidade* [Soil Chemical Analysis for Fertility]. Campinas, Brazil: Fundação Cargill, 1987, 170 pp.

Ramalho, A., E. G. Pereira, and K. J. Beek. *Sistemas de avaliação da aptidão agrícola das terras* [Land Use System for Evaluation of Its Potential]. Brasília, Brazil: Embrapa, 1978, 70 pp.

Schueller, J. K. *O estado da arte da agricultura de precisão nos Estados Unidos* [The State of the Art of Precision Agriculture in the United States)," in: Luiz A. Balastreire, ed., *Agricultura de Precisão no Brasil* [Precision Agriculture in Brasil]. Piracicaba, Brasil, 2000, pp. 8-16.

Soil Survey Staff. *Keys to Soil Taxonomy*, eighth edition. Blacksburg, VA: SMSS Technical Monograph No. 6, 1998, 422 pp.

Thomasson, J. A., R. Sui, M. S. Cox, and A. Al-Rajehy. "Soil reflectance sensing for determing soil properties in precision agriculture," *Transactions of the American Society of Agricultural Engineers*, Vol. 44, No. 6, 2002, pp. 1445-1453.

Vieira, M. J. *Solos de baixa aptidão agrícola: Opções de uso e técnicas de manejo e conservação* [Soils of Low Agricultural Potential: Management Options). Londrina, Brazil: Fundação Instituto Agronômico do Paraná, 1987, Circular 51, 68 p.