Vineyard soil mapping to optimise wine quality: from 'terroir' characterisation to vineyard management

Cartographie des sols de la vigne afin d'optimiser la qualité du vin: caractérisation du terroir et gestion du vignoble

Josep Miquel UBALDE[1*], Xavier SORT[1], Rosa Maria POCH[2] and Miquel PORTA[1]

1: Dept. of Viticulture, Miguel Torres Winery, Miquel Torres i Carbó 6, 08720 Vilafranca del Penedès, Spain

2: Dept. of Environment and Soil Science, University of Lleida, Rovira Roure 191, 25198 Lleida, Spain

***Corresponding author**: Tel. +34-938177604, jmubalde@torres.es

Abstract

In this study, a soil mapping methodology at subplot level (scale 1:5000) for vineyard soils was developed. The aim of this mapping method was to establish mapping units, which could be used as basic units for 'terroir' characterisation and vineyard management (precision viticulture). The developed methodology applied most of the criteria of the Soil Inventory of Catalonia and the Soil Survey Manual of the Department of Agriculture of United States, at very-detailed scale. The suitability of soil maps as a tool for definition of 'terroir' units and management units are discussed, according to our experiences. The method followed allowed good soil type discrimination at vineyard subplot level, differentiating zones with distinct soil properties important to vineyard development. However, the variability within the soil mapping unit could not be ascertained by this method. Significant differences in grape quality were found between distinct soil mapping units. Moreover, the application of variable rates of fertilizer at vine subplot level was possible using thematic maps calculated from soil maps, by means of Geographic Information Systems.

Keywords: soil mapping, viticultural zoning, terroir unit, management unit, precision viticulture

Introduction

During recent years, viticultural zoning studies have increased significantly, because of the expansion of the international wine market. Among the various environmental factors and for a specific mesoclimate, soil is the most important factor in viticultural zoning (SOTES and GOMEZ-MIGUEL, 2003), due to the direct effect on vine development and wine quality. The soil properties which have the most influence are the physical ones, namely the properties that control the soil water content, due to its direct effect on equilibrium between vegetative vigour and grape production (VAN LEEUWEN and SEGUIN, 1994).

There are different approaches for studying soils, among which soil mapping techniques stand out. Soil mapping allows both the knowledge of spatial variability of soil properties and soil classification according to viticultural potentialities (VAN LEEUWEN and CHERY, 2001). For these reasons, soil maps are usually used as basic mapping for zoning studies. Moreover, different thematic maps can be derived from a soil map, for instance fertilization maps or irrigation maps, which are very important in vineyard management. The soil mapping methodology depends on the aim of the zoning and the chosen scale. In DUTT *et al*. (1981) distinct viticultural regions at a regional scale were determined considering soil temperature regime. At a more detailed scale, VAN LEEUWEN *et al*. (2002) found water availability to be the most influencial property. Several studies highlight the importance of soil water content, which integrates edaphic factors (lithology, topography), climatic factors (rain, solar radiation, temperature) and both biological and human factors (DUTEAU, 1981; SOTES and GOMEZ-MIGUEL, 1992).

New trends in soil mapping are related to an increase of spatial resolution, thanks to new technologies in precision viticulture. New non-intrusive sensors of electrical resistivity and electromagnetic induction measure the apparent soil electrical conductivity, which enables the mapping of different soil properties, for instance the soil water content, clay content, clay mineralogy, cation exchange capacity, bulk density and soil temperature (CORWIN and LESCH, 2005; DABAS *et al*., 2001).

The aim of this study is to develop a soil mapping methodology at very-detailed scale (1:5,000) for modern vineyards located in Catalonia (Spain). The resulting mapping units should be able to be used as basic mapping for 'terroir' characterisation and vineyard management (precision viticulture) at subplot level.

Materials and methods

Setting. The soil mapping method was developed in modern vineyards from Catalonia (Spain), which are orientated to high-quality wine production. These vineyards are located approximately between 41º 8' N and 42º13'N and between 0º 38' E and 1º 43' E.

Soil mapping. Basically, the methodology developed applies most of the criteria of the Soil Inventory of Catalonia (BOIXADERA *et al*., 1989) and the Soil Survey Manual of the Department of Agriculture of United States (SSS, 1993), at a very-detailed scale (1:5,000). Different materials and methods have been used in distinct phases of soil mapping. Before field description, some existing cartography was consulted: geological maps at 1:50,000 scale by the IGME (Geological and Mining Institute of Spain, Government of Spain), digital topographic maps at 1:5,000 scale and aerial photographs by the ICC (Cartographic Institute of Catalonia, Government of Catalonia). The field description, which includes site description and profile description, was based on the SINEDARES method (CBDSA, 1983). The laboratory methods are described in the Soil Survey Laboratory Methods Manual of the Department of Agriculture of United States (USDA, 1996). In the micromorphological study, thin sections were elaborated according to BENYARKU and STOOPS (2005), and the criteria of STOOPS (2003) were used in microscopic description. The devices used during the hydrological study were a Guelph permeameter, a disk infiltrometer and capacitance sensors, in order to determine saturated hydraulic conductivity, infiltration rate and soil water content, respectively. The selected soil classification system was Soil Taxonomy (SSS, 1999) at family level. The basic mapping for field survey was detailed digital mapping at 1:5,000 scale by the ICC (orthophotographs and topographic maps), available on internet (www.icc.cat). The soil mapping units were delimited according to the criteria of VAN WAMBEKE and FORBES (1986).

Soil GIS (Geographic Information System): The software used in the elaboration of the Soil GIS, which should be capable of managing all generated data, were Microsoft Access (Microsoft) and ArcGIS (ESRI).

Results and discussion

Soil mapping at very-detailed scale

Figure 1 synthesizes the soil mapping methodology at a very-detailed scale (1:5000) developed in modern vineyards from Catalonia (Spain), which permits the delimitation and characterisation of 'terroir' units (viticultural zones) and management units (precision viticulture) at subplot level.

At first, a compilation of geological and geomorphological information is needed in order to determine physiographic units according to different landforms and lithologies. Photointerpretation can be used for the delimitation of these units. At least one soil pit was dug between vineyard rows in each physiographic unit, until a soil survey density of 1 soil profile every 1.5 hectares was achieved. The depth of soil profiles is the shallower of a root-limiting layer or 200 cm. The soil profiles are georeferenced by GPS.

Field description is divided into site description and profile description. Site description includes location, soil temperature and moisture regime, drainage class, depth to water table, geomorphic information, parent material and surface stoniness. These properties determine mesoclimate (climate at subplot level), soil climate and soil water availability, which are essential factors in determining grape and wine quality. Profile description includes horizon depth and genetic denomination (SSS, 1999), soil colour (Munsell charts), mottles, coarse fragments, structure, consistence, cementations, effervescence (hydrochloric acid), roots, pores, cracks, biological and human activity, accumulation of materials and ped and void surface features. The most relevant properties with influences on grape production are related to the soil volume suitable for root development, which depend mostly on effective depth, that is, the depth to which roots grow without limitations. These limitations can be the presence of compacted layers, cementations by carbonates, lithic or paralithic contacts or gravel deposits. A detailed description of the root system, which considers root quantity, size, shape, distribution, orientation and state, is essential in determining soil suitability for vine growth.

For each profile and horizon, physical and chemical properties are analysed. The selected physical properties are texture (pipette method) and moistures at -33 KPa and -1500 KPa (pressure-plate extraction from disturbed samples), which are used in the water holding capacity calculation. The selected chemical properties are pH (suspension of 1:2.5 soil:water), electrical conductivity (suspension of 1:5 soil:water), organic matter (Walkley-Black), nitrogen (Kjeldahl), calcium carbonate (Bernard calcimeter), active lime (Nijelsohn), gypsum (extracted by acetone), iron (extracted by EDTA), phosphorous (Olsen), cation exchange capacity and exchangeable bases (extracted by ammonium acetate). The most remarkable variables are nitrogen content, which has a high influence on vegetative development (CHONE *et al*., 2001), and active lime content, which determines the development of ferric chlorosis in calcareous soils.

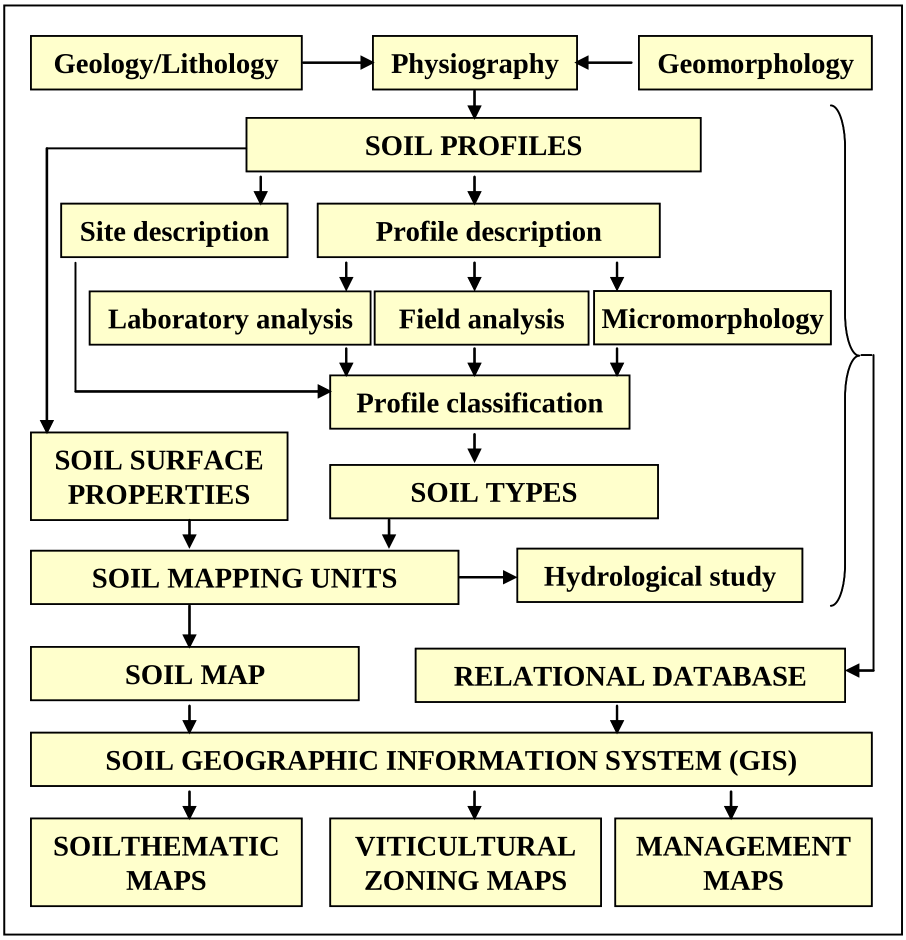

Figure 1. Vineyard soil mapping methodology.

A physical characterisation in the field is carried out for some profiles, which includes the determination of bulk density and content of coarse fragments (mineral fragments higher than 2 mm). The different methods are paraffin coated clods, cores or compliant cavity (USDA, 1996), which are used according to coarse fragment content, consistency and structure. From these variables and moistures at -33 KPa and -1500 KPa, water holding capacity is determined. This property is very important in management decisions, for instance in irrigation planning.

In some cases, a micromorphological study was undertaken in order to clarify or identify pedofeatures which were invisible to the naked eye, for example illuvial clay coatings or incipient carbonate coatings. The pedogenic processes that were described using micromorphology directly affected soil properties related to water regime, capacity of water retention and carbonate content, which have a direct influence on both vineyard management and wine quality (UBALDE *et al*., 2005).

When soil profiles are fully characterised, they are classified by Soil Taxonomy at family level. Different soil types are distinguished through the grouping of profiles of similar classification, and these soil types are used to delineate soil mapping units. These mapping units are characterised by soil type and surface properties, which usually are texture, slope and surface stoniness. These surface properties have influence on soil management (conditioning the use of agricultural machinery), soil water balance (conditioning water infiltration) and vine growth (the majority of roots are located at surface horizons). Orthophotographs in colour and at 1:5000 scale are used as mapping base. The soil survey party plots the boundaries of mapping units onto these orthophotographs. These boundaries are determined by means of observations, which use a soil auger and visual checking, looking for subtle differences in slope gradient, landforms, colours, stoniness… There are approximately 5 observations for each soil pit. If updated orthophotographs are not available, GPS can be very useful. When all mapping units are delineated, they are listed and codified and the soil map legend can be finished. The resulting soil map is digitized and introduced into a Geographic Information System (GIS).

For the most representative units, some hydrological properties can be determined: saturated hydraulic conductivity, infiltration capacity and soil water content. These variables can be used in soil water balance calculation.

A relational database was developed in order to handle all accumulated data and make full use of them. This database is capable of storing data at different levels (horizons, profiles and soil mapping units) and of storing all relationships between those levels. In addition, this database calculates different indices, important for vineyards, for example the chlorosis risk index. Finally, different queries can be made, at the levels of horizon, profile and mapping units. These data can be linked with the digitised soil map, using GIS. This system of data organisation can be named Soil GIS.

Applications of very-detailed soil maps

From Soil GIS data, the edition of soil maps, soil thematic maps (texture, carbonates…), viticultural zoning maps (chlorosis risk, optimal variety…) and management maps at subplot level (precision fertilization) is relatively easy.

Figure 2 shows the procedure followed in order to determine viticultural zoning maps from different thematic soil maps, which are elaborated by GIS from the soil map. A salinity map is determined from the reclassification of the electrical conductivity map, a chlorosis risk map is determined by combining active lime map and iron content map and a drought risk map is determined by combining effective depth map and water holding capacity map. The result of the combination of these maps is an optimal rootstock map at subplot level.

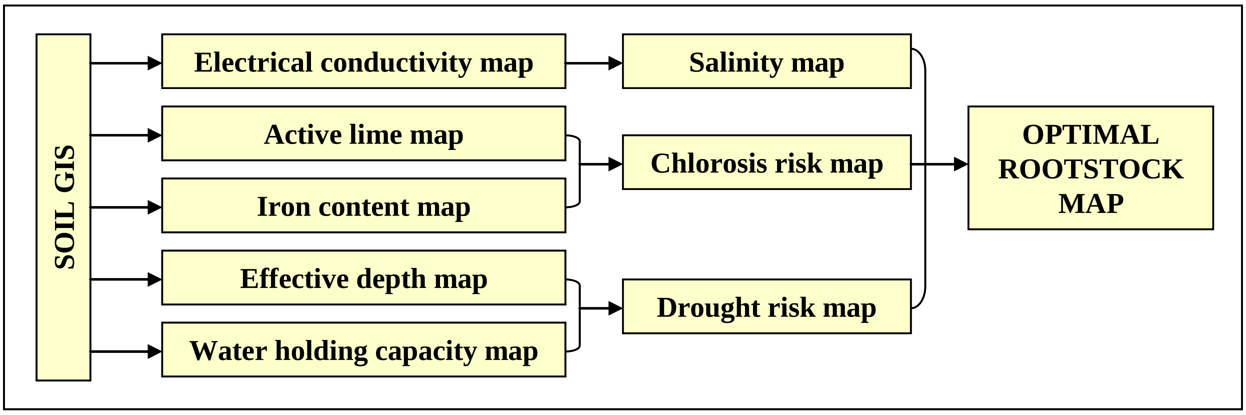

Figure 2. Procedure of elaboration of an optimal rootstock map at subplot level from a very-detailed soil map.

Figure 3 illustrates how to calculate a fertilization map at subplot level, by combining the soil map with other vineyard maps (yield and vigour). This map can be introduced into a variable-rate fertilizer, which can apply different rates of fertilizers according to the position determined by GPS (SORT and UBALDE, 2005).

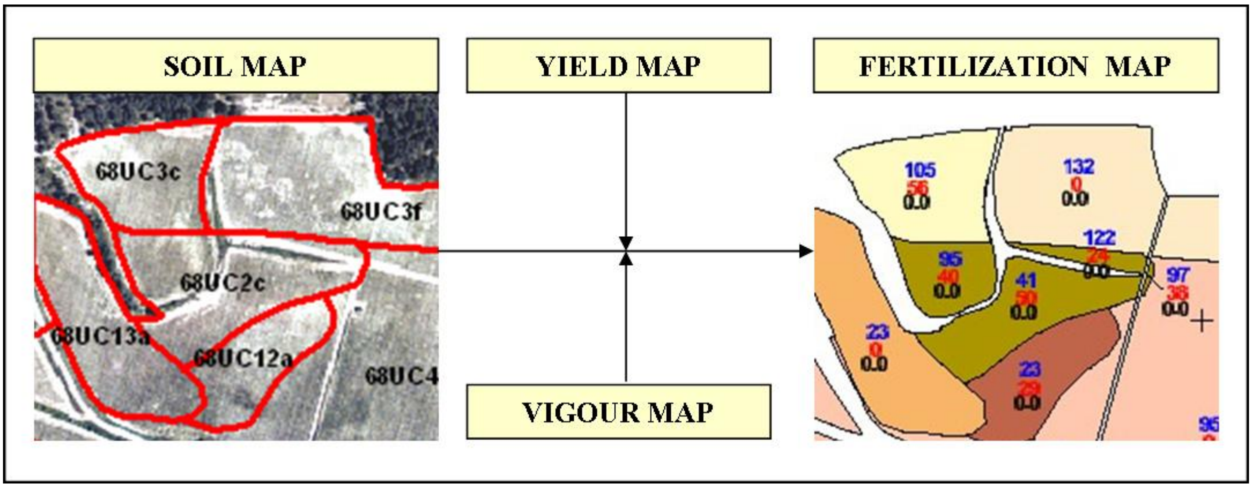

Figure 3. Procedure of elaboration of fertilization maps at subplot level from very-detailed soil maps.

Figure 4 shows the result of a viticultural zoning study undertaken by means of high-resolution multiespectral images (Quickbird satellite). First, a NDVI (Normalised Difference Vegetation Index) map was calculated combining red and infrared images. Then, a vigour map was determined, by means of a cluster analysis. This vigour map separates zones with significant distinct vegetative vigour. Our studies demonstrated a significant difference ($p < 0.05$) in grape quality (brix degrees, pH, acidity) between these zones. In order to analyse the efficiency of soil maps in separate zones with different grape quality, we have compared the soil map with the vigour map determined by satellite (Figure 4). A relatively good correspondence between those maps can be observed. This result suggests that very-detailed soil maps are suitable in viticultural zoning studies at subplot level, because they can differentiate zones with significant differences in grape quality. Obviously, other viticultural zoning studies at vine level would require new technologies of precision viticulture (e.g., electromagnetic sensors), which can determine soil variability within each subplot.

Figure 4. Comparison between viticultural zoning by means of satellite images and soil maps.

Conclusions

A soil mapping method at very-detailed scale was developed in modern vineyards of Catalonia during this study. The final aim of this cartography was to establish mapping units, which could be used as basic mapping for viticultural zoning at subplot level.

The method followed allowed good soil type discrimination at vineyard subplot level, differentiating zones with distinct soil properties, which are important to vine growth. During field study, the soil properties described determined mesoclimate (geomorphology), soil climate (soil moisture and temperature regime, water tables…) and soil suitability for root development (effective depth, coarse fragments, root system). The most remarkable physical properties analysed in laboratory were soil moisture at -33 and -1500 Kpa due to their influence on soil water holding capacity. Concerning chemical properties, the most remarkable are nitrogen content because of its importance for vegetative vigour and active lime content through its influence on ferric chlorosis occurrence. Soil micromorphological study was useful for describing soil forming processes with a direct influence on both vineyard management and wine quality. Finally, soil surface properties used in soil mapping unit delineation were important in vineyard management and the soil water balance.

Data organisation within a Soil GIS was a useful tool for data management, facilitating the edition of soil maps and soil thematic maps at subplot level.

According to our experience, distinct maps of viticultural zoning at subplot level can be desgined from very-detailed soil thematic maps. These viticultural zoning maps can be used in analysing soil suitability for grape cultivation (chlorosis risk, drought risk, optimal rootstock) and applying viticulture precision principles (precision fertilization).

Finally, although the variability in the soil mapping unit could not be ascertained by this method, significant differences in grape quality were found between distinct soil mapping units.

Acknowledgement

We would like to thank the SIGTEL Laboratory (University of Lleida) for the analysis of satellite images, and Mrs. Anya Doherty for the English revision.

References

BENYARKU C.A., and STOOPS G. 2005. *Guidelines for preparation of rock and soil thin sections and polished sections*. Quadern DMACS 33, Department of Environment and Soil Science, University of Lleida (Spain), 84 pp.

BOIXADERA J., HERRERO C., DANÉS R. and ROCA J., 1989. *Cartografía de suelos semiáridos de regadio: Área regable de los Canales de Urgell (Lérida).* XVI Reunión de la SECS. DMCS-UPC-SECS. Barcelona. 77 p.

CBDSA. 1983. *SINEDARES. Manual para la descripción codificada de suelos en el campo.* 137 pp. MAPA. Madrid.

CHONE X., VAN LEEUWEN C., CHERY P. and RIBEREAU-GAYON P., 2001. Terroir influence on water status and nitrogen status of non-irrigated Cabernet sauvignon (Vitis vinifera). Vegetative development, must and wine composition (Example of a Medoc Top Estate Vineyard, Saint Julien Area, Bordeaux, 1997). *S. Afr. J. Enol. Vitic*. **22:1**, 8-15.

CORWIN D.L., and LESCH S.M. 2005. Characterizing soil spatial variability with apparent soil electrical conductivity I. soil survey. *computers and Electronics in Agriculture*,**46**, 32-45.

DABAS M., TABBAGH J., and BOISGONTIER D. 2001. Multi-depth continuous electrical profiling (MuCep) for characterization of in-field variability. *Proceedings of the Third European Conference on Precision Agriculture. June 18-20, 2001, Montpellier, France.* 361-366.

DUTEAU J. 1981. Alimentation en eau de la vigne. Mecanismes de régulation. *Actualités Oeno. et Vitic*., 54-62.

DUTT G.R., MIELKE E.A., and WOLFE W.H. 1981. The use of soils for the delineation of viticultural zones in the four corners regions. *Am. J. Enol. Vitic*., **32:4**, 290-296.

SOTES V., and GOMEZ-MIGUEL V. 1992. Criterios de diferenciación y delimitación de comarcas y regiones vitivinícolas. Examen de los factores naturales y humanos que concurren. *Vitivinicultura,* **5**, 29-39.

SOTES V., and GOMEZ-MIGUEL V. 2003. Caracterización de áreas vitivinícolas: zonificación. A. Memorias del I Seminario Internacional de Vitivinicultura, Ensenada, B.C. Mexico, 40-60.

SOIL SURVEY STAFF (SSS). 1993. *Soil Survey Manual*. Soil Conservation Service. U.S. Department of Agriculture Handbook 18.

SOIL SURVEY STAFF (SSS). 1999. *Soil Taxonomy: a basic system of soil classification for making and interpreting soil surveys. 2nd. Edition.* USDA Soil Conservation Service. Agricultural Handbook nº **436**. US Government Print Office. Washington. 871 pp.

SORT, X. & UBALDE, J.M. 2005. Aspectes de viticultura de precisió en la pràctica de la fertilització raonada. *ACE Revista d'Enologia* **73,** 18-21.

STOOPS G. 2003. *Guidelines for analysis and description of soil and regolith thin sections.* Soil Sci. Soc. Am., Madison, WI.

UBALDE J.M., POCH R.M., BOIXADERA J., SORT X. and PORTA M., 2005. Formation and classification of vineyard soils from the Mediterranean Range System (NE Spain). *European Geosciences Union General Assembly, Vienna, 24-29 April 2005.*

U.S. Department of Agriculture, Natural Resources Conservation Service, 1996. *Soil Survey Laboratory Methods Manual*. Soil Survey Investigations Reports nº **42**, 693 pp.

VAN LEEUWEN C., and SEGUIN G. 1994. Incidences de l'alimentation en eau de la vigne appréciée par l'état hydrique du feuillage, sur le développement de l'appareil végétatif et la maturation du raisin (*Vitis vinifera* variété Cabernet Franc, Saint Emilion 1990). *Journal International de la Science de la Vigne et du Vin* **28**, 81-110.

VAN LEEUWEN C., and CHERY P. 2001. Quelle méthode pour caractériser et étudier le terroir viticole : analyse de sol, cartographie pédologique ou étude écophysiologique ? *In : Un raisin de qualité : de la vigne à la cuve, nº Hors Série du J. Int. Sci. Vigne Vin,* 13-20.

VAN LEEUWEN C., CHERY P., ROBY J.P., PERNET D., GOUTOULY J.P., and GAUDILLERE J.P. 2002. Methodologies pour etudier le sol en vue d'un zonage viticole. *A : Procedures IVth Int. Sym. Viticultural Zoning, Avignon, France,* pàg. 1-13.

VAN WAMBEKE A. and FORBES T.R. (eds) 1986. Guidelines for Using "Soil Taxonomy" in the Names of Soil Map Units. Soil Manage. Support Serv. Tech. Monogr. 10. U.S. Dep. Agric., Soil Conserv. Serv., and Cornell Univ., Agron. Dep.