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Abstracts

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Statistical Approaches for Soil Survey Updates

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The National Cooperative Soil Survey is responsible for constructing soil maps detailing the location of soil series throughout the US. Reports are generated for each county that contain maps and soil map unit descriptions. These maps are periodically updated to provide current information on the range of values for particle composition, depth of horizons, and other related attributes. Methods for updating soil surveys have been largely based on purposive sampling. Summary statistics used to describe the characteristics of a soil map unit include ranges and representative values (midpoints of ranges).

Statistical sample selection has frequently been avoided because it is believed to be resource intensive. However, many types of statistical designs are available that provide a balance between sample size and data collection needs. Random samples can also be used to provide improved estimates of means and ranges as well as a wider variety of parameters (e.g., percentiles) to summarize soil map unit characteristics. The variability associated with these estimates can also be quantified.

The NRCS, Iowa Cooperative Soil Survey, and Iowa State University are collaborating in MLRA 107 to implement a statistical sampling plan for soil survey updates. The multi-phase design balances the need to obtain data at numerous geographically dispersed points with the availability of resources for collecting observations and lab samples. Regression estimation is used to estimate horizon-specific characteristics for soil map units or other regions within the survey. In addition to providing improved estimates of the soil characteristics, the resulting database contains complete, spatially-linked data for use in modeling environmental processes.

Sampling Design and Spatial Modeling of Heavy Metals in Contaminated Soils

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Issues of sampling design and accuracy of soil survey data have become matters of priority in recent years (e.g. Domburg et al., 1994; 1997; De Gruiter et al., 1994). There is much need to develop sampling strategies to quantitatively assess spatial variability of heavy metals in contaminated soils. Such issues have to be taken into account by those buying, selling or developing such soils. This paper reports a case study which was undertaken at an old industrial site in Central Scotland. Use was made of a hierarchical sampling design based on an unbalanced sampling scheme of Webster & Oliver (1990). As a result, an unbalanced hierarchical nested design with random orientation of sampling points was used to represent spatial variation in heavy metals. Information from each sampling stage with stated quantified accuracy was obtained by applying geostatistical methods. Semivariance was calculated for log-transformed data to stabilize the variance. The sampling scheme was designed to allow the calculation of semivariance at small values of lag distance relative to the size of the sampling grids. Variables were described by isotropic linear semivariance model to reflect the spatial dynamics on the heavy metal parameters. This model proves that the degree of contaminant variability increases linearly with sample spacing and the range of spatial dependence is determined by the size of the dumped tip. Through applying semivariance analysis with error estimation for each sampling stage it was established that the nugget values increase with each sampling stage. The linear variogram maintains its shape but reduces the slope of the best fit line. It proves that on such artificial sites variability needs to be based on observations at rather close distances. At each stage goodness-of-fit for the semivariogram models was assessed by jackknifing analysis. Resultant kriged maps illustrate continuous spatial behavior of heavy metals. In order to develop an approach to risk assessment, disjunctive kriging was applied.

Soil Development Prediction Using Terrain Analysis in a Sandy Area of Southwest France

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Numerous studies have shown that the distribution of soil properties can largely be explained by landscape morphology and especially by the amount and flux of water in a given landscape. Digital terrain analysis provides a systematic basis for calculating topographic attributes and for relating them to soil attributes in order to improve the prediction within existing soil maps. Recent researches have shown such applications of quantitative soil-landscape models for soil mapping and for soil attribute prediction.

In southwest France, acid soils have developed from Quaternary sandy eolian deposits. The objective of this study was to determine if topographic situation influences pathways of soil development in order to improve the prediction accuracy on the presence/absence of some diagnostic horizons.

We used a digital elevation model (DEM) to calculate topographic attributes on a XXX ha area. Morphological analysis was run using this DEM (precision=1m; cell size 250x250m). The following classical morphological indicators were determined using the elevations from the eight nearest neighbors to each point; elevation (m), slope (degrees), plan curvature (across slope curvature degrees/m), profile curvature (dowslope curvature, degrees/m), flow accumulation area (m^2) (from a drainage model derived from the DEM), total curvature, range of elevations (m) on a square of 3x3 cells, standard deviation of elevations (m) on a square of 3x3 cells, and wetness index. In addition, we calculated the drainage feature proximity and the relative elevation from the nearest drainage feature.

Field data were soil descriptions from auger borings, which were separated into 3 groups on the basis of the existence of diagnostic horizons. The model uses multivariate discriminant analysis on digital eleveation model attributes in order to predict soil profile developments.

The results suggest that drainage feature proximity and the relative elevation from the nearest drainage features are the main factors controlling horizons local variability. This study shows that using spatial available landform attributes which might influence horizons distribution, and combining them into spatial models, can provide a useful tool to improve geographical prediction of soil profile development.

Assessment, Description, and Delineation of Soil Spatial Variability at Hillslope to Landscape Scales ($10m^2$ to $100m^2$)

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Bioiophysical processes operating through time differentiate the soil-landscape continuum into repeating patterns of variability that can be observed at multiple spatial scales. These patterns of variability for spatial resolutions in the range of 10 m^2 to 100 m^2 may be largely determined by hillslope and other geomorphic processes resulting in the redistribution of soil components. Mapping scales appropriate for this level of variability roughly corresponds to map scales of 1:10,000 to 1:100,000. Soil maps of these scales are typically used to make land-use decisions for individual and local governmental planning purposes documenting variability from within fields to within minor watersheds. These maps usually contain sufficient detail for making specific land-use decisions, yet are still cost-effective to produce. As such, considerable resources have and will continue to be dedicated to mapping soil variability at these scales. Feasible sampling densities for these spatial scales are generally too dispersed to map variability from one soil observation to another. Hence, relationships with observable landscape features (topography, vegetation, etc.) are used to infer the variability of soil properties. Both qualitative and quantitative approaches have been used to formulate these soil-landscape models. Traditional methods of describing and mapping soil variability within this range rely on conceptual soil-landscape models formulated by field soil scientists. These conceptual models are based on accumulated experience of soil-landscape observations. While these models are the mainstay of many soil survey activities, the specific decision criteria used to map soil variability is seldom documented and often is difficult for field scientists to articulate. Legends are based on multivariate soil taxa which define the composition of spatial mapping units and are used as the basis for making soil interpretations. More recent research has focused on quantifying empirical soil-landscape relationships based on observational data coupled with an understanding of local pedogenic and geomorphic processes. Many efforts at quantitative soil-landscape modeling have focused on mapping specific soil properties, rather than soil taxa. The use of multivariate statistical procedures permits assessments of class uncertainty, while other spatial modeling techniques have been used to map gradients of change for continuous soil variables. The success of quantitative modeling efforts relies heavily on the quality of ancillary spatial data, such as digital maps of topographic, land-cover, or climatic attributes.

Selecting Optimal Modes Of Surface Water Control By Means Of Soil Water Models And Surface Elevation Data

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Traditionally, surface water levels of ditches in Dutch polders are controlled in a rather simple manner. During the winter time surface waters are kept at low levels to allow for additional storage of soil moisture for the coming summer and to assure a firm topsoil and a quick rise of soil temperature in early spring. During the summer the surface water levels are kept high in order to replenish the groundwater via infiltration from the ditches. In this way one hopes to prevent the water tables from falling too quickly in summer, because during this time of the year an important part of soil moisture for crop growth must be supplied by capillary rise from the phreatic surface.

A problem with this traditional mode of surface water control is that it is rather crude. It does not take account of the actual moisture conditions and groundwater levels. Moreover, surface elevations and soil properties may vary considerably within a control unit (i.e. polder). Therefore, a mode of control that is optimal for one point within the control unit, may not be optimal for the unit as a whole.

Based on above problem description a research project was started at the Winand Staring Centre with the following goals:

1. To see whether it is possible to devise a mode of surface water level control that is based on actual measurements of the groundwater levels at a single location, but that is in some manner “optimal” for the entire control unit. Here, “optimization” means maximization of the net return per hectare, i.e. the maximization of actual transpiration (crop yield) and minimization of losses through ponding or saturation of the topsoil.

2. To evaluate if the optimal mode of surface water level control produces significantly better returns than the traditional method of surface water control.

A polder in the north of the Netherlands (size approximately 500 hectares) has been chosen as our study area. The performance of six different modes of surface water control (including the traditional mode) are evaluated at twenty random locations in the study area.

Performance is measured in net return, which is obtained from the mean yearly actual transpiration (i.e. crop yield) and losses through ponding or saturation of the top soil. These parameters are calculated at the selected locations with numerical soil water models. To aggregate the results of the soil water models to net returns for the entire study area, conditional geostatistical simulations of surface elevation data are combined with stochastic nonlinear regression relationships. The geostatistical aggregation method results in a probability distribution of areal average net return for each mode. The probability distributions are used to select the optimal mode of surface water control and to check whether this selected mode is significantly better than the traditional one.

Implementing Properties of Map Delineations in Ordinary Kriging

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Stratification of a region based on soil map delineations, followed by within-stratum interpolation, has been the most frequently used combination of choropleth soil maps and spatial prediction from point observations. Though not all delineations on a soil map are equally suitable to stratify an area and commonly expert knowledge is used to select appropriate map delineations. We developed a procedure to characterise the properties of map delineations to facilitate their selection for stratification. The identified properties of map delineations were: the physical nature of the mapped phenomenon, the mapping accuracy, and the structure of spatial variation of the adjacent mapping units. These properties determined the implementation of delineations in the ordinary kriging interpolation. For inaccurately mapped delineations we modified the ordinary kriging algorithm in order to take account of the uncertainty about the true location of the boundary. The procedure was applied to inventory topsoil sand content within the province of West-Flanders, Belgium. We selected this province as a real-case inventory because of the important textural variation and because both a soil texture map (1:100 000) and a large data base on soil texture were available. We compared ordinary kriging using properties of delineations (OKPD), the method developed in this paper, with the conventionally used stratified ordinary kriging (SOK). SOK handles all map delineations in the same way, i.e. as known sharp discontinuities, whereas in OKPD first the property of each map delineation is identified and subsequently kriging interpolation is performed using the appropriate conditions. We found OKPD gave more realistic experimental variograms and nearby inaccurately located map delineations a higher prediction accuracy and a more realistic prediction error was generated.

A New Sampling Strategy to Estimate the Mean Phosphate Content of Fields

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The intensive animal husbandry in the Netherlands produces a large surplus of manure. The application rates of manure exceed the phosphorus crop uptake. The soil gradually becomes saturated, and ultimately the phosphate leaches to the groundwater and surface water. To prevent further degradation of the environment, the application of manure is regulated by law at present. For fields with low phosphate levels the allowed quantity of manure leads to a further decrease of the phosphate reserves and of the crop yield. Higher application rates will be permitted for these fields under a new regulation.

A new sampling strategy, intended for nationwide application, is designed to estimate the mean phosphate content of fields and to test hypotheses statistically. The field to be sampled, is stratified geographically. The strata are of equal area and are as compact as possible. This stratification is done by non-hierarchical classification of the points of a discretization grid, using the x- and y-coordinates as classification variables, and the within-group sum of squares as minimization-criterion. Computing time could be reduced significantly by transferring points near stratum boundaries only. From each stratum one sample is selected by simple random sampling. These samples are bulked into one composite sample. In laboratory this composite sample is mixed, sub-sampled and analyzed.

The composite sample mean is an unbiased estimator of the field mean because the area of the strata is equal. To predict the sampling variance, the variogram have been estimated for 16 fields differing in landuse, parent material and phosphate level. The semivariance was related to the phosphate level, therefore we also estimated the pooled relative variogram. This variogram was used to predict the sampling variance for various levels of the sample size (20 to 50), field area (1 to 10 ha) and phosphate levels (30 to 60mg P_2O_5 per 100 gram or dm^3). For 40 sample points (standard sample size of the current strategy) the predicted sampling variance was smaller than the variance of the measurement error if the composite sample is analyzed only once. These variances are more or less equal if the composite is sub-sampled and analyzed twice.

The stratification leads to a good spread of the sample points over the field. This can also be achieved by systematic grid sampling but a drawback of this sampling design is that the sample size is random. The increase in precision due to stratification depends on the variogram (nugget-sill ratio and range). Also, given a variogram, the increase in precision generally increases with the sample size. For 40 sample points the variance ratio (sampling variance of Simple Random Sampling divided by sampling variance of Stratified Simple Random Sampling) varied from 1.2 to 2.5 for the 16 fields.

The cost model consists of three components: i) fieldwork cost; ii) laboratory cost; iii) equipment cost. The costs of fieldwork and equipment are related to the time needed for fieldwork. Time components are amongst others i) time to digitize the field; ii) computing time (stratification and random selection); iii) time to walk to sample points, and iv) sampling time. We assumed that to digitize the field and to locate the random points a Global Positioning System is used. The predicted once-only cost of digitizing and stratification varied from US$ 10 (1 ha) to US$ 50. The predicted recurrent cost of sampling and laboratory analysis varied from US$ 35 (1 ha, 5 points) to US$ 65 (10 ha, 50 points).

A GIS-based Soil-Landscape Modeling Approach to Predict Soil Drainage Classes and Depth to Iron and Manganese Concretions

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The relationships between soils and landscapes are seldom studied in conventional soil survey. The objectives of this study are to integrate the spatial analysis of GIS and the properties of soils for describing the relationships between landscape and the depth to iron and manganese concretions, and grey mottles of rural soils in Taoyuan county, northern Taiwan. Soil formation factors including relief, parent materials, vegetation, and hydrology were selected and defined as the quantitative variates of landscapes including elevation, soil parent materials, distance to local stream, distance to local irrigated channel, distance to local irrigated pool, distance to local road, and distance to living area. Two hundred and twelve soil pedons were sampled from 1774 hectares study area. The grid sampling method was used to take the soil samples from soil surface to 150cm depth and the sampling interval in every pedon was 10cm depth. The distance between two sampling pedons are 250 meters. The soils in the studied area can be divided into two groups, one is red earths (Ultisols) and the other is gravel or sandy soils (Entisols). These data were stored in a geographical information system (GIS) and processed with a multivariates discriminant analysis (MDA) to establish the soil-landscpe model based on field sample points and landscape variables and also to generate the soil class map and maximum probability map for predicting the different soil properties in the studied area.

The results indicate that the distribution of the Fe, Mn concretions in studied area were influenced by the distance to local stream and to living area, while the distribution of the depth to grey mottles were influenced by the distance to local living area. The shorter the distance to living area the more the oxic condition will be found in the soil profile, and the deeper to the Fe concretions, Mn concretions, or grey mottles will also be found in the lower part of the pedons. The accuracy of the depth to Fe concretions, Mn concretions, grey mottles, and soil drainage classes predicted by soil-landscape model in all studied area were 67%, 65%, 52%, and 70%, respectively. In gravel or sandy soil area, it reached 89% and 91% of the accuracy to predict the depth to Fe and Mn concretions, compared with only 33% and 35% of the accuracy based on the conventional soil survey approach. The accuracy of soil survey to predict the soil drainage class was about 50% which the errors were attributed to actual poor drainage were regarded as good drainage in soil survey report. The soil class map created by soil-landscape model have 40% agreement in the studied area compared with the soil survey map, and the most area of the disagreement was almost distributed in the area of red earths. The technique based on soil-landscape attributes will be helpful on soil survey in the future, it not only explains the relationship between the landscapes and soil properties and estimates the uncertainly area associated with soil mapping activity, but also updates the soil maps of different properties to be more ease and rapid. The raster geographic information data created in this study also can be shared for another researches in other GIS applications in the nature sciences.

Application of a Two-Phase Sampling Approach to Determine Soil Spatial Variability in Relation to Nutrient Dynamics

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Information on the spatial pattern of major nutrients and organic matter is important when studying soil-plant relationships. Variability of soil total C, total N, and pH in a grazed, fertilised sward was quantified using combined nested sampling and grid and transect sampling (Marriott et al., submitted). This approach implies collection of data on separate occasions. The nested sampling suggested an increasing variance for total C at the plot scale, i.e. a linear variogram. For the other soil properties most variation occurred over distances less than 15m. The pattern of the variation was further investigated by taking samples along three transects with points separated by 0.33m and on a 5m grid. Spherical variograms could be fitted for total N and pH using all sample sets after standardizing the data to remove the non-spatial component of temporal change. The described survey, for which samples were collected a year apart, focused on quantifying spatial variation. However, since some properties of interest are related to microbial activity and plant growth, temporal (seasonal) variation may be expected. Approaches for studying both spatial and temporal variability with the same sampling effort are discussed. Instead of sampling intensively on three occasions, smaller data sets could be collected throughout the year allowing analysis of the deterministic (temporal) component of variation related to microenvironmental factors. Better understanding of this deterministic component can be used to improve the method of standardization of the data sets for spatial analysis.

Quantitative Soil-landscape Modeling: A Key to Linking Ecosystem Processes on Hillslopes

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Quantitative soil-landscape models provide a spatial and structural component of the soil subsystem that may be integrated into broader ecosystem models for studying process dynamics and ecosystem function over time. With a plethora of new tools (i.e. remote sensing, digital elevation modeling, GPS, GIS, spatial statistics) available for quantifying soil-landscape patterns, soil-landscape models should supplant traditional “static” soil maps in most applications because specific models can be developed based on the situational circumstances (available data, spatial dispersion, laboratory analyses, quality of available continuous variables for environmental correlation, scale of application). Because of the diversity of factors influencing soil formation in different environments and the broad mix of potential tools for sensing and quantifying patterns, it is likely that standard methods should not be advocated, but rather a mix of tools and techniques applied within a flexible implementation framework.

Existing simulation models for carbon cycling, water and nutrient movement in ecosystems often do not deal explicitly with the critical role of topography as a modifier of local climate and parent material patterns. On hillslopes, ecosystem processes commonly operate in response to redistribution of soil water along flow lines that can be quantified using digital terrain attributes incorporated into soil-landscape models as explanatory variables. Simulation models linked to soil-landscape models provide more realistic ecosystem simulation because of better characterization of hillslope shape and convergence or divergence of water flow.

For greater detail on soil-ecosystem processes, we must rely on in-situ monitoring of fluxes of soil water and temperature, soil gas and nutrients. In addition, unraveling complex ecosystem processes often requires use of isotopic tracers to determine features such as soil-carbon turnover (^{13}C and ^{14}C), soil-water evaporation and transpiration (^{18}O), and source of ecosystem nutrients (^{87}Sr). Process studies require expensive, intensive site-specific sampling that must be linked to a broader context. Soil-landscape models provide a powerful scaling mechanism that can link results of site specific process analyses into a spatiotemporal framework. This talk will discuss and demonstrate the integration of tools and techniques for the study of ecosystem processes.

Geostatistics in Soil Science: State-of-the-Art and Perspectives

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The last two decades have witnessed a growing use of geostatistics in environmental sciences, and more particularly in the processing of soil data. Until the late 1980s, geostatistics was essentially viewed as a means to describe spatial patterns through semivariogram analysis and predict the value of unsampled attribute values by kriging. Too often, soil geostatistics was confined to the application of tools originally developed by mining engineers to address mining topics. The emergence of a generation of truly soil geostatisticians, who can handle the complexity of both geostatistical theory and soil processes, allows one to tackle problems more specific to soil science, such as the incorporation of soil map information in prediction, the assessment of the uncertainty about soil quality parameters, or the modeling of space-time processes. In this paper I review the main applications of geostatistics, with an emphasis on recent developments in soil science, and point out challenging questions for the future.

The recent developments of data acquisition and computational resources have provided the geostatistician with a large amount of information of different types (continuous, categorical). Multivariate approaches, such as factorial kriging analysis, are increasingly used to investigate how the correlation between variables changes as a function of the spatial scale, and to improve our understanding of scale-dependent physical processes. On the other hand, multivariate geostatistical interpolation allows one to supplement a few expensive measurements of the attribute of interest (e.g., metal concentrations) by more abundant data on correlated attributes that are cheaper to sample (e.g., pH or elevation data). In particular, indicator geostatistics enables secondary categorical information such as provided by land use or soil map to be accounted for in the prediction of continuous variables.

There is necessarily some uncertainty about the attribute value at an unsampled location. The traditional approach for modeling local uncertainty consists of computing a minimum error variance (kriging) estimate and the associated error variance, which are then combined to derive a Gaussian-type confidence interval. A more rigorous approach is to assess first the uncertainty about the unknown, then deduce an estimate optimal in some appropriate sense. This can achieved using an indicator approach that provides not only an estimate but also the probability to exceed critical values, such as regulatory thresholds in soil pollution or criteria for soil quality. Another application is the evaluation of the risk involved in any decision-making process, such as delineation of contaminated areas where remedial measures should be taken or areas of good soil quality where specific management plans can be developed.

Another way to model uncertainty is to generate alternative images (realizations) that all honor the data and reproduce aspects of the patterns of spatial dependence or other statistics deemed consequential for the problem at hand. A given scenario (remediation process, land use policy) can be applied to the set of realizations, allowing the uncertainty of the response (remediation efficiency, soil productivity) to be assessed.

Designing Sampling Schemes with Minimal Kriging Variance

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In this presentation, the technique of Spatial Simulated Annealing (SSA) is introduced and applied for minimization of the kriging variance. This technique is a modification of the well-known Simulated Annealing optimization algorithm. SSA allows for optimization of spatial sampling schemes, using several quantitative optimization criteria (Groenigen and Stein, 1997). The schemes are optimized at the point-level, finding the optimal configuration of the sampling points. The optimization process can be constrained by GIS-based information, consisting of boundaries of the area (soil units, factory grounds, etc.) and inaccessibility within the area due to buildings, desolate areas, etc.

Within the inaccessible area a distinction is made between areas that are of non-importance to the surveyor (e.g. canals in the case of soil pollution), and areas that are of importance (e.g. soil under houses). Earlier sampling points from a preliminary pollution assessment, previous soil surveys etc. These points are treated as an integral (but fixed) part of the sampling scheme.

In the presentation, three different optimization criteria are distinguished:

1. Estimation of the experimental variogram. This criterion aims at reproducing an a priori histogram of point pair distribution. By choosing the histogram and the expected axis of anisotropy, the expert can create a 'tailor-made' sampling scheme for variogram estimation.

2. Even spreading over the area. This criterion spreads the sampling points as evenly as possible over the area, minimizing the expectation of the distance between a random point and its nearest sampling point. This is especially useful in the presence of many constraints (e.g. urban center, complex soil map).

3. Minimization of the kriging variance. The presentation will focus on this criterion, which minimizes the mean ordinary kriging variance of the interpolated map. Assuming an a priori variogram, the sampling scheme can be optimized for this criterion. The variogram can be based upon expert-judgment, but it can also be estimated from an earlier survey. Important parameters to be set are the variogram model, variogram parameters, the size of the kriging neighborhood and (geometric) anisotropy.

These criteria can be used independently or in combination. This is demonstrated in a case-study on a river terrace in Northern Thailand. Initial sampling was conducted using a 60 point sampling scheme aimed at estimation of the anisotropic variogram. This variogram was used for designing an additional sampling scheme of 30 points for minimization of the kriging variance. Moreover, the variogram was used as an a priori variogram for an optimal sampling scheme on a similar terrace. The performances of the optimized sampling schemes were tested using stochastic simulations. These showed a much more efficient use of a limited number of sampling points, as compared to conventional methods of sampling design.

Mapping Land Units within Land Systems in Central Queensland Using a Fuzzy Expert System and Terrain Models

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In much of the world, large scale soil maps which would better inform land use decisions are not available. The major impediment to collection of large scale data is the cost of field survey over large areas. One promising approach to increase the efficiency of soil survey is soil-landscape modelling. Soil-landscape models formalise relationships between soil attributes and other environmental variables, particularly landform which may be modelled with terrain data. Experienced soil surveyors implicitly use known and derived relationships between soils and landforms to produce useful maps. An explicit representation of these relationships between soils and landforms could be applied predictively and spatially.

In Central Queensland, large areas of Vertisols are used for dryland agriculture. Water resource development on the Comet River will provide irrigation for more intensive crop production. Large scale soil and land suitability information is required for infrastructure development and farm planning but land resource information in the area is restricted to a small scale land system survey.

Land system surveys contain a wealth of information relating soil features and landform patterns at small scales. Land systems are not soil units, but composite patterns of landform, vegetation and soils. They incorporate smaller non-mapped entities called facets or units which are related to specific landform elements and soil and vegetation features. The distribution of facets within land systems could be mapped if landform elements can be spatially identified thus producing large scale information on soil features pertinent to land managers.

This paper describes a method of identifying facets within land systems using explicit modelling, detailed terrain data and fuzzy rule sets. A high resolution digital elevation model (10m grid) was generated from photogrammetrically sampled elevation values and drainage vectors, using ANUDEM software. A series of raster GIS coverages of landform attributes derived from the elevation grid was generated: elevation, relative elevation, slope, profile, plan and tangent curvature, topographic wetness index and distance from major streams. These attributes were derived using TAPES-G software and other algorithms. A fuzzy rule-based system was developed to classify the raster data sets and consequently to map the likely occurrence of land facets within each land unit. Each land facet was considered to be a single class, and each grid node within a land system was considered to have a degree of membership in each land facet class. Membership functions were generated for each attribute based on the distribution of values within each raster data set. Rules were generated to allocate membership in all facet classes for each grid node within each land system. For example, for Comet Land System, Facet Ct1 represents levees adjacent to active large streams. An appropriate rule set would be: If slope is low Ct1 is medium; if profile curvature is weakly convex, Ct1 is high. The rules were derived from the specific relationships between landform and facet described in the land system survey, and modified according to visual inspection of the terrain data sets, remote sensing images, aerial photographs, and several field traverses. The membership functions and rules were codified in fuzzy system software and a final membership in each facet class was generated using fuzzy algebra. Memberships in each facet class were visualised by mapping of the output raster datasets. The maps indicate the likely location of specific facets (ie. high membership in a facet class) and areas of transition (moderate membership in several facet classes).

The approach produced a large scale representation of soil attributes which better reflects changing land use intensity. The use of a validation data set and subsequent soil sampling allows measurement of reliability levels applicable to statements about specific soil attributes and/or soil variability in specific geographic space. The use of fuzzy class memberships rather than crisp classes permits a more continuous representation of gradually changing landscape attributes, and visualisation of intergrades between classes. It also better reflects the knowledge system from which the rules were derived. The approach is being used in land use planning in the new irrigation areas. It has clear potential in increasing the utility of small scale land system data elsewhere.

Spatial Aggregation and Soil Process Modelling

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Nonlinear soil process models that are defined and calibrated at the point support cannot at the same time be valid at the block support. This means that in the usual situation where model input is available at point support and where model output is required at block support, spatial aggregation should take place after the model is run. Although block-kriging does both in one pass, it is sensible to separate spatial aggregation from spatial interpolation. Contrary to aggregation, interpolation should better take place before the model is run, because in that case more use can be made of the spatial correlation characteristics of individual inputs. When a model is run with interpolated inputs it is important not to ignore the interpolation error. Substituting conditional expectations instead of probability distributions into a nonlinear model leads to bias, essentially for the same reason that aggregating inputs prior to running a model yields a different result than aggregating the output after the model is run. Running a model with inputs that are probability distributions will usually call for a Monte Carlo simulation approach. This brings with it a substantial increase of numerical load, but apart from eliminating bias, an additional important advantage is that the uncertainty in the model output becomes known. Many models used in soil science suffer not only from input error but also from model error. Model error is both support-dependent and case-dependent. The latter implies that model error can only realistically be assessed through validation. Here we face again a change of support problem, because point validation measurements must be aggregated to the block support. Use of meta-models to aggregate validation data must be discouraged because hidden similarities in behaviour between the meta-model and the model to be validated will yield too optimistic validation results.

Spatial Variability of Terric and Typic Medisaprists Within a Coastal Marsh

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Organic soils in some areas within the brackish and saline marshes in Barataria Bay Basin are mapped as associations of soil series in the soil survey conducted in 1981. The associated series within a particular salinity regime are delineated at subgroup level mainly based on the depth to mineral layer (i.e., Terric Medisaprists and Typic Medisaprists). Thickness of the surface organic layer is a major soil morphological feature that indicates the stability of the marsh. Soil morphology is spatially variable within the marsh. Hurricanes, saltwater intrusion, construction of channels, and other man-made changes may affect accretion and degradation of organic layers within the landscape. Spatial variability studies are necessary to understand pedogenic processes and their landscape relations. Thickness of the surface organic layer (or depth to mineral layer) was measured using a grid at 200m intervals established within a one square mile area in both saline and brackish marsh types. Soil morphology indicated spatial variability within the saline and brackish marshes. Data were used to generate contour maps for depth to mineral layer. Terric and Typic Medisaprists were delineated based upon micro scale spatial variation of organic layer thickness. Classification of these organic soils should be reconsidered as Sulfihemists due to pyrite accumulation within the profile.

The Relationship of Soil Variability to Slope Aspect in The Beauce Region (France)

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Easy access of Digital Elevation Model (DEM) allows to quantify relationships between soil variables and terrain attributes. Slope is certainly one of the most important and widely used criteria. Gradient and derived parameters (curvatures) are related to flow velocity and runoff rate. Aspect is also the starting point for many derived parameters using flow path (drainage network, contributive area, etc.). Aspect is commonly used in soil landscape modelling, mainly for hydrological processes. Direct relationships between aspect and soil variables are rarely analysed as the result of other energy factors like solar radiation or wind.

A first objective of this study is to identify relationships between aspect and soil depth in a small area of the Beauce Region in France. A second objective is to search for energy factors (flow path, solar radiation, wind intensity) which could improve understanding of soil genesis.

We described 340 field observations for 1600 ha of an experimental area used for water and nitrate supply monitoring. For each observation, several soil variables were coded, one of these was the presence and the thickness of a silty-clayey-loam (SLC) horizon. Relief is very smooth in this region (mean slope around 0.5%). We established a DEM at 20x20m grid thanks to 9000 field elevation measurements. Main terrain attributes were derived from this DEM and assigned to the pedological observations. Statistical and graphical methods were used to analyse the relationship between the SLC horizon and the terrain morphology. Special statistics were used for aspect due to the circular nature of this variable.

The results show a high relationship between presence of SLC and aspect whereas hydrological parameters are not correlated with this horizon. The mean angle of the aspect frequency of the SLC horizon is calculated and compared to the mean angles of wind direction and solar radiation balance. It shows a low difference between the wind direction and the aspect frequency of the SLC horizon. This result confirms the role of wind in the spatial pattern of soils. It needs other results to better know the combination of several factors (role of vegetation) and the age of the reshaping.

A generalization of this approach was attempted on a larger area. The same relationship was found showing the importance of wind reshaping in the Bassin Parisien. However other factors, mainly the diversity of parent materials, lead to a more difficult interpretation of the wind factor. However, aspect remains as a good criteria to model the spatial pattern of soils at regional scale.

Soil Sampling—A Review

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Soil sampling is reviewed from the perspective of rationalizing data acquisition using statistical methodology. Various practical, statistical and scientific issues in designing sampling schemes are discussed. It is stressed that a sampling scheme which is appropriate for one purpose may be highly inefficient for others. In other words: different purposes require different types of results, which should be produced by different types of sampling schemes. In designing sampling schemes it is therefore useful to reason backward, from the type of end result requested, via the statistical analysis leading to that result and the sample data needed for that analysis, to the actual sampling in the field. The two main statistical approaches in soil sampling are the design-based and the model-based approach. Their principles, mutual differences and basic techniques are discussed, along with some common misconceptions and possibilities of making a rational choice between them. Finally, some interesting recent developments and research topics in soil sampling are indicated.

Evaluating Water Holding Capacity Across Spatial Scales with Neural Networks

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Detailed soils characterization data is often stored in complex and large data sets that are difficult to aggregate and interpret. Aggregating or “scaling” this information from the pedon level to coarser generalizations requires subjective decisions by researchers that are not always consistent from one study to another. With the proper analysis tools, practical information about soil properties can be derived, and the relationship between models at different spatial resolutions can be defined. Neural networks have been shown to be a valuable tool for classifying or predicting soils information, and identifying complex nonlinear relationships in large data sets.

Neural networks “learn” the mathematical function of the relationship between a set of inputs and the desired output presented to them. Inputs are applied and weighted based on their “strength”, and then are summed and passed through a transfer function to produce an output at each node within the network structure. Input and output variables can thus be related without any knowledge or assumptions about the underlying mathematical representation. They attempt to find the best nonlinear function, based on the network’s complexity, without the constraint of linearity or pre-specified non-linearity used in regression and other traditional analyses.

Neural networks also can combine quantitative, descriptive, and ranked data in making predictions or classifications. This is especially useful when soil description, classification, and quantitative data are all available. In addition, when used with a genetic algorithm, neural networks are able to identify, from a large number of possible inputs, only those input variables that behave synergistically to produce the best network performance. In this way, better models can be derived by identifying those parameters most important for explaining the system.

In this study, neural networks were used to predict available water holding capacity across taxonomic classes. Water holding capacity is a critical measurement for many applications from field plot through global scales including understanding vegetation response to drought, responses to climate change, effects of land use on water dynamics, balancing global energy budgets, etc. The soils chosen for this study were part of the pedon database of the USDA, Natural Resources Conservation Service (NRCS). Data sets for each individual soil order were created, as well as a combined data set including all of the orders. Horizons from each profile in the data set were regarded as individual points in the data. A subset of quantitative, descriptive, and taxonomic parameters were chosen from the large number available from the data base.

Simulation of Soil and Vegetation Dynamics with Coupled Models

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Simulation modeling is a powerful method for predicting and understanding the dynamics of ecosystems. Yet, individual ecosystem models tend to be have most detail within their specific scientific field, and only generalizations about other connected parts of the ecosystem. A model of soil physics (FroST: Frozen Soil Temperatures) was linked with a model of vegetation dynamics (Hybrid) in order to predict ecosytstem properties within forests in Canada. FroST contains details describing moisture and temperature flux, but only simple equations for vegetation dynamics. Hybrid details biogeochemistry and forest succession, with little emphasis on soil properties. The linkage between these models was performed using a modeling framework which allowed querying of information from one model to another at each time step and with common data format. FroST provided information for Hybrid about soil temperature, and the amount of water available for roots. Hybrid provided information to FroST about latent heat and transpiration. Results of linked models showed results that were significantly different than results for simulations using the models in "stand-alone" mode. By linking these models, the complexity for individual systems is captured, and simulations appear to provide more realistic results. This method also can be used to evaluate how much detail is necessary about other parts of the ecosystem within any given model, and can provide a means for obtaining "scaled" values for "other discipline" parameters that would be an improvement over "best guesses" currently used.

Root mean square error (rms) and regression coefficients (r^2) were derived for each network and showed similar predicting ability for each data set. The network trained from the combined data set used taxonomic data and a few quantitative parameters. Networks trained from the soil order data required more quantitative data, and these differed between orders. These trained networks can be used to make predictions of water holding capacity when the required parameter data is available. In addition, the parameters used by the networks can give insight into complex relationships embedded in data at varying scales that might not be otherwise observed.

Developing a Quantitative Analogue of Conventional Soil Survey for the Prediction of Soil Properties at Resolutions from 100m to 1km

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A large proportion of conventional soil survey activity has been concerned with spatial prediction at resolutions between 100m and 1km. In conventional surveys, point observations of soils are extended to broader regions using qualitative and complex mental models of relationships with more readily observed landscape features. The mental models are rarely communicated and users of surveys find it difficult to separate evidence from interpretation. Accuracy and precision of mapping are not often stated and soil variation is usually portrayed simplistically as being discontinuous with map units having sharp boundaries. Conventional surveys also provide maps of pre-classified soil types, with minimal information on patterns of variation within polygons. Emerging technologies have created opportunities for the development of a more scientific survey method which generates predictions of individual soil properties with a stated accuracy and precision. A central task for such quantitative survey is development of explicit statistical or rule-based models that replace the implicit mental models used by soil surveyors. A related task is the development of readily observed environmental explanatory variables of pedological significance that can be used for extending point observations to areas. Geographic information systems and statistical software are a prerequisite. However, advances with digital elevation models (DEMs), terrain analysis, global positioning systems and gamma radiometric remote sensing have removed many impediments for predicting soil properties at resolutions between 100m and 1km. The use of these technologies for quantitative soil survey is illustrated using an example from the Bago and Maragle State Forests in southeastern Australia. A simple stratified random sampling scheme was adopted for the 50,000 ha area using digital geology, landform and climatic variables. An index of local landform was generated using a high resolution DEM with a grid size of 25 m. Climate surfaces of annual rainfall and evaporation were generated using the DEM in conjunction with the ESOCLIM and SRAD computer programs. These predictions were combined to generate a simple index of the annual water-balance. The climate and landform digital coverages were classified and cross-tabulated to generate a coverage of 12 discrete environments in each geological unit. Replicated instances of each environment were then randomly selected and sampled. Detailed field descriptions of readily measured properties were made at 172 sites. Generalized linear models and regression trees were then used to generate spatial predictions of soil properties using the stratifying variables and gamma radiometric survey data as explanatory variables. The resulting spatial predictions have resolutions unmatched by comparable conventional methods although they have large confidence intervals. The survey method is strongly influenced by Jenny's functional factorial approach and is a quantitative analogue of conventional survey. Making each phase of the survey process explicit, consistent and repeatable exposes many of the difficulties of predicting soil distribution at scales relevant to management. Examples are presented of soil properties amenable to prediction along with those that are less tractable. Landscape complexity in polygenetic systems, issues of scale and the relative merits of quantitative and intuitive predictive models are discussed.

Comparison of Different Mapping and Classification Algorithms for the Evaluation of Soil Salinity in Iran

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A standard survey of soil salinity in Iran has produced a classified soil salinity map and a data set of about 600 electrical conductivity (EC) measurements of the saturated paste extract determined at three depth intervals (0-50cm, 50-100cm and 100-150cm). However, since the EC values ranged from 1 to 109 mS/cm, a more detailed quantitative evaluation was desired. The study area covers about 450km^2, including different landscape units, and is located in the southwest of Iran. Using an independent test data set, the need to account for the coregionalization between the three depths was evaluated by comparing ordinary kriging (OK) with ordinary co-kriging. No improvement in the consistency over depth was found by using co-kriging. Therefore OK of EC at the different depths was chosen above the much more complex co-kriging to evaluate the soil salinity map. It was found that the overall similarity between the salinity classification predicted by OK was 0.4, whereas it was 0.34 for the soil salinity map.

An Iranian salinity evaluation criterion, combining the EC at the three observed depths, was used to compare different classification methods: a Boolean approach, a fuzzy set classification and multiple-variable indicator kriging (MVIK). The Boolean approach performed worse, fuzzy set improved the discretisation between sites with and without salinity limitation, but the best performance was obtained with MVIK. Therefore, we conclude that the latter method is a promising in land evaluation.

Hard Data—The <1m Scale

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The majority of soil processes occur at the <1m scale: soil minerals weather, nutrients are transformed, biological activity is controlled, raindrops fall and structure is maintained at the <1m scale. Wind and water flow accumulation, tectonics and catastrophes, and therefore long time scale differentiation of soil properties, are examples of the few processes operating at the >1m scale. One of the current trends in geostatistics in relation to soil management is conditional simulation or stochastic imaging. The major proponents of this work, namely Journel and collaborators, have coined the term "hard data" for properties that have been estimated by measurement on physical soil samples. These hard data are used as the benchmark for determining the utility of the so-called soft (often remotely-sensed) data. The hard data are necessary for effective use of the soft data. The lack of hard data often provides the greatest restrictions to information interpretation and gives rise to the greatest component in the uncertainty in information content for land management. The vast majority of hard data come from measurement at the <1m scale. This alone provides an imperative for maintaining research at the <1m scale. The challenge, however, is to make the leap from research driven by curiosity or desire for knowledge to providing support for those trying to use the hard data for interpretation and subsequent decision-making and/or regulation for land management. Some examples of how measurements from the <1m scale can be used to improve modelling and spatial extension of hard data will be presented. In addition, the commonality of use of data analysis techniques across a range of scales will be briefly explored.

Neural Networks in Soil Science: A Tool or Just Cool?

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The use of artificial neural networks (ANN) in geosciences is on the rise. An appealing claim made for ANNs is that they are based on biological learning principles. Publications on ANN applications are mostly success stories. An ANN is a mathematical model (or physical device) in which many simple, small, nonlinear submodels (or subdevices) are connected with unidirectional communication channels. The terms “neuron”, “node”, “element” or “neurode” are often used to describe the submodels. Each submodel processes numeric inputs coming from other submodels via the connections. Weights are given to each connection of each submodel. A graduate adjustment is made to the weights in all submodels as the observed “input-output” patterns are sequentially presented to the ANN. This process is commonly called “learning” or “training”. ANNs are manifold nowadays. Multilayered feed-forward neural networks (MFNN) became very popular because of their relative simplicity, stable performance, and multiple applications. Quite often, MFNNs are equated to ANNs. This misconception may lead to selecting inappropriate ANN. The task-dependent selection of the ANN is a necessary precondition of its successful application. It is not easy to do, though, because the software for many types of networks is either proprietary and costly or just not developed. ANNs have been developed primarily as pattern recognition tools, and ANN are used classification or discrimination tools. It has been demonstrated and in some cases proven that ANNs can be good approximation tools and successfully compete with regression techniques. ANNs are useful in making short term predictions in time series that are registered in observations or generated by simulation models. Some ANNs are effective at identifying relevant input variables. There are essential differences between ANNs and conventional classification, discrimination, or regression algorithms. ANNs are not as predictable as conventional algorithms. They must be trained several times, and there is no guarantee that the best net will be found. Computer time and computer memory requirements can be prohibitively large. ANN learning depends on selection of the learning sample. This seems to be the main encumbrance in ANN applications. No general recipe exists to build a learning sample or to select the network architecture and parameters of the network learning process. Examples of ANN applications in soil science are found mostly in soil hydrology. With ANNs, estimating water retention and hydraulic conductivity from readily available data and determining drainage patterns from digital elevation models was reasonable successful. Other applications will undoubtedly appear soon. The existing applications in geosciences show that ANNs are a complement rather than a replacement for conventional techniques. Building a good ANN requires understanding how the ANN works, involves a heuristic trial-and-error process, and may demand an ability to change and/or amend the algorithm. A compensation for this effort is an efficient classifier or predictor.

Research at the 1 to 10m Scale in Pedology: The Emergence of Landscape-Scale Patterns of Soil Properties

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Research on soil properties at the 1m scale has long been a focus of activity in soil classification and genesis for it is at this scale that the soil pedon emerges as the major spatial unit of investigation. At scales of 10m, the individual pedons begin to form discernible spatial patterns in the landscape. These patterns result from distinctive pedogenic regimes that occur in response to differences in the type and intensity of pedogenic processes. In regions such as the glaciated Canadian prairies, which lack significant age differences along a topographic continuum, the pedogenic regimes occur due to differences in redistribution of water and microclimate and their effects on soil processes. Both the moisture redistribution and the microclimate controls are primarily governed by the morphology of the landscape. In these regions landform morphology provides an important link between the quantifiable patterns of soil properties and the pedogenic processes responsible for these patterns. The quantitative evaluation of soil properties involves coupling this basic landform-soil relationship with an understanding of the time required for a distinctive spatial pattern to emerge. The models of soil distribution used in soil mapping are based on the occurrence of specific soil taxonomic individuals (i.e., soil pedons in formal taxonomic systems) which result from the action of pedogenic processes over hundreds or thousands of years in these landscapes. The resulting pattern of soil pedons can be quantified into landscape-scale soil distribution models which form the basis for extrapolation of 1- to 10m scale studies into successive, smaller scale studies. Human use of the soil influences the basic landscape-scale soil distribution pattern over a time scale of decades. For example, accelerated rates of soil redistribution due to cultivation in Prairie landscapes has greatly increased the range of soil organic carbon and nitrogen levels, and redistribution leads to accentuation of the pre-cultivation pattern. The rates of processes such as gaseous losses of nitrogen show much less of a memory of past landscape changes but are very strongly influenced by annual differences in landform-mediated hydrological controls. For example, denitrification rates within a 1m cell can show very high spatial variability, typically with coefficients of variation in the range of 100-200%; however despite the great range of values within individuals pedons, a clear landscape-scale pattern of emissions can be discerned and quantitatively evaluated. This evaluation allows the extrapolation of site-specific rates to scales of more relevance for global evaluations of gaseous emissions. The greatest challenge remaining for pedological research at this scale is to integrate observations on the state of individual soil processes with the most important of the responses to these processes, the production of plants at the field scale. With the emergence of precision agriculture as a major research and applied objective in soil science, the need for this greater understanding has become much more acute.

Use of Fractals to Model Soil Structure and Structurally-Mediated Processes

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Soil structure refers to the form or internal geometry of natural porous media. Structural form is both spatially and temporally variable, and is the product of many different biochemical, physical and mechanical processes including soil aggregation, compaction, cracking and fragmentation. Fractals are hierarchical, often highly complex, spatial or temporal systems generated using iterative algorithms with simple scaling rules. The patterns within such systems repeat themselves over a defined range of scales (self similarity). As a result, no matter how intricate a particular pattern might be, its statistical properties can be reproduced at other length or time scales. Fractals offer new opportunities for modeling hierarchical structures and the processes that take place within such structures. Because of their complexity at any given scale, they are particularly applicable to heterogeneous media such as soils.

This presentation will cover the introductory principles of statistical self-similarity and survey recent developments on spatial fractals as applied to soil structure, with emphasis on the fields of soil physics and soil mechanics. Applications of fractals in these areas can be grouped into five broad categories:

(i) characterization of the geometry of structured porous media,
(ii) prediction of soil water retention and transport processes,
(iii) adsorption phenomena on irregular surfaces,
(iv) crack growth and fragmentation, and
(v) quantification of soil spatial variability.

In terms of structural characterization, fractal geometry has been used to model ped shape, changes in aggregate density with size, and pore-size distribution. In terms of water retention and transport processes, fractals have been used to develop physically-based models to predict the soil water characteristic curve and saturated hydraulic conductivity based on structural characteristics, and to model diffusion and hydrodynamic dispersion within tortuous porous media. Investigations of physio-chemical adsorption phenomena have focussed on the irregular surfaces of pore walls. The area of such surfaces changes when measured with molecular probes of different diameters, which has implications for exchange reactions, adsorption isotherms and solute transport. Advances have also been made in fracture mechanics based on the propagation of fractal cracking patterns within homogeneous solid materials. This work needs to be extended to heterogeneous porous media. Multiple fractures result in fragmentation, and several models are available for the prediction of fragment-size distribution from knowledge of structural form characteristics, assuming the same probability of failure for different-sized structural units under a given applied stress. In terms of spatial variability, fractal techniques, including semi-variograms, power spectra and multifractal spectra, have been employed to analyze large data sets collected at different length scales within the landscape.

Further research is needed to investigate the physical support for different fractal models, to collect data sets specifically for testing these models, and to move from the current descriptive paradigm towards a more predictive one. Fractal models offer the opportunity of not only quantifying the geometry of structured porous media under static conditions, but of using this information to predict physio-chemical and mechanical processes within these media under dynamic conditions.

Integration of Quantitative Pedological Data Collected at Multiple Scales

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Digital data sets of the earth's surface spectral properties are routinely collected from various sensors mounted on satellite and airborne platforms. The temporal and spectral properties of any one pedon in an agricultural field will soon be available from high-resolution satellites. Soil samples for digital data sets of representative micro-pedofeatures must be carefully chosen to represent their distribution on landscapes. There is a lack of studies linking quantitative data between varying scales of measurement.

We report on the development of a system for the study of soil landscapes at multiple scales by combining remotely sensed data with image analysis techniques, global positioning systems, and soil micromorphology techniques. At a regional scale, the agricultural landscape can be monitored using the 25m Landsat TM satellite data. At the field scale, data from a Compact Airborne Spectrographic Imager (CASI) with a 1m pixel resolution, combined with global positioning systems allows for the spectral characterization and monitoring of agricultural soils for soil organic matter and soil erosion (using ^{137}Cs) related to topography. At the pedon scale, impregnated soil blocks and thin sections can be produced for spectral imaging with a 12 micrometers pixel resolution over a 4 X 5cm area. Soil voids (>30 micrometers equivalent diameter) can be differentiated from the solid matrix, and pore size and shapes can be quantified to assess the influence of management practices on soil structure and short-term pedogenesis in agricultural fields. Thin sections are imaged with an Array Technologies scanner in transmitted light, reflected light and circularly-polarized light. The 9 spectral data sets can be simultaneously used in an unsupervised classification, followed by aggregation to differentiate pedofeatures at this scale, utilizing image analysis algorithms within EASI/PACE (PCI Inc.) software.

The linking of processes at multiple scales will be the basis for prediction of changes in soil organic matter, and detailed soil-landscape relationships within agroecosystems. Robust computer hardware, software and sampling designs are key components of this system.

Use of Asymmetric In Shape Fuzzy Membership Functions on a Land Evaluation Study in an Agricultural Experimental Field in Venezuela

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The ranges of certain variables can determinate the suitability or not of one field for some agricultural use. However, maybe a higher (lower) level of the range is more harmful than a lower (higher) level, indicating an asymmetric unsuitability. This suggests that the use of a semantic import model with different shape parameter in the lower and higher levels of the variable fuzzy membership function could represent more appropriately the characteristic under study. In this work we use this concept in a land evaluation study based mainly in sand, organic matter and pH. We obtain empirically appropriate membership functions. Based in an interpolated grid obtained by kriging, the membership values were mapped by isolines. The proposed methodology seem to be appropriate for a more effective land evaluation studies of agricultural systems.

Hydraulic Conductivity of a Soil Pedon

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Numerical modeling of water flow and pollutant transport in soils attempts to describe a dynamic equilibrium among the elements of a pedon whose characteristic properties are assumed to be known. Soil water will then move within a pedon in response to pressure gradients which are unique to each element. We propose here a method to define characteristic properties of such elements within a pedon matrix from a limited knowledge of soil profile characteristics. The property chosen for detailed analysis was field saturated hydraulic conductivity (K_{sat}). The method is based on profile description, in situ measurements of K_{sat} with a Guelph permeameter, available soil survey information, and geostatistical probability field *(P-field)* simulation. A 30m long, 10m wide, and 1.5m deep trench was excavated within an area mapped as Leck Kill channery silt loam. The profile was described as a fine-loamy, mixed, mesic Typic Hapludult, and a detailed description was prepared by conventional means. The pedon was also evaluated in a GIS format on a 10x10cm grid. To do so the horizontal face was examined visually as to whether it was firm or soft, wet or dry, composed of rock or soil. The orientation of the coarse fragments in each grid square was then noted, and an overlay of each property was prepared. Combining overlays of soft and wet soil areas with an overlay of all non-horizontal coarse fragment directions gave an overlay of potential water-conducting zones in the pedon. In another approach K_{sat} values both measured and estimated from texture, were assigned to selected pedon elements, staggered in 10cm increments with depth. A 3-D distribution of hydraulic conductivity within a pedon was then conditionally simulated using a geostatistical *P-field* approach. Analysis showed similarities between visually observed flow regions and the conditionally simulated realizations. Ability to generate multiple realizations allowed computation of probability of exceeding a given flow threshold. The method is self-validating. Based on measured values, the goodness of fit can be related to standard concepts of accuracy and precision using a *leave-one-out* cross validation approach. Potential applications are many. Here the method is illustrated by a distribution of K_{sat},, but any other property could have been used. The method is well suited to spatial characterization of most 3-D soil properties based on the field access hole record, so long as the respective locations are properly georeferenced.

Using Relief Parameters in a Discriminant Analysis to Stratify Geological Areas of Different Spatial Variability of Soil Properties

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Spatial distribution of soil properties in landscape is controlled by the soil forming factors relief, parent material, climate, organism and time. Although this relation is a paradigm in soil survey, it is rarely considered in the analysis of spatial variability of soil properties. The objective of this paper is to show how discriminant analysis can be used to identify on an objective basis the soil depth at which geology changes. This information can then be used for a better soil survey and geostatistical regionalization of soil properties. The study area was a 1.5km^2 soilscape 50km north of Munich with high variability in parent material and relief. Altitude varied from 445 to 498m above sea level. Topography included valleys in all directions and asymmetric slopes with different aspects. Sediments of the Tertiary period ranged from gravely and sandy fluvial sediments to silty and clayey sediments over short distances. They are partly covered by Pleistocene loess of variable thickness (0-2m) and colluvial material. Field survey was done on 450 nodes of a rectangular 50x50m grid and fundamental soil properties were measured for each classified soil horizon. Relief parameters were calculated using a Digital Elevation Model (DEM) derived from more than 4000 elevation measurements.

A discriminant analysis was performed to distinguish areas of sediments of the Tertiary period (TS) from areas with Quaternary sediments (QS). For this, soil horizons, which were classified without any doubt to TS (class 1) resp. to QS (class 2) as parent material in the field survey, were selected as test data set. The 86 soil horizons for class 1 and 496 soil horizons of the class 2 were obtained. They were weighted by their different horizon thicknesses to account for their representation within a soil. Beside several relief parameters, soil depth of the horizons was used as discrimination variable. With elevation above sea level, soil depth, slope and upslope watershed area as independent variables, it was possible to reclassify 86.6% of class 1 and 85.4% of class 2 by the discriminant analysis. The significance for discrimination of these variables can be well explained by the geological processes forming the soilscape of the study area. Dissolving the discriminant functions by the soil depth and applying the result to the DEM yields a map of the boundary depth (BD) between the TS and QS. Thus, transforming the result to the parameter BD gives several advantages: With BD a mappable visualization of the classification function was possible. Finally, the BD was used to divide the study area-dependent on the soil depth of interest into two strata, which allowed variogram calculations for each strata and soil depth separately. Thus, the variograms for pH, organic carbon and soil texture showed in the subsoil much higher spatial variability for the strata of class 1. Consequently, four times more measurement points must be taken for the strata TS than for the strata QS to reach the same precision when interpolating e.g. soil texture in subsoil. This confirms again the necessity to include relief and geological information to geostatistical analysis.

Digital Elevation Model Resolution: Effects on Terrain Attribute Calculation and Quantitative Soil-Landscape Modeling

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The accuracy of a digital elevation model (DEM) and DEM-derived products depends on (i) the resolution (both horizontal and vertical) at which the elevation data is represented, (ii) the source of the elevation data, and (iii) the data model, or structure of the elevation data (grid, contour), that is used. This accuracy becomes more important as we extend the use of DEM data for quantitative soil-landscape modeling for prediction of the spatial distribution of soil attributes. Our previous research has led to the development of empirical models that were used to predict the spatial distribution of A-horizon thickness, depth to secondary carbonates, and a soil color index related to soil organic carbon content. The objective of this research was to compare terrain attributes and quantitative soil-landscape models derived from grid-based DEMs (i) represented at different horizontal and vertical resolutions and (ii) collected by different methods. For a hillslope in west-central Minnesota we generated a DEM with a 10-m horizontal and 0.1m vertical resolution from an intensive field survey. For the same 17-ha study area, USGS DEM data with 30-m horizontal and 1m vertical resolution was also acquired. Interpolation and subsampling of these data sets produced both field survey-derived and USGS-derived DEMs with 10- or 30-m horizontal and 0.1- or 1-m vertical resolutions. Primary and secondary terrain attributes (e.g., slope gradient, slope curvature, specific catchment area, and the compound topographic index) were calculated from each of the DEMs. Distributions of terrain attributes were compared using matched t-tests. Significance tests were also performed on correlation coefficients and regression line slopes between paired data sets. Empirical models relating a soil color index, the Profile Darkness Index, to selected terrain attributes were developed from the field survey-derived DEMs and the USGS-derived DEMs. On average, the elevations from the USGS DEM were approximately 9m above the elevations from the field survey DEM within this study area. Slope gradients calculated from the USGS DEM were also significantly steeper than slope gradients calculated from the field survey DEM. While elevations were highly correlated in comparisons of DEM source, other terrain attributes were not and the distributions of terrain attributes were significantly different. For the field survey DEMs represented at different horizontal resolutions, slope gradients were steeper and compound topographic index values were less when calculated from the 10-m resolution DEM. A decrease in vertical resolution of the 10-m horizontal resolution field survey DEM produced a large proportion of points with zero slope gradients and zero slope curvatures as a result of the loss of vertical precision. However, this also produced a large number of steeply sloping and more highly curved points because all relief between points in the DEM must be in increments of 1m. Empirical models developed at different resolutions included different predictive terrain attributes. Slope gradient, profile curvature, and elevation above local depression were included in the model developed from field survey DEM (10m horizontal resolution, 0.1m vertical resolution). The model developed from the USGS DEM (30m horizontal, 1m vertical) included the compound topographic index and elevation above local depression.