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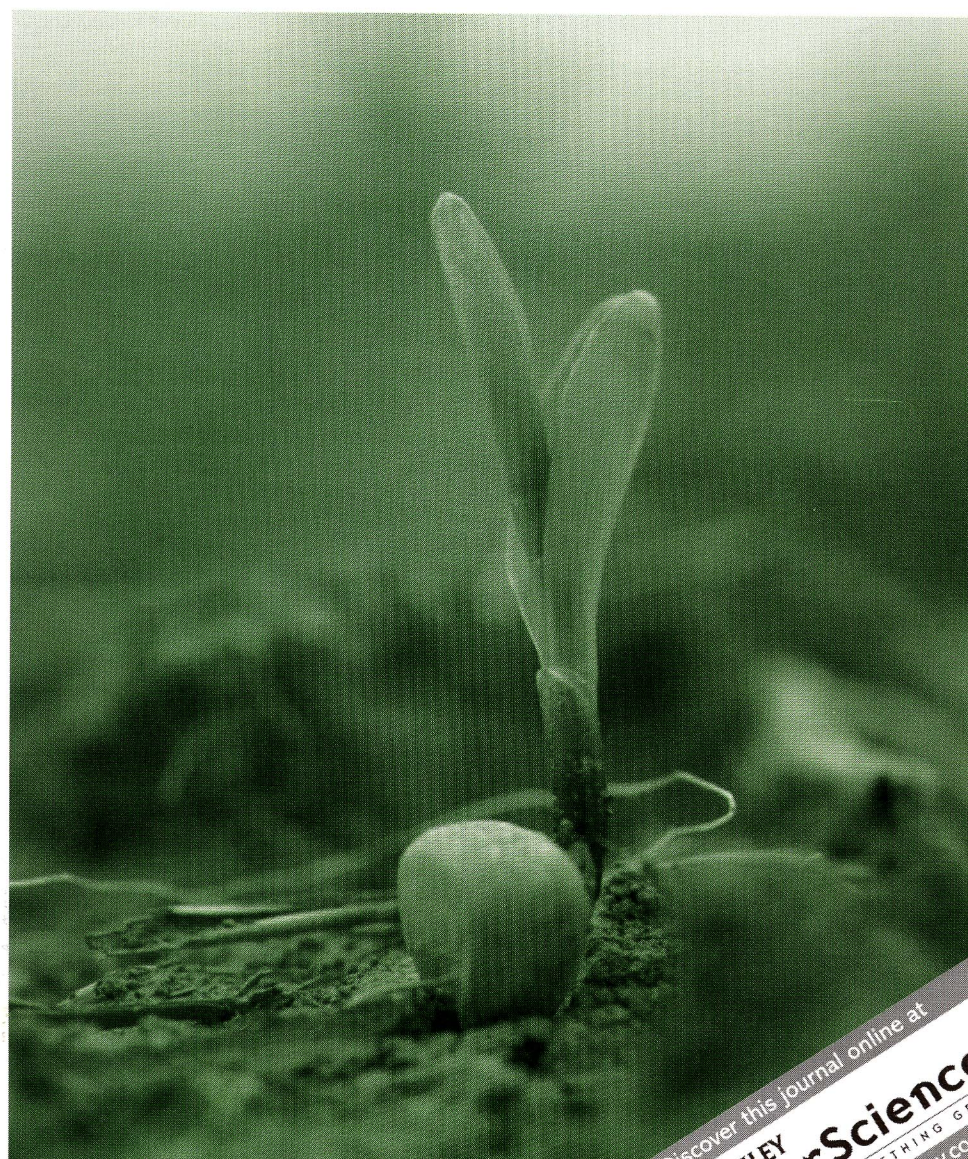

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had been published in 1965 (*AG Bodenkunde*, 1965) to harmonize the soil-classification system. Another major change was caused by the German reunification in 1990, as the former German Democratic Republic and the Federal Republic of Germany used different classification schemes and mapping guidelines (*Eckelmann*, 2005) resulting in the 4th edition (*AG Boden*, 1994) of the soil-mapping guidelines and the unified description of soil substrates (*AG Bodensystematik*, 1998) which recently found a further update with the 5th edition (*Ad-hoc-AG Boden*, 2005).

The mapping scheme is a morpho-genetic approach based on soil-forming processes and morphologic features and dates back to ideas of *Dokuchaev* (1883) and *Jenny* (1941). The soil classification is based on a hierarchical system of soil divisions, soil classes, soil types, and soil subtypes relating to moisture regime, diagnostic horizons, and pedogenetic processes. The soil-mapping guideline is developed for field surveys at a scale of 1:25,000 which is meant to be detailed enough for planning purposes and coarse enough to map soils in an appropriate time (*AG Bodenkunde*, 1965).

Another important pedological dataset with a long tradition is the German soil assessment (*Bodenschätzung*; *cf., Pfeiffer* et al., 2005) carried out at scales of 1:500 up to 1:5,000 for agrarian sites only by the fiscal authorities since the early 1930s for a fair taxation due to soil-driven differences in yield. Even if this approach is completely different to the soil-mapping guidelines described above, as for example all profile data like particle size are averaged over a soil depth of 1 m, the German soil assessment provides important information for high-resolution soil mapping and prediction.

In the former German Democratic Republic, another type of soil assessment which was the successor of the German soil assessment called "mesoscale map" (MMK) is digitally available at a scale of 1:100,000 or as hand-drawn working sheets at 1:25,000 and, thus, also important for soil surveys.

For soils under forest, the so called "forest-site map" *(Forstliche Standortskarte, AK Standortskartierung*, 1996) with a scale of 1:10,000 provides soil information, again not comparable to the current soil-mapping guidelines. As the mapping scheme has clear differences between individual federal states, these maps need to be interpreted by experts to derive transfer rules for soil surveys. As for the German soil assessment, most of these maps are not digitally available yet.

2.2 Soil data

Thanks to the helpful contributions of the soil surveys of the individual states, we were able to compile a list of digitally available soil maps at different scales in Germany (Tab. 1) as well as digitally available maps of the German soil assessment (Tab. 2) in 2005 and the future perspectives for 2010.

Based on the ongoing mapping and digitalization process as well as different interpretations and sources, the information provided in these tables must be regarded to some degree

Table 1: Digitally available soil maps in Germany mapped according to the German soil-classification scheme [%].

		Scale					
		large 1:5,000; 1:10,000		medium 1:25,000; 1:50,000		small 1:100,000 – 1:300,000	
Federal State	km²*	2005	2010	2005	2010	2005	2010
Baden-Württemberg	35.752	0	0	25	90	100	100
Bavaria	70.549	0	0	60	100	30	100
Berlin	892	0	0	100	100	100	100
Brandenburg	29.478	0	0	4	40		
Hamburg	755	0	0	0	0	75	100
Hesse	21.115	0	0	100	100	100	100
Lower Saxony/Bremen	47.620 / 404	85	85	100	100	100	100
Mecklenburg-Western Pomerania	23.179	0	0	30	100	10	100
North Rhine-Westphalia	34.084	47	70	96	100	50	100
Rhineland-Palatinate	19.853	0	0	65	100	100	100
Saarland	2.569	0	0	5	5	100	100
Saxony	18.415	0	0	30	70	100	100
Saxony-Anhalt	20.446	0	0	80	100	100	100
Schleswig-Holstein	15.763	1	1	40	50	99	100
Thuringia	16.172	0	0	10	65	100	100
Germany	357.046	16	18	57	87	76	100

* according to the *Federal Statistical Office* (2005)

Table 2: Digital available maps of the German soil assessment [%] based on *Pfeiffer* et al. (2005).

Federal State	2005	2010
Baden-Württemberg	8	8
Bavaria	0	100
Berlin	50	100
Brandenburg		
Hamburg	100	100
Hesse	17	100
Lower Saxony/Bremen	70	70
Mecklenburg-Western Pomerania	0	0
North Rhine-Westphalia	5	5
Rhineland-Palatinate	50	100
Saarland	0	0
Saxony	10	50
Saxony-Anhalt	100	100
Schleswig-Holstein	0	100
Thuringia	10	10
Germany	25	63

unsharp. The German soil assessment (Tab. 2) can be differentiated in three different basic datasets, (1) digitized field sectors with class numbers, (2) additional soil-profile descriptions, and (3) translations from the soil-assessment nomenclature to the German soil-mapping scheme (*Ad-hoc-AG Boden*, 2005). As mentioned in section 1, each federal state has its own processing order which results in distributed progress in compilation of these basic datasets. Comparable differences in information content and density are typical for soil maps of the 16 federal states (Tab. 1), but they are not in the scope of this paper.

Beyond the intended scale of soil mapping at 1:25,000, soil maps at a scale of 1:50,000 are very popular and a kind of unspoken standard because the financial resources are steadily decreasing and do not permit soil surveys at larger scales for the whole country (Tab. 1).

Nevertheless, North Rhine-Westfalia and Lower Saxony/Bremen provide soil maps at large scales (1:5,000–1:10,000) for between 47% and 85% of their corresponding state area. In North Rhine-Westfalia, these maps are traditionally surveyed whereas all other large scale soil maps are derived from the German soil assessment on the basis of pedotransfer-rules.

Concerning the German soil assessment, the fiscal authorities are responsible for the digitalization process, resulting in a relatively small amount of finalized maps of about 25% (Tab. 2) only. The future perspective for 2010 with almost 65% coverage is remarkable and very promising. For field surveys, scanned and geo-referenced maps are available in most federal states. Since each federal state adapted transfer-rules to translate information of the German soil assessment into soil classes according to the German soil-mapping guidelines, the ongoing digitalization effort will increase the availability of large-scale digital soil information.

In contrast, soil survey at medium and small scales is determined by the individual conditions in the individual federal states due to the respective financial situation and political interests. As a result, the coverage of these maps varies between 0% and 100% (Tab. 1). At medium scales—in most cases 1:50,000—the federal states intend to further soil survey from about half to two thirds of the overall area in 2010 in contrast to larger scales which seem to be beyond feasibility.

Small-scale soil maps are available for over 75% of the German territory. In this domain, the soil map 1:200,000 is of special interest, as the development is based on a joint program of the federal states and the Federal Institute for Geosciences and Natural Resources (BGR) and comprises a standardized legend and an underlying soil database (*Eckelmann*, 2005).

3 Digital soil mapping

In *Wikipedia* (2005), digital soil mapping (DSM) is defined as the creation and population of spatial soil information by the use of field and laboratory observational methods coupled with spatial and nonspatial soil inference systems (*McBratney* et al., 2003; *Lagacherie* et al., 2006). Thus, DSM goes far beyond digitizing existing soil maps and is further extended to continuously mapped soil attributes. Other terms instead of digital soil mapping are soil-landscape modeling (*Gessler* et al., 1995) and predictive soil mapping (*Scull* et al., 2003).

Generally, DSM can be divided in three approaches: (1) pedotransfer functions, (2) geostatistical approaches, and (3) state-factor (clorpt) approaches. In the sense of soil mapping, a pedotransfer function describes a mathematical function where one soil property is predicted by other, generally easier to measure, soil properties (*Lamp* and *Kneib*, 1981; *Bouma* and *van Lanen*, 1986), where predicting hydraulic characteristics based on particle size dominates the research field (*Wösten* et al., 2002). Geostatistical approaches, as introduced by *Krige* (1951) and *Matheron* (1962), use sampled and analyzed data to interpolate soil-attribute maps (*Webster* and *Oliver*, 2001), whereas clorpt or scorpan approaches (*e.g.*, *McBratney* et al, 2003) have their seeds in the works of *Dokuchaev* (1883) and *Jenny* (1941) and use regression (*e.g.*, *Moore* et al., 1993; *Minasny et al.*, 2004), classification (*e.g.*, *Behrens* and *Scholten*, 2006), or fuzzy-set theory approaches (*e.g.*, *Zhu*, 2000) to create soil-attribute or soil-class maps. While the main foci of DSM are scorpan and geostatistical approaches, nearly all methodological combinations are possible as empirical quantitative soil–spatial prediction functions (*McBratney* et al., 2003).

To provide a classification scheme to compare and interpret digital soil datasets, we propose three different types or orders to distinguish digital soil maps:

– First-order digital soil maps consist of digitized soil maps that are classically surveyed.

- The second-order comprises conceptual soil maps, compiled by spatial overlays of different environmental covariates, without deeper statistical and mathematical analysis.

- Third-order digital soil maps are generated using pedotransfer functions, geostatistical or scorpan approaches.

Even if it is not possible to classify every digital soil map correctly within the proposed scheme as there often are smooth methodological transitions, it can provide important metadata for interpretation.

3.1 Digital soil mapping in Germany

3.1.1 Soil surveys in the federal states

Based on the federal structure in Germany, the approaches in terms of soil mapping as well as digital soil mapping are highly diverse. Digital soil mapping in terms of second- and third-order digital soil maps is applied in Brandenburg, Baden-Württemberg, Lower Saxony, Rhineland-Palatinate, Thuringia, and Saxony-Anhalt mainly based on scorpan approaches and geostatistics. The major source of environmental covariates is the digital elevation model in terms of digital terrain analysis, which has a long and lasting tradition in Germany (*Bork* and *Rhodenburg*, 1986; *Dikau* 1992; *Kleefisch* and *Köthe*, 1993; *Köthe* and *Lehmeier*, 1993; *Friedrich*, 1996; *Schmidt* and *Dikau*, 1999; *Behrens*, 2003). Thus, all approaches are mainly based on these attributes. Concerning Brandenburg, a fuzzy-rule and kriging-based system is implemented to derive a third-order digital soil map (*Hannemann*, 2005). In Baden-Württemberg, a maximum-likelihood approach was used to predict karst soil classes based on soil-profile data (*Köberle*, 2005). In Lower Saxony, 100% of the area are covered by second-order digital soil maps (*Boess* et al., 1999) and about 15% by first-order digital soil maps. Research projects on digital soil mapping have a long tradition and range from soil information systems (*Kleefisch*, 1994; *Gehrt and Sbresny*, 1999) to Universal-Kriging interpolations to compile functional soil maps (*Bock* and *Köthe*, 2005). In Rhineland-Palatinate, *Behrens* et al. (2005) and *Behrens* and *Scholten* (2006) used artificial neural networks and an extended digital–terrain analysis approach to extrapolate more than 5,000 km^2 at a scale of 1:50,000 for different soilscapes and regions. In Thuringia, as shown in this article (*cf.,* 3.2), we used classification trees to create a third-order digital soil map 1:50,000. In Saxony-Anhalt, *Scholten* and *Behrens* (2005) created second-order digital soil maps for the chernozem region based on statistical approaches on climate, relief, and information of the mesoscale map, and third-order digital soil maps for the flooding area of the Schwarze Elster river based on learning–vector quantization approaches (*Behrens* and *Scholten*, 2006) which is now extended to the Elbe river, where a detailed soil map is needed for flood and environmental protection.

The Federal Institute for Geosciences and Natural Resources (BGR), which is the national geological authority, started to establish a nationwide soil information system in 1991 (*Eckelmann*, 2005). Along with this national approach, the surveys in the federal states published state-wide soil maps at scales ranging from 1:300,000 to 1:500,000. Based on political demands, a national program was established to produce a consistent soil map of Germany at a scale of 1:200,000 which now is almost finalized (*cf.,* Tab. 1). As all other mentioned digitally available soil maps, the soil map 1:200,000 is based on traditionally surveyed soil maps, subsequently revised, spatially aggregated, and standardized.

In Germany, most federal states provide platforms, pedotransfer rules databases, or soil information systems like MEMAS or NIBIS (*Müller*, 2004) to manage soil information derived from soil maps and related profile databases. Methods are applicable across different spatial scales forming a basis to describe solute transport, bio-geochemical transformations, and hydrological processes. Most of these methods are based on field-surveyed soil properties or laboratory analysis linked to standardized soil descriptions (*e.g., Fritz* and *Waldmann*, 1998).

3.1.2 Scientific research

Generally DSM is an applied research field. Even though it is not possible to reference all publications of all research activities in soil science and related fields, it is fairly certain that many researchers use pedometrical techniques to solve their daily tasks. On the other hand—in our point of view—regarding research on these techniques and approaches has not been paid yet as much attention as necessary in the German soil-science community.

The following overview of publications, as an addition to the previous section, which is by far not meant to be complete, lists some recent, partly overlapping research topics related to pedometrics and digital soil mapping in Germany:

- Accuracy and uncertainty in soil information systems
  Hennings and Boess (2000) introduced user-oriented concepts to assess the accuracy of nationwide land-quality maps, which *Hennings* (2002) analyzed as a function of the upscaling procedure used for soil data. *Lösel* (2004) focused on the information content and density of the German soil map 1:1,000,000.

- Automated soil-identification approaches
  Albrecht et al. (2006) compared different soil-identification schemes on existing data using classification trees in terms of category-forming characteristics.

- Data-mining-based digital soil mapping
  The works of *Behrens* et al. (2005, 2006a) and *Behrens* and *Scholten* (2006) focused on third-order digital soil-class maps predicted by different data-mining techniques like artificial neural networks, classification trees, support-vector machines, and learning vector quantization. *Selle* et al. (2005) compared data-mining techniques with Kriging to regionalize available water capacity. *Mertens* et al. (2002) tested the ability of classification and regression trees (CART) to regionalize soil profiles.

- Fuzzy-set theory–based (3D) predictions of soil attributes
  The application of fuzzy-set approaches ranges from the 3D rule-based continuous soil-horizon modeling (*Ames-*

kamp, 1996), the combination of fuzzy forest-soil information aiming to spatially disaggregate classical soil maps (*Friedrich*, 2002), to soil attribute and class mapping (*Hannemann*, 2005).

- Geostatistics for functional soil mapping
  Böhner and *Köthe* (2003) as well as *Bock* and *Köthe* (2005) demonstrated the creation of third-order digital soil-attribute maps based on Universal Kriging and the use of data from the German soil assessment.

- Pedotransfer functions
  Pedotransfer functions are widely used and analyzed ranging from the regionalization of Cd-sorption characteristics (*Springob* and *Böttcher*, 1998) to unsaturated soil hydraulic conductivity (*Wagner* et al., 2001). Pedotransfer rules as part of soil databases or soil information systems like MEMAS or NIBIS are described by *Müller* (2004) for Lower Saxony and by *Ad-hoc-AG Boden* (2000) for nationwide purposes to interpretate soil data derived from soil maps and profile data. *Böttcher* (2004) focused on the uncertainty of nonlinearly estimated parameters from incubations of soil organic matter.

- Precision agriculture
  Herbst and *Lamp* (2000, 2003) used geostatistics to implement optimal sampling schemes for precision agriculture and derived pedotransfer functions to map available water capacity based on the German soil assessment and electrical conductivity.

- Sampling and representativity
  In contrast to international research efforts on sampling design (*e.g., Brus* and *de Gruijter*, 1997), the research activities in Germany focus on the concept of representativity. Based on works of *Fränzle* (1978) on a spatial neighborhood analysis of soil maps, *Fränzle* and *Kuhnt* (1994) developed an approach to derive representative sample locations and applied it to find characteristic soil profiles in Europe. *Szibalski* et al. (1999) applied their approach successfully to predict the spatial distribution of soil pH and soil C_{org} at a scale of 1:5,000 in three districts in the Lahn-Dill area in central Hesse, each comprising about 1–4 km^2. *Behrens* and *Scholten* (2003), *Behrens* et al. (2006a), and *Behrens* et al. (2006c) developed and tested an approach to search representative areas for monitoring purposes and detailed studies. *Schröder* et al. (2003) analyzed the representativity and the comparability of existing soil monitoring areas.

- Space-time variations
  Wendroth et al. 2003 evaluated soil and remotely sensed variables in bi- and multivariate autoregressive state-space analysis to predict spring-barley grain yield.

- Spatial disaggregation of soil information
  Möller (2005) demonstrated the application of multihierarchical object-structure analysis based on spatial and nonspatial classification and segmentation approaches to classify terrain attributes as a basis to disaggregate soil information.

- Spatial variability of soil properties
  Based on a discriminant analysis on terrain attributes, *Sinowski* and *Auerswald* (1999) stratified geological areas into parts of different spatial variability of soil properties.

- Terrain analysis and soil-attribute prediction
  Soil-attribute distribution within the mid-latitude landscapes in Europe is bound to the distribution of Pleistocene periglacial slope deposits which is highly influenced by relief (*e.g., Scholten*, 2003). *Friedrich* (1996) used spatial-segmentation approaches to classify terrain attributes and to map periglacial slope deposits. *Behrens* (2003) analyzed more than 500 variations of terrain attributes on their impact on periglacial slope deposits. *Scholten* et al. (2001) and *Scholten and Behrens* (2002) used statistical approaches to map periglacial slope deposits whereas *Behrens* et al. (2006a) used ground-penetrating–radar information and data-mining-based approaches in the mapping approach.

- Open-source GIS out of the soil-science community
  Based on works of *Conrad* (1998) on comparing different flow-accumulation algorithms, a full-featured open-source GIS emerged (*Conrad* et al., 2005), containing a large library of terrain attributes and soil-related indices and spatial-interpolation approaches.

To summarize, it can be stated that there are plenty of important and promising contributions. Most of these articles are written in German and reflect the current situation of pedometric research in Germany. Due to the financial restriction at universities as well as the soil surveys in the federal states, the main research is done on small projects by PhD students, who are often not really able to pass their knowledge down to the next generation. Another problem is the generally very traditional orientation of soil-science research which fortunately seems to have changed slightly within the last years.

3.2 Scorpan predictions in Germany using classification trees—an example from Thuringia

Assuming *Dokuchaev's* soil-forming factors (1883), conventional field surveys are based on available information about bedrock material, vegetation, and topography aiming to create a conceptual model—mental or analogue—that is tested and improved on the site. The quality of this expert-driven approach strongly depends on the surveyor's experience, local knowledge, and survey concept. In this respect, relief is an integral factor that has a lasting influence on the effects of gravitation, climate, geology, water, and biota (*e.g., Gerrard*, 1980). The same conceptual framework can be applied using techniques like classification trees or artificial neural networks (*Behrens* et al. 2005; *Behrens* and *Scholten*, 2006), both standard techniques in the range of artificial intelligence and data mining in general.

Classification trees (*Breiman* et al, 1984; *Kim* and *Loh*, 2001) are designed to learn rules from examples, *i.e.*, to extract or learn knowledge that can be used for a subsequent prediction. Since information for building a tree is required, such methods are referred to as supervised learning (*Mitchell*, 1997). The application of supervised algorithms consists of two stages. During the first stage, the tree is automatically built, based on statistical analysis, which means that it learns the conditions in which a certain feature, *e.g.*, a soil class, occurs. During the second stage, the learned knowledge in terms of the resulting rules of a tree can be applied to prediction areas, for which the same input parameters (*i.e.*, terrain attributes, land use, and geological units) are available, but no soil map has been surveyed. The classification tree then predicts the soil units based on the learned rules.

Different from expert systems, supervised classifiers implement knowledge in form of mathematical expressions. Thus, the predictions are reproducible, verifiable, and relevant as long as the soilscape shows conditions similar to those in the training area regarding the soil-forming processes (*Lagacherie* et al., 2001; *Behrens* et al., 2005).

The algorithm used for digital soil mapping in the Thuringia study is called CRUISE (Classification Rule with Unbiased Interaction Selection and Estimation; *Kim* and *Loh*, 2001) which has already been successfully tested for soil-class prediction (*Behrens* and *Scholten*, 2006).

Generally, classification trees are built through binary recursive partitioning. Suppose a dataset consisting of one continuous input feature x and one two-class feature to predict y, with N observations, that is, (x, y) for $i = 1, \ldots, N$. The split variable x and the split or threshold value λ assign observations to either left or right branch of a node in a tree. The observations with $\{x\ \lambda\}$ are assigned to the left branch and those with $\{x > \lambda\}$ to the right respectively (*Behrens* and *Scholten*, 2006). In contrast to the well-known greedy search algorithm introduced by *Breiman* et al. (1984), the approach used in CRUISE is based on an ANOVA-F-test which is faster and more stable (*Kim* and *Loh*, 2001).

3.2.1 Database, preprocessing, and prediction

The database used in this study to predict soil classes for the map sheet L5130 is considerably reflecting the heterogeneous situation in Germany which results from the principle of subsidiarity. Beyond a 25 m DEM and its derivates (*Behrens*, 2003; *Behrens* et al., 2005), a so-called "soil-geological map" (*Bodengeologische Karte*) with a similar scale compared to the target map was available and thus used as an additional predictor to extrapolate soil classes. The soil-geological map is an aggregation of the German soil-assessment maps, originally surveyed at a scale of 1:500 up to 1:2,500 considered to be printed at a scale of 1:100,000. Even if the scale seems to be >1:100,000 and might range between 1:50,000 and 1:75,000, the information content of the soil-geological map is not sufficient to directly derive soil classes according to the current German survey guidelines. Therefore, the soil-geological map was used as an additional predictor data set helping to differentiate between soil substrates.

For training, three different conceptual soil maps surveyed at a scale of 1:25,000, two within the prediction area, and one from a neighboring area were available, forming an outstanding basis for a prediction. However, the two neighboring concept maps had to be analyzed before and after the prediction by expert knowledge, because dislocations at the borders in terms of positional uncertainties and errors within the soil-class description occur. Another problem which had to be addressed is the almost exact match of some units in the soil-geological map and the concept maps, which is especially the case for colluvisols and gleysols in valley bottom positions as the soil-geological map also formed the basis for parts of the concept maps. An overlay with the DEM reveals dislocations resulting from the generalization process when creating the soil-geological map and of course the differences between the old topological map used for the soil assessment and the actual DEM. As a result, the predicted soil classes are orientated at the delineation of the soil-geological map and not at the DEM as the relationship to the DEM is weaker. To overcome this shortcoming, all valley-bottom soil classes were removed from the soil-geological map, and the resulting gaps were filled by means of Euclidian allocation. As a result, the prediction is based on terrain attributes, and the topology of the predicted soil classes is even better than within the concept maps.

As an additional preprocessing step, the delineation of the soil-geological map was fitted to relief by iteratively replacing pixels showing outliers in the underlying terrain attributes based on supervised classification (*Behrens* et al. 2006b).

3.2.2 Prediction results

Based on the scale of the conceptual soil maps used for training and the scale and the resolution of the soil-geological map and the DEM, the resulting scale is between 1:25,000 and 1:50,000. As mentioned above, due to the removal of some generalized soil-geological classes and the supervised correction of the delineation, the final delineation in some parts is even better than in the concept maps with a scale of 1:25,000 used for learning.

As soil classes are conceptual models themselves, surveyed by an experienced soil surveyor the only data to validate soil-class predictions are additional soil-class surveys either as point samples or as soil maps representing the physical reality. In this study, validation is based on a comparison between the extrapolated soil classes and the spatial location of soil classes in concept maps that were not used for prediction. In that sense, the validation results are about 0.4 up to over 0.8 in terms of the F measure demonstrating the importance and the opportunities provided by supervised digital soil-mapping approaches.

The resulting digital soil map "L5130" reveals the importance of combinations of terrain attributes and lithography in soil-class prediction (Fig. 1). Although some soil unit boundaries of the soil-geological map are still preserved, many uncertainties compared to the input data are corrected by topography (*Behrens* et al. 2006b).

In digital soil class–prediction projects where the training database is not that rich as in this study, we recommend an integrated and iterative approach of field soil surveys and pre-

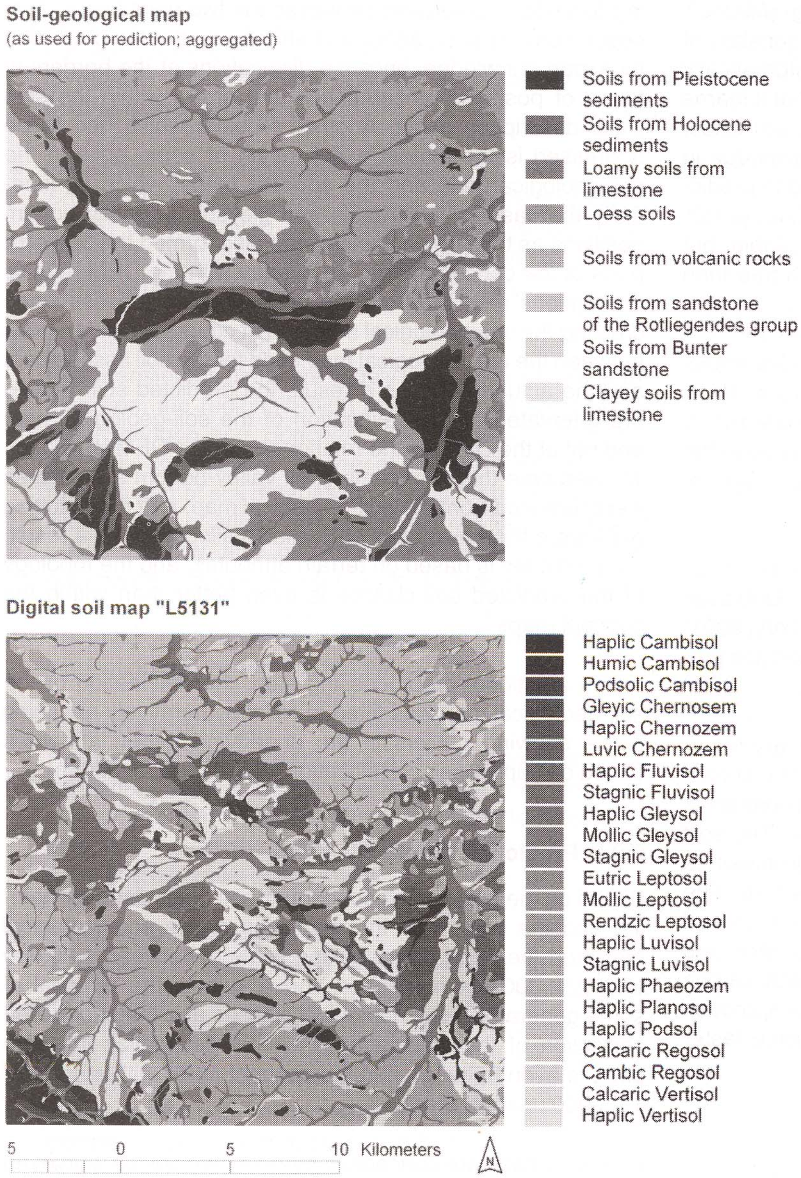

Figure 1: The soil-gelolgical map and the predicted digital soil map "L5130" in Thuringia.

dictions, which can successively be validated in the field during the ongoing survey process.

From the pedological point of view, a combination of field surveys and prediction should generally be preferred over a pure prediction approach. In terms of decreasing financial resources, this approach ensures high-quality soil maps with reduced field-survey time. Furthermore, it offers the ability to map larger scales for lower costs. Another advantage—pedologically as well as for the geological surveys in the federal states—can be seen in the systematic delineation resulting from predictions which is also a matter of quality control.

4 Future perspectives and needs

Within the last years, the major work on soil mapping in Germany—which is almost finalized in these days—is the compilation of the nationwide soil map at a scale of 1:200,000 as a basis for the soil map 1:250,000 of the European Union. The production of soil maps at other scales must be regarded as highly diverse. One major trend will be towards project-based soil maps at scales of 1:5,000 up to 1:10,000 based on the German soil assessment.

Another important change within the next decade might—though in our opinion *should*—be the transition to classification schemes like the WRB, as an Esperanto for (digital) soil surveyors as well as users and stakeholders, which must be seen as a European challenge, as each member still uses its own soil-classification system.

A third important topic to discuss is a change in the philosophy of soil mapping from the classical soil-class map at least towards additional soil-attribute maps and functional soil maps which seems to be contrary to the soil scientists "love-affair" to soil-class maps but which is forced by users' needs and by political regulations.

5 Conclusions

Strong efforts concerning DSM are recently undertaken in many countries as well as by the European Union which founded an official European working group on DSM with regular meetings to enforce standardized soil maps with the highest resolution possible. In Germany where only about 57% are surveyed at a scale of 1:25,000 up to 1:50,000, the need to provide high-resolution soil maps rises. Hence, the application of pedometrical methods in terms of digital soil mapping becomes more and more popular and important and thus scientific research as well.

In Germany, first- and second-order digital soil maps do exist almost nationwide or form the basis for actual soil surveys. Third-order digital soil maps are still not widespread, which might be the result of subsidiarity on the one hand and the relatively small cost pressure in the past on the other hand.

The requirements based on political directives such as for cross compliance and especially the strong demand of high-resolution soil-attribute information from users and stakeholders must be seen as one of the biggest challenges and driving forces in terms of digital soil mapping with impact on fundamental and applied research on the one hand as well as the German soil surveys as the enforcement authorities on the other.

The ongoing development of computer hardware and software provides the ability to refine and complete existing soil databases and, even more important, provides solutions for regions and countries with sparse soil-data infrastructures. As Alex McBratney wrote (*WG-DSM*, 2005), the scaling model of Moore's Law "predicts that we should be able to have a 10-metre resolution digital soil map of the world by 2040, but we must not sit back and believe it will just happen!"

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