Delimitation of naturally handicapped areas due to their pedological features in Hungary according to common European biophysical criteria

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Abstract
EU's Common Agricultural Policy encourages maintaining agricultural production in less favored areas (LFA) to secure both stable production and income to farmers and to protect the environment. Recently the delimitation of LFAs is suggested to be carried out using common biophysical diagnostic criteria on low soil productivity and poor climate conditions all over Europe. The criterion system was elaborated by European Commission's Joint Research Center (JRC) and its operational implementation comes under member state competence. This process requires the existence of an adequate national spatial soil information system with appropriate data structure and spatial resolution as well as a proper methodology for its analysis. Hungary possesses a suitable, nationwide, 1:25,000 scale legacy data set originating from the national soil mapping project, which was digitally processed and developed into the Digital Kreybig Soil Information System (DKSIS). In our paper we present how DKSIS was applied for the identification and delineation of areas in Hungary concerned by the common biophysical criteria related to soil. Soil data linked to soil profiles and SMUs were semantically inferred and jointly analyzed spatially for the compilation of nationwide digital maps displaying spatial distribution of specific limiting factors.

Key Words
Natural handicap, biophysical criteria, inference, spatial soil information system, Less Favored Area.

Introduction
One of the main objectives of the EU's Common Agricultural Policy is to support maintaining agricultural production in less favored areas (LFA) in order to sustain agricultural production and use natural resources, in such a way to secure both stable production and income to farmers and to protect the environment. LFA assignment has both ecological and severe economical aspects. Since its introduction in 1975, the objectives of the LFA measure have evolved, reflecting a shifting constellation of social and environmental needs in less favored areas, and a changing set of priorities. Formerly national governments designated their own LFAs independently based on some common but rather qualitative rules and flexibility was afforded to the Member States in their interpretation. However wide ranges of national criteria were not comparable at European level, the consequent diversity significantly reduced the transparency of the system (CEC 2009).
In Hungary, as the first approximation, the areas with less favored conditions for agricultural production were defined in terms of the one-and-a-half century old "Golden Crown Standard" (Burger 1998). In the next turn the National Rural Development Plan (2004) regularized the designation of LFAs. In this process the areas affected by specific handicaps were identified and spatially delineated using AGROTOPO (1994) spatial soil information system, whose spatial resolution corresponds to about 1:250,000 - 1:100,000 scale.
Recently the delimitation of LFAs is suggested to be carried out by using some explicitly defined, common, biophysical, diagnostic criteria on low soil productivity and poor climate conditions all over Europe, which is a promising approach for setting up an objective and transparent system for designating areas affected by natural handicaps (Van Orshoven 2008). It is suggested that they provide a simple and comparable system for LFA designation, unambiguously linked to soil and climate handicaps for agriculture and implementable by all the Member States. As the first step of the cooperation with and operational implementation by Member States, the application of the common criteria should be simulated on the basis of sufficiently detailed soil and climate data, using data sets under member state competence, due to the lack of sufficiently detailed pan-European data. Regionalization of the soil related biophysical, criteria (drainage, texture and stoniness, rooting depth, chemical properties and soil moisture balance) requires the existence of (preferably one) adequate national spatial soil information systems with appropriate thematic and spatial resolution.
In Hungary the national soil mapping project initiated and led by Kreybig was a national survey based on field and laboratory soil analyses and at the same time serving practical purposes. Its aim was the preparation of a map series which gives an insight to the geographical site and extent of soil conditions and soil properties for the production directing authorities, agricultural policy-makers, farmers, and the research institutes

related to production problems (Kreybig 1937). The similarity between the objectives of the old national mapping and those of the present European activities is noteworthy.

The Kreybig mapping approach identified the overall chemical and physical soil properties of the soil root zone featuring soil patches for agricultural areas. Three characteristics were attributed to soil mapping units and displayed on maps; further soil properties were determined and measured in soil profiles. The unique feature of the Kreybig method was the usage of representative and further, non-representative soil profiles occurring within soil patches. These profiles jointly provide information on the heterogeneity of the area. The Kreybig legacy represents a valuable treasure of soil information, which is developed in the Digital Kreybig Soil Information System (DKSIS; Pásztor *et al.* 2010).

Materials and methods

The elaborated European system consists of detailed definitions, justification and associated critical limits or threshold values for each biophysical criterion as well as indications for its assessment. There is one criterion considering limitations due to terrain features: *Slope*. There are two criteria dedicated explicitly to climatic conditions: *Low Temperature* and *Heat Stress*. *Soil Moisture Balance* is a criterion taking paralelly into consideration soil and climatic conditions. The further four criteria are exclusively defined by pedologic characteristics: *Drainage, Texture and Stoniness, Rooting depth* and *Chemical properties.*

It is recommended by the protocol for soil related criteria that Member States identify the most suitable representation in the national datasets that corresponds to them. Even it is allowed that the fulfillment of a criterion could be estimated from the soil names used in the national soil classifications system. National systems may use different limits but it is suggested to harmonize data using transfer functions. The main expectation is that soil and climate data of sufficient spatial and semantic detail are used.

Spatial and semantic resolution can (and usually does) significantly differ for different datasets. One database may fit better the system's semantic requirements containing more up-to-date and/or sophisticated parameters, which can be explicitly used or easily converted. Another database however might be much more detailed spatially, while its parameters can be applied more indirectly using more complex inferences. Additionally, the databases belong to different institutions and are not necessarily shared even for within country utilization. Thus, even if better results could be achieved by integrated usage of various datasets, generally the solution must be a compromise assigning a sole database, which can offer an optimum basement. The expert group, commissioned with the execution of LFA assignment task in Hungary, discussed thoroughly the various opportunities and decided for the application of DKSIS, which has at least three major advantages in the present context as compared to any other possible Hungarian datasets:

- The main objective of the original mapping is almost the same as that of present LFA assignment.
- DKSIS is the most detailed nationwide spatial dataset covering the whole area of the country.
- The database contains utilizable information to fulfill all the soil related criteria, and due to their spatial features they can also be used for countrywide regionalization of these criteria.

DKSIS data structure

DKSIS contains two types of geometrical datasets simultaneously. Soil mapping units (SMU) are represented by polygons and characterized by three attributes: (i) combined texture and water management categories, (ii) overall soil chemical properties, (iii) areas with shallow depth are also distinguished (yes/no). The approximately 100,000 SMUs were delineated based on overall chemical and physical soil properties of the soil root zone for agricultural areas. The soil conditions for other land use were not identified, however a simplified landuse categorization is also provided, delineating temporarily waterlogged areas; forests; lakes, marshes, rivers and settlements. Detailed soil properties were determined and measured in soil profiles (even temporarily waterlogged areas and forests are seldom represented pedologically this way). The survey applied various pits and boreholes, some of which were deepened to 10 m or to the groundwater level. The most detailed data are provided for "representative sites", localized on survey sheets, examined in situ, and sampled for laboratory analysis (about 30-110 points per map sheet, which covers roughly 250 km^2). The "observed sites" were examined in situ, with description in the explanatory notes, but without laboratory analysis (40-300 points per sheet). The "delineator sites" were used for delineation of soil patches (100-1500 points per sheet). The similarity in soil profiles was used for their coding within a map sheet. If a soil profile with similar geographical position, and very similar properties had already been described, its code was attributed to this one, too. There is representative profile description in the database for about 22,000 plots, and this profile information is transferred for further 250,000 locations.

DKSIS data model and structure reproduces this mapping context, consequently the soil profile database contains hard and soft data simultaneously. This fact facilitates the spatial inference of any profile related variable, thus achieving much better spatial resolution than what is provided by the application of representative profiles, which method simply attributes the profile information to the supporting SMU.

Semantic fulfilling of soil related biophysical criteria

Criterion on soil drainage: "Areas, which are waterlogged for significant duration of the year."
Some poorly drainaged areas are very clearly represented in DKSIS. There is a unique landuse category (temporarily waterlogged areas), which is dedicated directly to this limiting factor. However not only these directly denominated areas were assigned to be affected. The original survey used this category for non-agricultural areas (which later also could be turned into cultivation), thus the croplands actually suffering from waterlogging should have been identified, too. SMUs characterized as "soil with poor hydraulic conductivity and very high water retention, prone to cracking" as well as profiles with the heaviest texture properties were selected and restricted being located in deep topographic position.

Criterion on soil texture and stoniness: "Relative abundance of clay, silt, sand, organic matter (weight %) and coarse material (volumetric %) fractions in top soil material." This item is composed of six independent sub criteria combined with "or" logical function: >15% of topsoil volume is coarse material OR unsorted, coarse or medium sand, loamy coarse sand OR heavy clay (>60% clay) OR organic OR vertisol, clay, silty clay or sandy clay with vertic properties OR rock outcrop, boulder within 15 cm of the surface.
DKSIS provides various possibilities for the physical characterization of soils. SMUs are partly delineated based on these features. There are classes, which directly correspond to one of the sub-criteria (blown sand; stony surface; gravelly surface; peat soils). As for profiles, the field estimation of the textural classes, hygroscopic moisture content (*hy*) and the so-called "capillary rise of water" were taken into consideration in texture class definition.

Criterion on soil rooting depth: "Depth (cm) from soil surface to coherent hard rock or hard pan < 30 cm." The original survey distinguished areas with shallow depth, where agricultural management is impeded by dense soil in the plough layer, which is usually considered to be 30 cm. Thus all SMUs with this attribute were identified as handicapped, in spite of that there is no direct measurements on rooting depth.

Criterion on soil chemical properties: "Presence of salts, exchangeable sodium and gypsum (toxicity) in the topsoil." This is also a complex item composed of three independent sub criteria combined with "or" logical function: salinity: > 4 dS/m OR sodicity: > 6 Exchangeable Sodium Percentage (ESP) OR gypsum: > 15%. Treatment has been similar to that of soil physical properties, since chemical features are also represented in multiple ways in DKSIS. One exception should be mentioned: practically there are no gypsiferous soils in Hungary and consequently gypsum content measurement is not involved in the basic laboratory practice.

Criterion on soil moisture balance: "Number of days within growing period as defined by temperature >5°C (LGPt5), for which the amount of precipitation and water available in the soil profile exceeds half of potential evapotranspiration ≤ 90 days." The Hungarian Meteorological Service was commissioned with the modeling of potential evapotranspiration and its spatial inference. But this modeling process had to be based on a solid soil background. DKSIS was used for the estimation of field capacity water content (pF 2.5) combining SMU and profile related data on soil physical properties and then for a suitable spatial inference.

Spatial inference of specific limiting factors

Possibilities for the spatial inference of limiting factors were determined by two main considerations.

- The fulfilling of a specific criterion had to be regionalized, that is the final product should be a binary map displaying yes-no categories.
- The fulfilling of a specific criterion could be evaluated using various kind of source data, either based on SMUs, or in profile related form.

Our intention was to establish the decision as much as possible, thus we used multiple decisions on fulfilling a given criterion, if they were available. Decisions were carried out on SMU and soil profile level carrying out proper SQL queries on the profile database and then joining their results to the spatial entities, which resulted in spatial features categorized in binary (indicator) form (i.e. black and white polygons and points). SMUs provide complete coverage, but point information had to be spatially extended. Indicator kriging seemed to be a perfect approach, being a nonparametric method without any assumption on concerning the distribution of the modeled variables (Isaaks and Srivastava 1989; Marinoni 2003). It provides a probability (spatial) distribution map, indicating the probability of fulfilling the criteria within the block used for the calculation (in our case 1 ha cells were used for the interpolation).
Once having a probabilistic approach, the vagueness concerning the spatial behavior of binary classified SMUs might also be taken into consideration. Soil patches provide sharp edges between the two types of decision (fulfilling the criteria or not) in spite of the background soil properties may have much smoother,

continuous variation from one area to the neighboring one. We turned to a fuzzy representation of boundaries to cope with this problem (Wang and Hall 1996).

Results

Semantic and spatial inferences of specific limiting factors resulted in a digital map series. Each map displays a probability field displaying the membership probability of the 1 ha size blocks for the whole area of Hungary. To achieve the final delineation two further steps were required.

- In the case of multiple evaluation, the different results should be combined properly.
- A suitable threshold value should be defined for the membership probability for each criterion (to convert the "grayscale maps" into "binary ones").

As a first approximation, we used a weighted sum of multiple assessments for their combination applying empirical weights according to the reliability of the data source used for the inference. The highest weights were assigned to maps originating from data related to representative sites (considered as hard data), soft data concerning "delineator sites" were less ranked. Since SMU related information is the most generalized, weights of layers related to polygon origin were determined as the lowest, however they play a very important role, stratifying the various soil properties in space. As for thresholds, simply P (fulfilling the criterion) = ½ was used, due to the lack of any knowledge on the distribution of the background variables.

Conclusion

Present work is just in the stage of its finalization, which has been the first result of a rather speeded work process. This means that the digital processing of the whole legacy dataset had to be carried out parallelly with the elaboration of the methodology for its specific analysis while making the most out of the existing data. Consequently not all the steps are elaborated in enough details, but the solid scientific basis was always primary when making compromises. Anyway, the nationwide spatial soil database is finally assembled and its LFA specific analysis is roughly elaborated. In the next step the parameters and thresholds could be fine-tuned, which is also predicted for the basic criteria set up by JRC after a European level evaluation of member state results.

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