A tool for estimating soil water available for plants using the 1:1,000,000 scale soil geographical data base of Europe

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1. Abstract

For agricultural or environmental purposes, the European Union needs to have tools giving sufficient and reliable information on soils at a global scale for decision making. For example, the MARS project developed an agrometeorological model for predicting yield at regional and national levels for the main crops in Europe. The knowledge of Soil Water Available for Plants (SWAP) is essential for estimating the water balance. The Soil Geographical Data Base of Europe at scale 1:1,000,000 represents the most detailed data source on soil covering the whole European territory. Using this database, a tool for estimating SWAP was developed. This tool estimates SWAP using basic variables from the Soil Geographical Data Base, variables estimated by pedotransfer rules stored in a knowledge data base, and users-defined parameters. The calculation is made on three layers which limits are determined by the users-defined parameters and the estimated depth of soil. The available water for each layer is calculated using three suction limits: at -5 kPa for field capacity, -200 kPa for the easily available water limit, and -1500 kPa for the wilting point. The SWAP corresponds to the summing of the available water of each layer. The tool was developed within the same system as those used to store the Soil Geographical Data Base, and the knowledge database. This leads to an easy access to the results and allows easy thematic mapping.

2. Introduction

The European Union needs to manage and protect soils both for agricultural production and environmental purposes. To carry out this task, the European Commission needs tools giving sufficient and reliable information at a global scale for decision making. In this context, the MARS project was initiated for developing tools for monitoring agricultural production using remote sensing techniques and agrometeorological modelling (Vossen and Meyer-Roux, 1995). The aim of such a model is to predict yield at regional and national levels for the main crops in Europe. To do this, water balance estimate using climatic data known with a decade time-step is carried out. For this purpose, the knowledge of the Soil Water Available for Plants (SWAP) is of main importance. The Soil Geographical Data Base of Europe at scale 1:1,000,000 represents the most detailed data source on soil covering the whole European territory. Using this database, a tool for estimating SWAP was developed. The objectives of this paper are to describe the 1:1,000,000-scale Soil Geographical Data Base, to present the methodology used for the SWAP calculation, and to discuss the first results, mainly presented in thematic maps.

3. Materials and Methods

3.1 The Soil Geographical Data Base of Europe at scale 1:1,000,000

The tool we will present has been built as an application to the Soil Geographical Data Base of Europe at scale 1:1,000,000 (King et al., 1994). This database results from harmonization of soil data available for Europe (Jamagne et al., 1994; King and Le Bas, 1996). In the database, soils are described for Soil Typological Units (STU) which form the basic unit of the database. Each STU is defined by the values of some variables such as soil name, textural class of the topsoil horizon, etc. STUs cannot all be delineated at the scale of 1:1,000,000. The STUs are therefore grouped into Soil Mapping Units (SMU) that can be delineated at this scale.

Information is stored in two data sets, within the Arc/Info Geographical Information System software (Figure 1):

- The geometric set stores the geographical extension of the polygons representing the delineation of SMUs. This set is modelled by an Arc/Info coverage.
- The semantic set is composed of three Arc/Info data base files:
  - One file contains the variables describing the SMUs. These variables mainly concern the number of STUs by SMU and the area of the SMU.
  - The second file describes the relationship between the SMUs and the STUs that composed the SMUs. This relation is described through the percentage of area of the SMU represented by the composing STU.
  - The last file stores the variables describing the STUs. These variables are essentially qualitative such as the soil name, the parent material, the texture classes, etc. They represent expert knowledge and essentially concern pedogenic information. Analytical data are neither provided nor estimated.

The lack of analytical information on soils complicated the use of this database, for both agricultural and environmental problems. Thus two ways of enrichment were envisaged. First, the collection of representative profiles (Figure 1) describing STUs was begun in order to have analytical data (Madsen and Jones, 1996). This data set is composed of two types of profiles: estimated profiles providing information for all the requested variables but using expertise or guesstimates, and measured profiles with data only for the variables that were actually measured. The second way of enrichment was the elaboration of a knowledge database (Daroussin and King, 1994), providing, through pedotransfer rules, estimated variables using the available STU variables (Figure 1).

3.2 The knowledge data base

The aim of this knowledge database is to provide interpreted variables for agricultural or environmental purposes, for helping non-expert users, or for giving analytical parameters for modeling. Ideally, this knowledge database should use pedotransfer functions that are based on mathematical relationships between basic soil properties, such as clay content, and complex properties like water holding capacity (Breeuwsma et al., 1986; Van Genuchten et al., 1992). But as mentioned above, the data describing STUs in the database are qualitative. So the concept of pedotransfer function was extended to the concept of the pedotransfer rule (Jones and Hollis, 1996).

The pedotransfer rules, elaborated by several experts (Van Ranst et al., 1995), use the basic data from the soil geographical data base for estimating the needed parameters through logical relationships. The way of building the rules tries to formalize how the soil expert interprets the soil data stored in the Geographical Data Base. For example, the soil name is a way of labeling information concerning the soil type, such as its depth, its water regime, etc. The rules can also use data from other sources e.g. climatic, land use or elevation data.

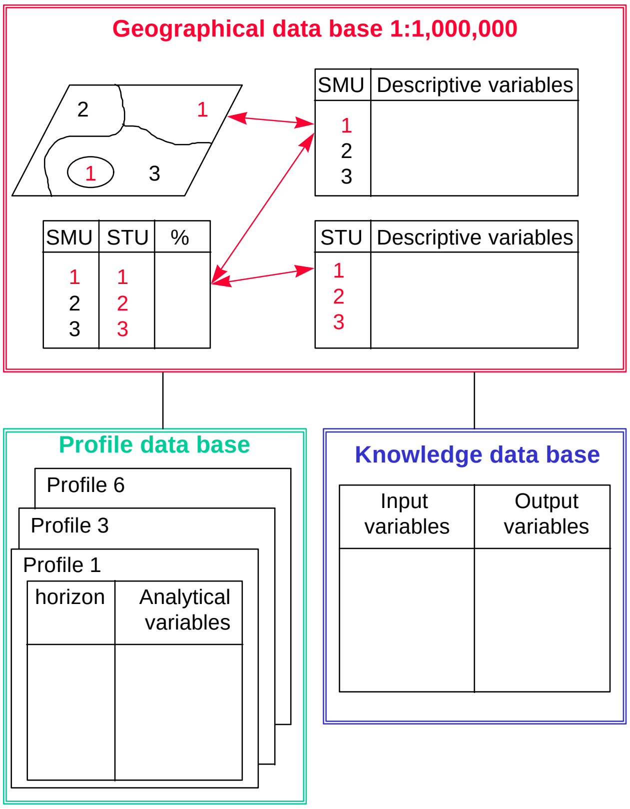

Figure 1. structure of the Soil Geographical Data Base of Europe at scale 1:1,000,000.

This knowledge data base works like an expert system; it is stored in Arc/Info, and contains all pedotransfer rules (Daroussin and King, 1994). Each rule is a table containing the values of the input variables, and the corresponding values for the output variables (Figure 2). Each line of the table, called an occurrence, represents one of the possible combinations of values for the input variables, and the corresponding values for the output variables. A confidence level is attributed to each occurrence, giving the reliability of the assessment. For each occurrence, the authors and the date of the last update are stored for easier management.

Input variables					Output variables		Reference attributes		
Regional codes	1	2	...	n	class	Confidence level	Authors	Date	Notes

Figure 2. Structure of a pedotransfer rule within the knowledge data base.

For each STU, the input variable, values are compared to each occurrence of the rule. The system chooses the occurrence of which values are the nearest from the STU values. The confidence level is the minimum between those of the input variables and that of the selected occurrence. Then the variables from the pedotransfer rules can be added to the STUs descriptive file in the database, allowing to make thematic maps. Output variables from pedotransfer rules may also be used as input variables in further pedotransfer rules.

The knowledge data base was previously used for estimating parameters like Cation Exchange Capacity, Bulk Density, Mineralogy, etc. For estimating the Soil Water Available for Plants, we use both basic variables coming directly from the Geographical Data Base, and variables derived through pedotransfer rules. The detailed method is described in the following paragraph.

3.3 Calculation of soil water available for plants (SWAP)

3.3.1 Principle

The water reserve available for plants is classically defined as the difference between the water retention at field capacity and the water retention at wilting point. But field measurements show that the ability of plants to extract water decreases with depth. This led to the definition of extractable available water (EAW) (Thomasson, 1995). For this study, we used the water retention at different suction limits as reference: -1500 kPa for wilting point, -200 kPa for the easily available water limit, and -5 kPa for field capacity. The water available in a horizon can be either:

Equation 1: $$R_h = E_h\left(W_{fc} - W_{wp}\right)$$

or

Equation 2: $$R_h = E_h\left(W_{fc} - W_{eaw}\right)$$

where R_h represents the available water reserve in the horizon h
E_h the thickness of the horizon
W_{fc} is the water volume at the -5 kPa suction
W_{wp} is the water volume at -1500 kPa suction
W_{eaw} is the water volume at -200 kPa suction

The application of either of these two equations depends on the depth of the horizon, and on the depth at which the limitation of water extraction appears, in line with the characteristics of the plant. The calculation for the whole profile is obtained by summing the values for each horizon situated in the root zone.

3.3.2 Application to the Soil Geographical Data Base

As the water retention values necessary for the SWAP calculation are not directly available in the database, pedotransfer rules are applied to assess them. These rules are based on links between the water volume at a certain suction and the physico-chemical properties of soil (Hall et al., 1977), taking into account the available data and their precision. The basic rule estimates the quantity of water using texture class and packing density class (Thomasson, 1995). Other rules are used to estimate subsoil texture class, topsoil and subsoil packing density classes, and depth of soil (King et al., 1995). The main input variables are the soil name, the parent material, the phases, and the topsoil texture class of the STU. The calculation of SWAP is summarized by the Equation 3.

Equation 3: $$R = \sum_{i=1}^{n}\left(E_i.W_i\left[Tx_i, Pd_i\right]\right)$$

Where: R is the total SWAP over the profile
E_i is the thickness for the horizon i
W_i is the available water of the horizon i estimated by a pedotransfer rule using its texture (Tx_i) and its packing density (Pd_i) classes.
n is the total number of horizons.

The soil profile is schematized as shown on Figure 3. Only three horizons are retained:

- a worked surface layer, defined by the ploughing depth. The available water for this layer corresponds to a total available water (Equation 1) estimated by rules using the topsoil variables.
- a subsurface layer, between the ploughing depth and the EAW depth. The available water for this layer corresponds to a total available water (Equation 1) estimated by rules using the subsoil variables.
- a deeper layer, between the EAW depth and the maximum rooting depth. The available water for this layer refers to easily available water (Equation 2) estimated by rules using the subsoil variables.

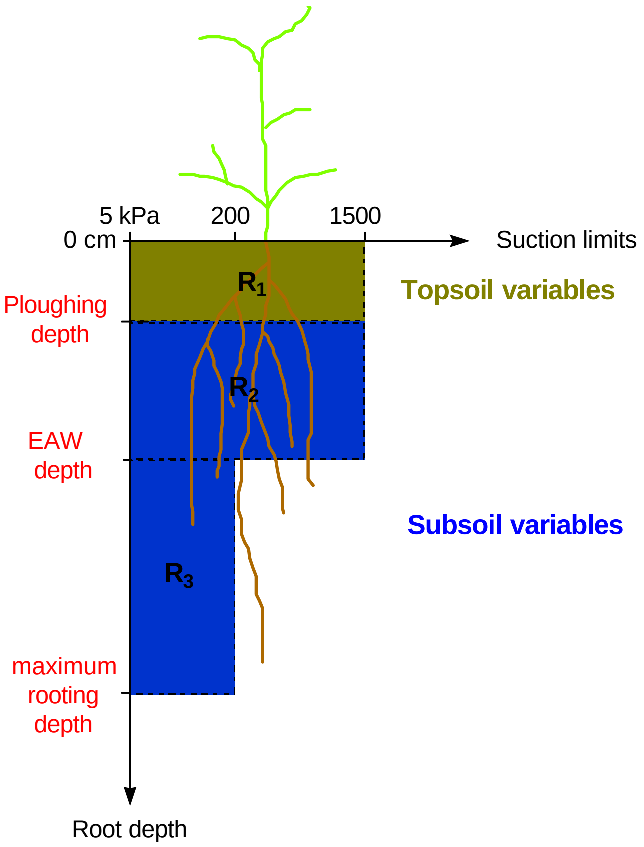

Figure 3: Schematic profile for calculating the SWAP

The total SWAP is obtained by summing the available water for each layer. The calculation of SWAP as described above is done without taking account of stones or gravels. If gravels or stones are present, a percentage of water is removed from the calculated SWAP. In the same manner, for taking account of capillary rises, an amount of water is added to the SWAP for particular substrata such as loess or chalk.

The different depths used for defining the three layers are given by users as input parameters to the program. This allows the user to adjust these parameters in accordance with the following crop requirements. The program takes also into account the estimated depth of the soil, which is compared to the user-defined depths, so that layers could be adapted if the estimated soil depth is less than the user-defined depth.

The tool for estimating SWAP works in two steps as described in Figure 4. The first step consists in assessing the variables not directly available from the Geographical Data Base, using the knowledge data base. Secondly, a calculation program uses the needed variables, direct or assessed, to estimate total SWAP as described above. This tool is directly usable within Arc/Info allowing a direct link with the Geographical Data Base. It has been developed for easy access by users.

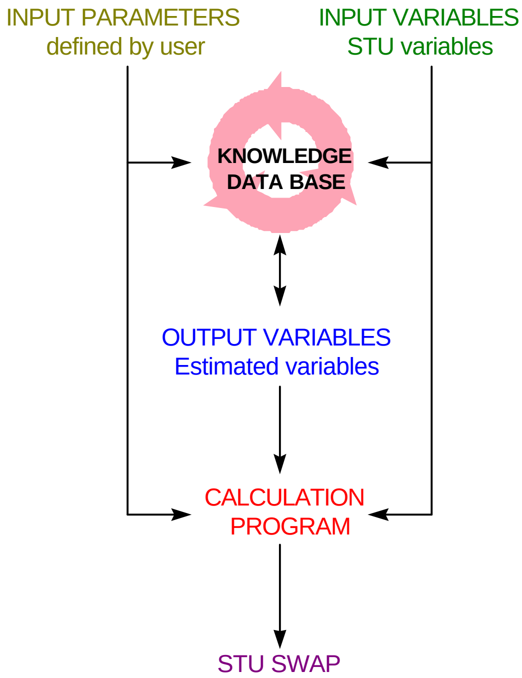

Figure 4. Diagram showing the different steps in calculating SWAP

4. Results and Discussion

The results of the calculation of SWAP applied to the Soil Geographical Data Base are numerous. The program calculates a total SWAP for each STU adjusted to the crop requirement. This SWAP can be used for modelling in a water balance model. It can also be used for making thematic maps as shown in Figure 5. But one must be aware that only the dominant class of SWAP for each SMU is represented on this map. It is thus important to associate this map with a purity map (**Error! Reference source not found.**) giving the percentage of area of the SMU really represented by the thematic value shown on Figure 5. This purity map permits to have an idea of the internal variability of the SMUs for the considered theme. The confidence level map (Figure 6) estimates the reliability of the estimation, taking account of both the confidence level that the experts give to the estimation and the accuracy of the basic data. This map is very useful to know where the basic data or the rules should be improved.

In addition to the SWAP calculation, the program provides also the intermediate output variables assessed by pedotransfer rules. These variables could be added to the STU descriptive file allowing their use for other purposes.

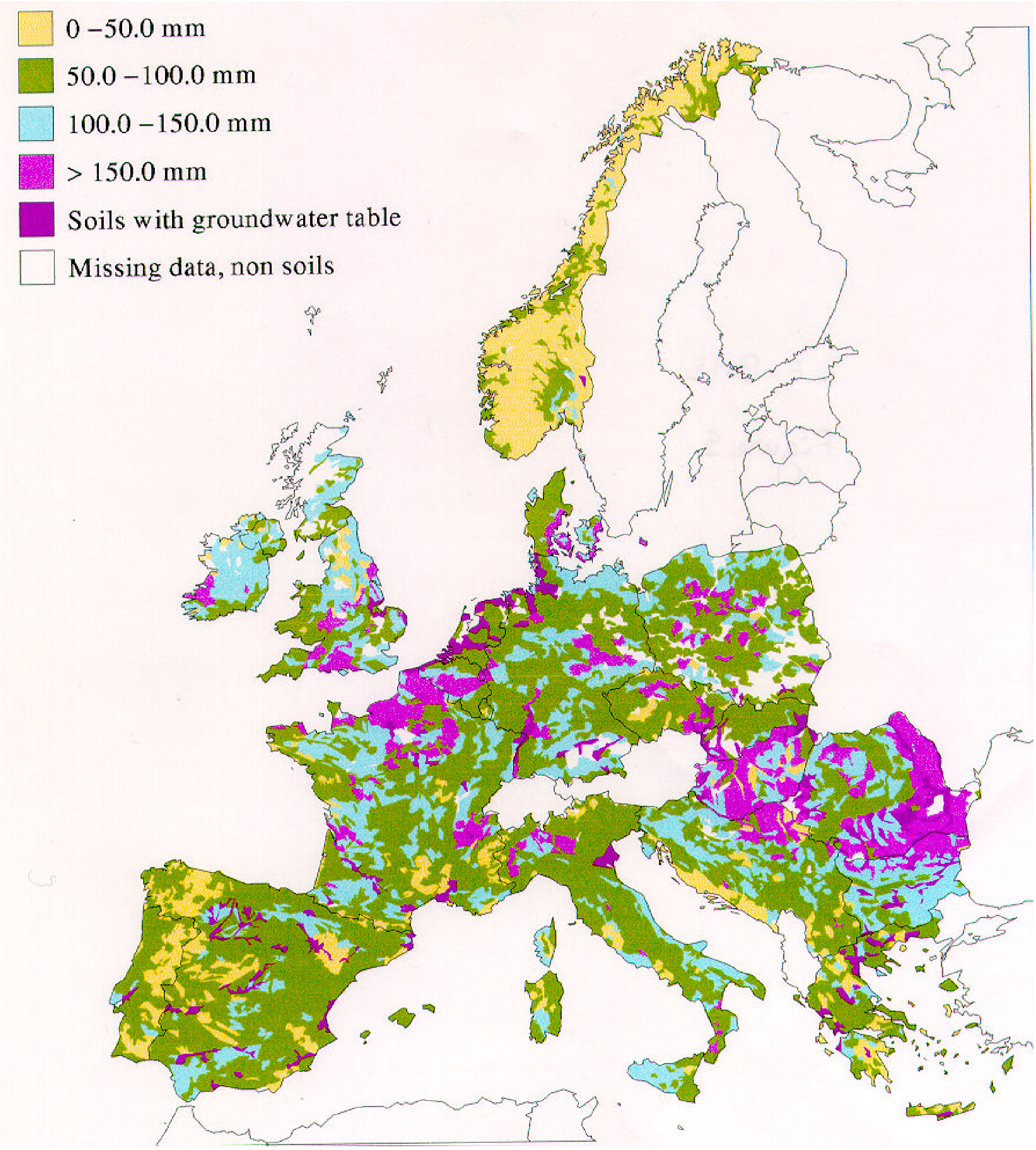

Figure 5. Example of a 'Soil Water Available for Plants' map.

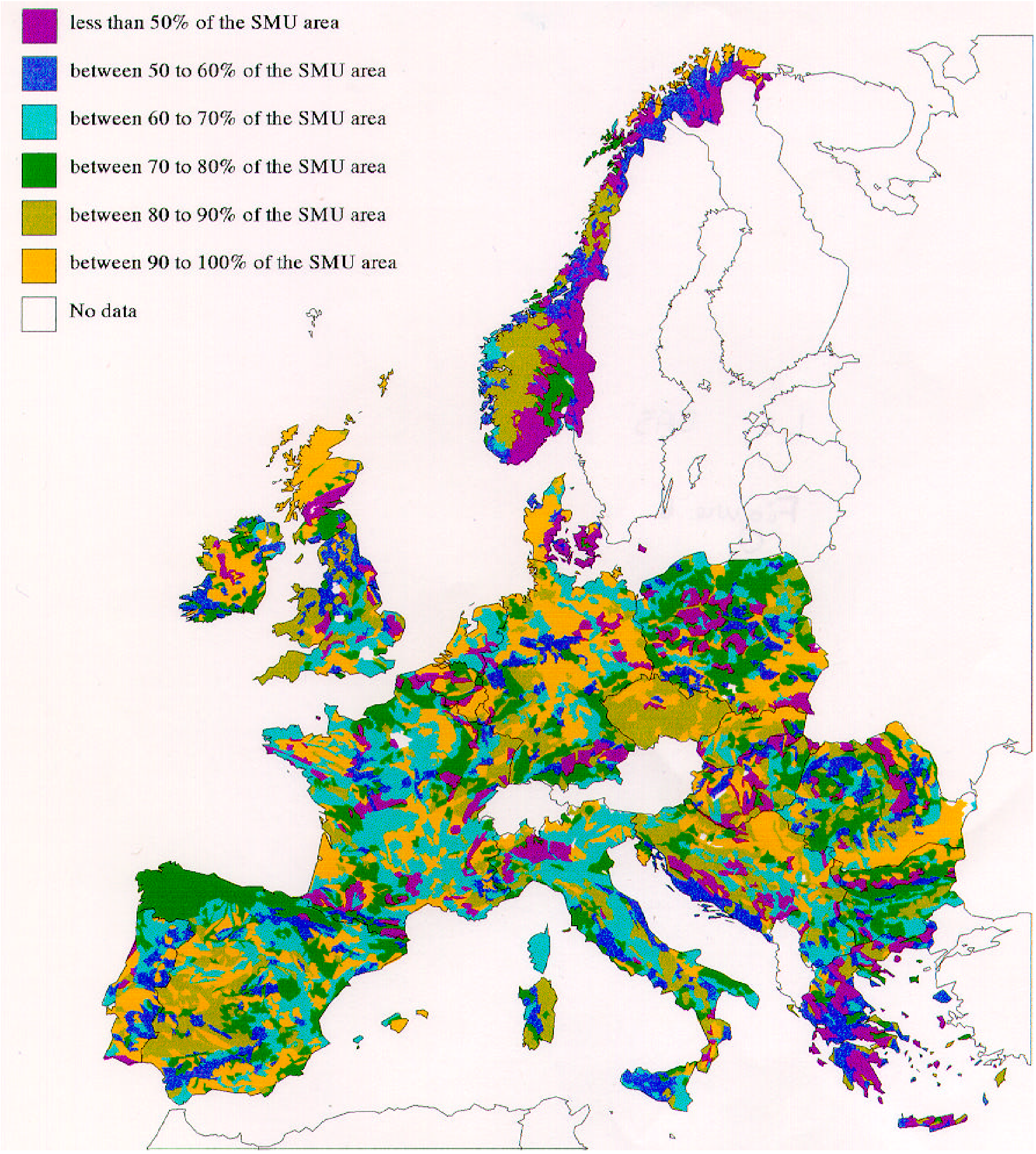

Figure 6. Purity map for the SWAP map shown on Figure 5.

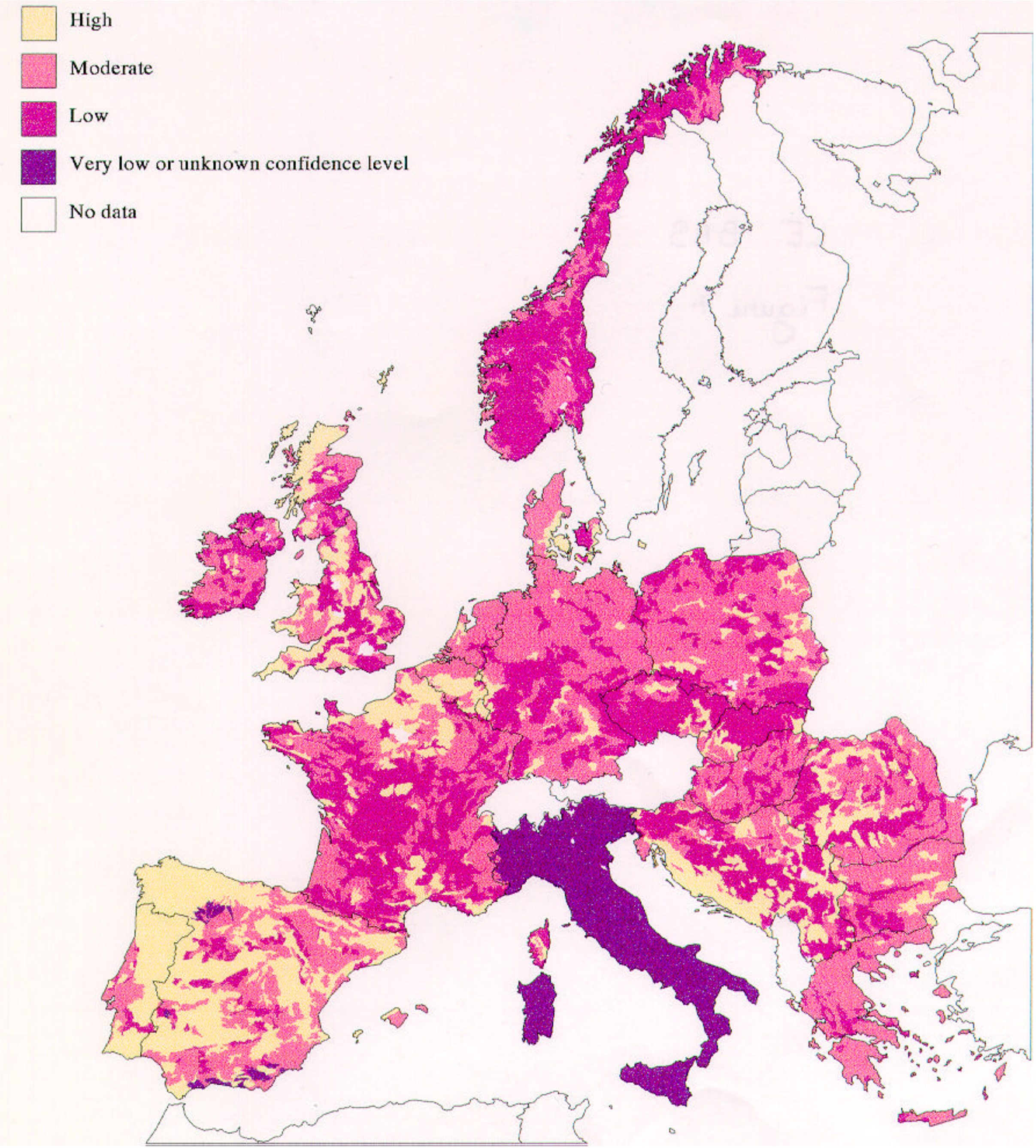

Figure 6: Confidence level map for the SWAP map shown on Figure 5.

5. Conclusion and perspectives

The aim of this work is to propose an automatic interpretation of the data available in the Soil Geographical Data Base of Europe at scale 1:1,000,000, leading to estimates for environmental or agricultural use that are as reliable as possible. This interpretation is made through pedotransfer rules that formalize the informal interpretation made by an expert confronted with the soil data. These rules are stored in a knowledge database in a standard format facilitating their handling and use.

The calculation of the 'Soil Water Available' for Plants is made using this knowledge database. The program runs within the software system used for the Geographical Data

Base giving to this tool a direct link with its input data source and an easy access by users. This link allows results to be attached directly to the Geographical Data Base allowing thematic mapping or modelling.

At this stage, we use only a small part of the data available in the database. We planned to use the profile database attached to the Geographical Data Base. Another profile database on hydraulic properties (Lilly, 1997) will soon be available for this purpose. The profile databases contain more precise data but we have no real information about the representativeness of the profiles. In spite of this difficulty, the comparison of the results coming from the two sources of data should highlight the main difference among STUs and the possible distortion due to the method of calculation.

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