INTRODUCTION

The World Reference Base [12] is a soil classification system that has been indicated as an international reference for soil classification; however, in the past few years, the WRB was not only chosen as a reference for the exchange of soil profiles information, but also for characterizing soil types in soil cartography. This is the case for several EU countries, which followed the suggestions of the European program aimed at soil mapping of the continent at a 1 : 250000 scale, to recognize and establish soil typologies (soil bodies) by means of the WRB [2].

However, the actual WRB application in small-scale soil maps has produced inconsistent results, for the attribution of soil type to soil cartographic units, because different methodologies were adopted. Sometimes, a simple identification (soil taxonomic unit = soil map unit) was chosen; in other cases, a more detailed description of the soil type, before assigning it to the related map unit, was preferred [1, 13–16].

If we analyze the solutions taken on in the cited national experiences, we can see that, although the correlation mechanism for single soil profiles is tested, it seems very difficult if not impossible to correlate soil maps, because of the lack of a common system of rules guiding the gathering and grouping of soil properties into a soil map unit.

In Italy, the program of soil mapping on the 1 : 250000 scale is based on a work procedure that defines soil typologies with both the WRB and ST–USDA systems and with adjunctive specific soil functional characters and qualities, which are more detailed than those comprised in the soil body concept [3, 4]. The mapping program is led by regional soil services, which tune the methodology according to local experiences and needs.

This work reports the solutions adopted in applying the WRB to benchmark soils and mapping units of the Tuscany region (central Italy) and the suggestions for a modification of the WRB system that could improve its performance in soil mapping.

MATERIALS AND METHODS

Reference Databases for the Tuscany Region

The Tuscany region occupies an area of about 22,990 sq. km in the central part of Italy. A series of soils samples on different scales were built, on behalf of the National Soil Mapping project belonging to the “Agriculture and Quality” Measure of the Italian Ministry for Agricultural and Forestry Policies [3]. The Soil Regions (1 : 1 M) level was provided by the national working group in the European area [18], whereas the
elaboration and production of Soil Systems (1:500 000) and Soil Subsystems (1:250 000) were original (Fig. 1). The semidetailed pilot-areas with land units and land elements partly came from pre-existing surveys (30 areas) and partly from new surveys carried out within the project itself (17 areas). All legends of cartographic units were reviewed and recoded when necessary. All pedons (new and old) were classified with the WRB [12] and ST–USDA systems [23].

Fig. 1. Example of a final sheet of the first approximation of soil map 1:250000 (sheet no. 121): the polygon labels refer to the main STU present, and in gray squares are the soil pedons analyzed. The jointed legend shows the type of soil information related to the new WRB proposal for a subset of the recognized STUs.
from other cartographies previously published in scientific studies (430) or from on-going surveys in the new pilot-areas (400).

A total of 689 Soil Typological Units (STUs) were made according to a standard national soil dataset [4] using both the WRB and the ST as soil classification. Of the regional STUs, 254 benchmark soils were considered for application of the WRB. They were classified both with the current WRB system and with the new proposed qualifiers. The STUs were joined to the 1 : 250000 delineations, so as to build map units and obtain the final soil map at the 1 : 250000 scale (Fig. 1).

The regional database is organized according to the architectural structure of a soil relation database (Fig. 2) [9, 10]. More particularly, the adopted structure is that of a geodatabase, that is, the structure obtained through a linkage between different geographic levels and soil typologies [18].

**Soil Typological Unit and Soil Cartographic Unit**

The STU is a “conceptual” entity used to group similar soils having a spatial variability for their characteristics and qualities. It is used in soil mapping to link soil features to soilscape, and it has the basic concept that the soil mantle is a collection of natural bodies [11].

It was defined in several different ways according to the cultural schools, with different requirements: in Italy, the most used are soil series [20, 22], defined by soil subgroups and family classes [21, 23], and soil bodies (EU manual), defined by the WRB classification, parent material type, depth to a limiting roots layer, dominant texture, and coarse fragments class in the first 30 cm.

**Application of the WRB to Soil Mapping: Lack of Reference Concepts and Guidelines**

**Similar Soils**

When we classify a soil profile, we must follow specific rules, so that it is possible to define in the same way “similar pedons,” that is, pedons showing a similar set of properties. Similarly, this is also necessary in gathering and allocating surveyed pedons to the same STU, provided that it already exists, or to establish ranges of variability for soil characters and properties, if the STU must be still created. In our opinion, some criteria must be developed aimed at helping soil scientists to decide how to put together soils that have the...
Table 1. Proposed ratio between the scale map and the number and type of qualifiers and representative data required

<table>
<thead>
<tr>
<th>Scale of soil map</th>
<th>Number of qualifiers allowed to define STU taxon</th>
<th>“Pragmatic level” qualifier</th>
<th>Minimum number of representative pedons required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognition level (smaller than 1 : 250000)</td>
<td>1 (e.g., Vertic Cambisol)</td>
<td>Yes</td>
<td>8–10</td>
</tr>
<tr>
<td>Semidetailed level (1 : 250000–1 : 25000)</td>
<td>2 (e.g., Chromi-Cutanic Luvisol)</td>
<td>Yes</td>
<td>4–7</td>
</tr>
<tr>
<td>Detailed level (larger than 1 : 25000)</td>
<td>3–4 also definitions in brackets—es. Chromi-Cutanic Luvisol (bathy calcic)</td>
<td>Yes</td>
<td>1–3</td>
</tr>
</tbody>
</table>

Table 2. Proposal for low pragmatic qualifiers to join the actual first and second WRB levels

<table>
<thead>
<tr>
<th>Soil characters</th>
<th>“Low level” qualifiers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil solution chemistry classes</td>
<td>Toxic, Alcalic, Aercric, Carbonatic, Chloridic, Sulphatic, Arzic</td>
</tr>
<tr>
<td>ECEC related classes</td>
<td>Acroxic, Gibbsic, Vetic</td>
</tr>
<tr>
<td>Base/acid saturation classes</td>
<td>Dystric, Eutric, Mesotrophic, Alumic</td>
</tr>
<tr>
<td>Surface structure</td>
<td>Mazic, Grumic</td>
</tr>
<tr>
<td>Coarse fragments/rock limiting rooting classes</td>
<td>Skeletic, Hyposkeletic, Hyperskeletic, Fractured (the same as the fragmental in ST), Ruptic (and the adjunctive suffixes Endo-Epi)</td>
</tr>
<tr>
<td>Texture classes</td>
<td>FAO classes</td>
</tr>
<tr>
<td>Soil moisture regimes</td>
<td>Aquic* Udic, Ustic, Xeric, Aridic, Torric (from ST definitions), Ombric, Rheic (for Histosols only)</td>
</tr>
<tr>
<td>Soil temperature regimes</td>
<td>Hypergelic, Pergelic, Subgelic, Frigid, Mesic, Thermic, Hyperthermic, Isofrigid, Isomesic, Isothermic, Isohyperthermic (from ST definitions)</td>
</tr>
<tr>
<td>Reaction classes</td>
<td>Hyperacid &lt; 4.5</td>
</tr>
<tr>
<td>Acid—4.5–6.0</td>
<td></td>
</tr>
<tr>
<td>Neutral—6.0–7.5</td>
<td></td>
</tr>
<tr>
<td>Alkaline—7.5–8.5</td>
<td></td>
</tr>
<tr>
<td>Hypercalcaline—&gt;8.5</td>
<td></td>
</tr>
<tr>
<td>Drainage classes</td>
<td>V—Very poorly drained</td>
</tr>
<tr>
<td>P—Poorly drained</td>
<td></td>
</tr>
<tr>
<td>I—Somewhat poorly (imperfect) drained</td>
<td></td>
</tr>
<tr>
<td>M—moderately well drained</td>
<td></td>
</tr>
<tr>
<td>W—well drained</td>
<td></td>
</tr>
<tr>
<td>S—somewhat excessively drained</td>
<td></td>
</tr>
<tr>
<td>E—excessively drained</td>
<td></td>
</tr>
<tr>
<td>Clay mineralogy classes</td>
<td>To be defined**</td>
</tr>
</tbody>
</table>

*The definition of the aquic regime could seem redundant in comparison with the gleicy and stagnic properties, but it might be necessary to establish the soil water saturation as an existing actual, not relict, condition. **Clay mineralogy classes are yet to be defined to establish the differences in STUs.
same taxonomic unit at a certain level although not all the same internal and external functional characters and qualities.

Using the WRB, in particular, many soils could be allocated in the same taxonomic unit, except for secondary diagnostic characters, which are less expressed and usually reported in brackets. A good example is represented by the Endo-Stagnic Cambisols of low hills in central–southern Tuscany, on fluvio-lacustrine tertiary marine sediments: 17 benchmark soils were classified in this way, but almost all with adjunctive definitions for other properties (Hyperochric, Siltic, Chromic, Endoskeletic, etc.). Should we consider them as different or similar soils? How many and to what degree should differences be admitted, and at which level? To solve these questions we introduced a “pragmatic” level, allowing the description of soil properties and related features to be activated whenever we need it to distinguish a STU.

### Diagnostic Properties and Functional Characters

In applying the WRB to the Tuscany soils, it happened that the suggested ranking of qualifiers did not embrace the variability of soil functional characters which were crucial for the management of specific agro-environmental situations and had been used in creating the STUs. Therefore, we noticed a discrepancy between many taxonomic units and the related STU. Theoretically, a “perfect for Tuscany” classification system should exactly fit our STUs. Thus, to appreciate and improve the classification ability to match soil taxa to STUs, we introduced a “performance rate,” that is, the percentage ratio between soil taxa and the STU. The higher the percentage value, the better the performance of the classification system.

By applying the performance rate, we noticed that one of the main causes of discrepancy arose from the fact that the WRB system put at the same level qualifiers related to either soil processes or characters not caused by pedogenesis (e.g., illuviation—“cutanic” suffix and rock fragments—“skeletic” suffix). In addition, we had some qualifiers related to soil features that were too variable in space and time and too easy to change by human activity to be considered at high taxonomic levels. This is the case of some chemical soil properties, like base saturation, that could be easily affected by agricultural practices. The same held true for the surface structure (e.g., grumic, mazic), depending of the strong influence of farm machinery in destroying and creating it.

On the other hand, some important information for land management and evaluation, like texture, drain-
age, pedoclimatic regimes, etc., were not considered. Therefore, we decided to take into account these properties and, together with the others with practical relevance already present in the WRB, to create a "practical level," so as to represent a better and complete way to describe all properties needed to encompass most criteria used in creating the STUs. The result was tested checking the increase in the "performance rate" of classification, as described before.

A New Proposal for the Introduction of a Lower “Practical” Level

A general discussion around the need for a more advanced system, constituted by strongly expressed rules in the application of qualifiers, has been already developed [17], leading to a new version of the WRB for teaching purposes [7]. Moving towards the division of qualifiers in different groups of importance, our proposal was the introduction of a new pragmatic level to be used for a more precise qualification of soil pedons belonging to the same STU. According to the proposed system, all the qualifier suffices that refer to nongenetic processes would be skipped to a lower practical level (i.e., those not directly related to defined diagnostic horizons, properties, or soil materials) (Table 2), as shown in a short example for some Cambisols (Table 3).

In soil mapping, it seems wise to define rules for the number of qualifiers to be used. According to the detail of the map, the smaller the scale, the greater the number of STUs that can be related to a soilscape unit. So we stated a different maximum number of qualifiers permitted for any soil map scale, with the aim to provide comparable levels of information in using the classification (Table 1).

**RESULTS AND DISCUSSION**

The results produced by elaboration of 255 selected pedons, all benchmark of STUs, showed a different distribution of them according to the taxonomic level (Fig. 3). As regards Reference Groups, pedons are distributed for the most part within Cambisols, Luvisols, Regosols, and Fluvisols, which represent 85% of the whole dataset. As minority soils, we had Calcisols and Vertisols, and, to a minor extend, Leptosols, Arenosols, Gleysols, Andosols, and Chernozems. If we consider the number of pedons at the second level (showed in the second column of Fig. 3), we can observe a smoothing of the pedons distribution among taxa, which corresponds to an increase in the classification performance.

In Fig. 4, the ratio between the number of taxonomic units and the STU number for each hierarchical level, i.e., the “performance rate” of the classification system, is reported. The current WRB classification, the new WRB proposal, and Soil Taxonomy were compared on the same dataset.

The performance of the current WRB system is rather low (53%). The application of the new WRB proposal with the use of the first qualifier only, although it impairs the performance (the percentage decreases to 31.4%), makes it almost equivalent to the ST–USDA subgroup level.
However, if we take into account the new pragmatic level, we improve the performance of the WRB classification considerably, getting a better rate than the ST–USDA family corresponding level (78.4 vs. 72.9%).

CONCLUSIONS

The new proposed structure improved the performance of the WRB classification in our regional cartographic application because it made soil classification closer to the STU definition; that is, the taxa characteristics and variability were similar to those of the STU and allowed a clear distinction between soil features dependent on pedogenetic processes from the others, which were moved into a lower classification level.

Consequently, having more soil information about functional characters for applicative purposes in the soil name, the merely descriptive soil maps fit in a better way the needs of users, like regional and local planners and stakeholders.

Furthermore, the introduction of new characters and classes can allow land evaluation methods and models, simply using the information implied in the description of STUs in the map legend.

REFERENCES