Toward delineating hydro-functional soil mapping units using the pedostructure concept: A case study

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1. Introduction

Current soil maps are the result of extensive, comprehensive soil survey activities conducted by pedologists over many years. Soil maps consist of a collection of soil mapping units that are used to delineate areas with similar soil properties. The mapping units are generated following well-established rules and approaches. However, these mapping units leave soil functional properties unattended (Bouma et al., 1999), which limits their use in agronomic models or decision support systems. Many researchers have put great effort into enhancing and increasing standardization of soil mapping units (Moore et al., 1993; Odeh et al., 1994; Voltz et al., 1997; Lagacherie and Voltz, 2000). For example, Moore et al. (1993) enhanced soil maps and databases using terrain attributes (computed from high-resolution DEMs) to spatially distribute estimated soil attribute data and were able to correlate a slope and wetness index with soil attributes measured at 231 locations.

1.1. Hydropedology

Synthesis and quantification of disciplinary knowledge at the whole system level, using process models of the agricultural system, are critical to achieving improved and dynamic management and production systems that address environmental concerns and global issues of the 21st century (Ahuja et al., 2006). This fact is...
also evident in investigating soils and soil–water interactions. Relevant work linking pedology, soil physics, and hydrology was reviewed by Lin (2003) and given the name Hydropedology. He pointed out that “when addressing the diverse soil and water issues at various spatial and temporal scales, it becomes clear that bridging traditional pedology with hydrology and other related disciplines is necessary as well as synergic.” Hydropedology works as a bridge to integrate the pedon and landscape paradigms with phenomena occurring at microscopic (e.g., pores and aggregates), mesoscopic (e.g., pedons and catenas), and macroscopic (e.g., watersheds, regional, and global) scales.

Landscape water flux was proposed by Lin et al. (2006) as a unifying concept for hydropedology through which pedologic and hydrologic expertise can be better integrated. Source, storage, flux, pathway, residence time, availability and spatio-temporal distribution of water in the root and deep vadose zones within the landscape were included in the term “landscape water flux.” Several knowledge gaps that hydropedology can address were discussed by the authors, and strategies were proposed to accomplish the integration of pedology and hydrology.

1.2. Hydro-structural pedology

Recent progress and development in the understanding of the soil–water medium and its hydrostructural characterization, behavior, configuration, and interactions, together with the advancement in high-speed computing technologies and modeling, allow for a new approach to mapping soils that takes into account their internal organization and functionality with respect to water flow. During a project to establish a Spatial Information System for irrigated soils in Tunisia, Braudeau et al. (2002) applied a systems approach (SA) to mechanistically characterize and model the soil by referring to an old pedological map made in 1963, and introducing the new concept of pedostructure and hydrostructural characterization. In this concept, hierarchies within the soil organization have been considered and new descriptive variables of the soil structure properties were defined and introduced into the equations describing the physical soil characteristics. They showed that by working within a SA framework, the functional levels of the internal and external organization of the studied system, i.e., the soil and its environment, can be investigated, defined and characterized. In this framework, characteristic variables, functions, and parameters for each scale, as well as the transfer function across scales, are acknowledged. The pedostructure concept is based on this new ‘systems view’, and offers a physical description and characterization of the soil’s internal organization (Braudeau et al., 2004). The pedostructure is a representative volume of the soil-medium structure in the soil horizons. Braudeau et al. (2005) showed that the pedostructure characteristics can be used to identify soil type according to their hydro-functional properties which are compatible with the pedo-genetic classification.

The pedostructure concept permits the physical definition of the variables and parameters describing the soil structure (arrangement of soil particles) and the soil organization (water and air repartition relative to the solid surfaces of the structure), than the formulation of the physical equations describing the hydro-structural soil properties, such as the shrinkage curve (Braudeau et al., 2004) and the water potential curve (Braudeau and Mohtar, 2009).

1.3. Hydro-structural pedology vs. hydropedology

There is an essential knowledge gap that hydropedology cannot address: the link between pedology (the science of soil organization) and soil water physics within the internal structure of the organized soil medium (thermodynamic interactions between the internal soil structure, the soil water, and the soil air). Braudeau and Mohtar (2009) showed that a change of paradigm in soil science must occur to be able to take into account the internal hydro-structural characteristics of the soil medium in equations describing soil water properties. These equations are currently based on the macroscopic behavior parameters of a black box (the REV, Representative Elementary Volume), which has no possibility of taking into account the internal hydrostructural characteristics of this black box, namely the pedostructure parameters. Using the SREV concept (Structural REV) defined by Braudeau and Mohtar (2009) instead of the REV allows modeling the hydrostructural functioning of the pedon at all its functional scales and has led to the development of the multi-scale soil–water model Kamel (Braudeau, 2006; Singh et al., 2012).

This research paper builds on this new soil water paradigm and tries to update the soil mapping units through characterizing these units using the hydrostructural properties of the pedostructures of the soil column (mainly Ap and Bt horizons). Using the pedostructure hierarchy concept, the physical quantitative attributes (characteristic parameters of the hydrostructural soil–water behavior) will be added to the existing soil map. This addition to the soil mapping units will assist in the decision support system data analysis, which, in turn, will allow for the prediction of water and chemical transport and interactions by using the soil–water model Kamel which works specifically with these new attributes.

2. Materials and methods

Three data layers (study area map, landform map, and SSURGO map) were used in order to characterize the hydro-functional soil mapping units (i.e., the primary “homogeneous” soil map units nested into geomorphologic map units), following the hierarchical approach used in Braudeau et al. (2002). Fig. 1 summarizes this procedure. The first step was to define the area of study within the watershed under investigation. The second step was to generate the landform map obtained from a two foot contour map. The Terrain Analysis System (TAS) developed by Linday (2003) was used for this task. The landform map shows topographic units that delineate the different landforms: foot slope, shoulder, back slope, or level. The third step was obtaining the SSURGO soil map and overlaying it over the generated landform map to generate new soil mapping units. The fourth and final step was to check for the homogeneity of the generated soil mapping units by collecting representative soil samples then obtaining their pedostructure parameters. Discriminate analysis was used to validate the results.

The details of generating the hydro-functional soil mapping units are described in the section below.

2.1. Defining the areas of study – the first data layer

The study area shown in Fig. 2 was selected within the Jordan Creek watershed (ID number 05120108030010) which is a small sub-watershed of the Wabash River watershed. This sub-watershed lies near West Lafayette, Indiana, close to Purdue University. This site was selected because it includes significant topographic relief, which addresses the need to have an area with a wide range of landforms.

2.2. Generating the landform Map – the second data layer

The second step was to generate the second data layer, which is the landform map. A sixty centimeter contour map was obtained from the Tippecanoe County GIS office (2006) and used to derive a five-foot landform map. The contour map was used to generate a three meters Digital Elevation Model (DEM) in ArcGIS®, which was used as an input for TAS® to generate the landform map.
2.3. Delineating the soil mapping units

The third step was to delineate soil mapping units within the study area by overlaying the SSURGO soil map on the landform map obtained from the previous step (Fig. 1). These units will be considered while selecting the sampling sites and later will be integrated with the pedostructure parameters to generate the hydrofunctional soil mapping units.

Since in our hierarchical approach challenge is to delineate nested functional levels of organization and do not accept overlapping between the different data layers, the output map was manually examined for overlapping areas. If an overlapping area exists, further investigations including field visits should be made to decide either to consider the overlapping as a new unit or to ignore it and combine it with the adjacent functional mapping unit.

2.4. Characterizing the soil mapping units

The fourth and final step was to check for the homogeneity of the generated soil mapping units by collecting representative soil samples with the help of the existing SSURGO soil map and the generated landform map then obtaining the pedostructure parameters for them following the characterization procedures described by Braudeau et al. (2004,2005), and Salahat (2006).

The SSURGO soil map used in this study is the one available online at the NRCS website (2006). Due to time and cost constraints, the research was restricted to three soil units out of the six conventional soil mapping units delineated in the study area. The three units used in this research are: SwA, Starks–Fincastle complex with 0–2% slopes; MsC2, Miami silt loam, 6–12% slopes; and HoA, Hononegah fine sandy loam, 0–2% slopes. The study area is in the Tipton Till Plain physiographic region. The northern part of the study area is on a till plain overlain by loess, while the southern part is on a small terrace of Jordan Creek. Two map units, the SwA and MsC2 (defined below), are on the till plain, while the HoA map unit are on the terrace.
The SwA map unit consists of a Starks–Fincastle complex on 0–2% slopes. The Fincastle series is classified as a fine-silty, mixed, superactive, mesic Aeric Epiaqualf. Fincastle soils are somewhat poorly drained and formed in 55.9–101.6 cm (22–40 in.) of loess overlying loamy glacial till. They are deep to dense till and the depth to carbonates varies from 35 to 60 in. The Starks series is classified as a fine-silty, mixed, superactive, mesic Aeric Endoaqualf and is very similar to the Fincastle series except for the presence of water-worked, stratified material at the base of the profile. These two soil series often occur so closely associated that it is impractical to separate them during mapping. Hence, they are mapped as a complex of two similar soils.

The MsC2 map unit consists primarily of Miami silt loam on 6–12% slopes. The Miami series, classified as fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs, consists of moderately well-drained soils formed in up to 18 in. of loess overlying dense, loamy glacial till. Depth to carbonates varies from 20 to 40 in. The Miami series occurs on the more sloping areas of the site, and the Ap horizon is frequently eroded.

The HoA map unit consists primarily of Hononegah fine sandy loam on 0–2% slopes. The Hononegah series, classified as sandy, mixed, mesic Entic Hapludolls, consists of very deep, excessively drained soils formed in sandy alluvial material underlain by water-sorted sand and gravel at a depth of 20–40 in. Depth to carbonates is typically 30–40 in.
2.5. Soil sampling

Finding the sample locations within each delineated soil mapping unit was aided by using a shapefile generated using ArcMap® 9.1 software, ArcPad software, iPac, and a Global Position System (GPS) unit. Fig. 2 represents sample locations at the field. Once the required sample location was determined, undisturbed soil samples that extended the entire length of the soil profile were obtained using a hydraulic soil probe mounted on a truck. The horizons in which the soil samples were obtained using the probe were identified following the nomenclature of the existing soil survey. Two undistributed replicates were obtained for each sampling location corresponding to its horizons. One sample was taken from the surface horizon Ap and another sample was taken from the mid-point of the B horizon of each soil mapping unit under investigation. Each sample was kept in a 5-cm diameter x 10-cm high plastic sleeve and stored in the laboratory until the time of analysis. Seven Ap horizons and 7 B horizon samples were obtained from each soil type (Hononegah, Starks, and Miami) for a total of 42 soil samples.

2.6. Laboratory measurements

Measurements of both soil characteristic curves were conducted separately for 21 Ap and 21 B horizon samples distributed as follows: seven samples from Hononegah (HoA), seven samples from Miami (MsC2), and seven samples from Starks (SwA). One lot of the 42 replicates was sent to the laboratory of IRD in Martinique equipped with the retractometer (Braudeau et al., 1999) for the shrinkage curve measurements, the other was used to measure the soil–water potential curve using the tensiometer (0–80 kPa). A mini tensiometer with a 2 mm diameter porous cup was used for this purpose, and connected to a transducer that converts the water tension into an electrical signal sent to a data logger monitored by LabView. The water tension and the weight of the sample were recorded every 10 min. At the end of the measurement, the microprobe water tension was stored in the laboratory of IRD in Martinique and connected to a transducer that converts the water tension into an electrical signal sent to a data logger monitored by LabView. The water tension and the weight of the sample were recorded every 10 min. At the end of the measurement, the soil sample was moved quantitatively to obtain soil dry weight.

For both soil analyses, stored soil samples were cut into two 4.5 × 5 cm pieces for replication in case of non-valueable measurement. At the time of analysis, each sample was saturated with water by placing it on a near saturated sand bath (2 cm of water head). The samples were self-supporting and were not confined or constrained in any way. After saturation for 48 h, the sample was placed on the corresponding device to continuously measure the soil water potential and shrinkage curves upon air drying.

2.7. Pedomorphosis parameters extraction from the soil potential curve and the shrinkage curve together

A sample of measured pedomorphosis moisture characteristic curves (water potential and soil shrinkage curves) is shown in Eq. 2. The link between both curves is extended using the physical equation describing the soil water potential curve given by Braudeau and Mohtar (2004), Eq. (1). This equation relates the soil water pressure, $h_{\text{ma}}$, read on the tensiometer and the macropore water content, $W_{\text{ma}}$, such as:

$$ h_{\text{ma}} = \rho_w E_{\text{ma}} \left( \frac{1}{W_{\text{ma}}} + \frac{1}{W_{\text{ma Sat}}} + \sigma \right) $$

where $W_{\text{ma}}$ and $h_{\text{ma}}$ are the water content and the water potential in the macropores of the pedomorphosis (represented by the soil sample); $\rho_w$ is the water bulk density; $E_{\text{ma}}$ is the potential energy of the solid phase resulting from the external surface charge of the primary peds, in joules/kg solid; $\sigma$ is a part of the micro-pore water at

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discriminant analysis results table shows how many samples from a certain group are statistically grouped under the different groups, which evaluates the precision of the proposed methodology to discriminate samples and classifying them under the correct groups.

3. Results and discussion

3.1. The pedostructure parameters obtained

For the sandy loam soils in this study area, the shrinkage curve measured was found to be flat or weakly swelling (Fig. 4) for most of the samples. The shrinkage curve did not distinguish between the different water pools and inflection points as shown by the typical curve discussed by Braudeau et al. (2004). It is why the shrinkage curves could not provide more than $V_0$, $W_s$ and $K_b$ as characteristic parameters that can be used for the discriminant analysis. However, the obtained PS parameters from shrinkage and potential curves ($K_b$, $V_0$, $W_{sat}$, $W_s$, $K_b$, $r$, and $E_{ma}$) were used in the final discriminant analysis.

Table 1 shows values of the soil PS parameters, and silt, clay and OM content for each soil type for the Ap and B horizons. Surface horizons show higher pedostructural parameter values than sub-surface horizons, mainly due to higher organic matter content in surface horizons that overcomes the higher clay content in the sub-surface horizons. In general, Hononegah (HoA) soils show higher values of $\sigma$ and $E_{ma}$ than Miami (Ms C2) and Starks (SwA) soils due to slightly higher organic matter content. Clay content is higher in Miami and Starks than in Hononegah, which gives them higher values of $W_c$, $W_t$, $W_{sat}$, $K_b$, and $V_0$. $K_b$ is the only characterizing parameter that is not affected by organic matter content since it reflects the rigidity of the soil structure.

In general, the values of the micropore water at the surface of the primary peds ($r$) and potential energy of the external surface of the primary peds ($E_{ma}$) have the same trend because both parameters are related to the total surface of their primary peds and thus, to the soil structure division. They have higher values for Ap horizons than B horizons (Table 1). Organic matter has the highest influence on both parameters, since the higher the organic matter the higher are $r$ and $E_{ma}$. The $r$ is believed to be a structural parameter. The Hononegah’s Ap horizon has higher $r$ and $E_{ma}$ values than the Miami or Starks Ap horizons, probably due to a higher organic matter content. Miami and Starks have similar $\sigma$ values and similar organic matter content.

Fig. 3. Example of shrinkage curve and soil water potential curve, measured (dots) and simulated (lines) on two replicates of a soil sample.
The water content at saturation \((W_{sat})\) is directly related to the total porosity. In general, the values of Ap horizons are higher than B horizons for all soil types due to higher organic matter content in Ap horizons leading to a better structure.

The water content at point \(C(\, WC)\) on the shrinkage curve corresponding to the water content at 100 kPa showed higher values for Ap horizons than B horizons. At 100 kPa tension, the macropores out of the primary peds will be empty of water, while the primary peds remain filled with water (Braudeau et al., 2005). The higher values of \(WC\) for Ap horizons compared to B horizons can be attributed to higher silt contents in Ap horizons than B horizons in this soil landscape. Moreover, the value of \(WC\) increases with the increase of the clay content and \(E_{suc}\). \(W_D\) is the water content at field capacity. Field capacity status could be reached after gravitationally draining a saturated soil for 48 h. This point is very important because it reflects the best soil status to conduct agricultural practices. The trend for \(W_D\) is similar to what was discussed for \(WC\). Surface soils have higher \(W_D\) values than B horizons due to high organic matter and silt contents. The HoA soil has the lowest values for the Ap and B horizons.

\(K_b\), the slope of the linear basic phase of the shrinkage curve, is a structural feature of the assembly of aggregates that represents the volume change ratio between the aggregated soil sample and the primary peds. At the same time, the parameter is positively correlated to organic matter. In general, the Ap horizons have lower \(K_b\) values than the B horizons. This is because Ap horizons have better structure due to the OM. This is very clear when studying the shrinkage curves because a large number of Ap horizons have
Table 1
Soil pedostructural parameters, silt, clay and OM content for Ap and Bt horizons.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Sample no.</th>
<th>Soil horizon</th>
<th>Depth (cm)</th>
<th>σ (Kg_{water}/Kg_{solids})</th>
<th>ε_m (J/kg_{soil})</th>
<th>W_r (Kg_{water}/Kg_{solids})</th>
<th>W_D (Kg_{water}/Kg_{solids})</th>
<th>W_2w (Kg_{water}/Kg_{solids})</th>
<th>K_v, (dm^3_{soil}/Kg_{water})</th>
<th>V_v (dm^3_{soil}/Kg_{solids})</th>
<th>OM (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
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<td>HoA I</td>
<td>471</td>
<td>Ap</td>
<td>5-15</td>
<td>0.009</td>
<td>0.9</td>
<td>0.246</td>
<td>0.346</td>
<td>0.420</td>
<td>0.25</td>
<td>0.69</td>
<td>3.8</td>
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<td>0.088</td>
<td>0.156</td>
<td>0.177</td>
<td>0.10</td>
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<td>1.8</td>
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<td>Sw A7</td>
<td>431</td>
<td>Ap</td>
<td>3-13</td>
<td>0.012</td>
<td>1.3</td>
<td>0.319</td>
<td>0.384</td>
<td>0.389</td>
<td>0.28</td>
<td>0.71</td>
<td>3.7</td>
<td>68</td>
<td>16</td>
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<tr>
<td>Sw A8</td>
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<td>Bt</td>
<td>103-113</td>
<td>0.006</td>
<td>0.7</td>
<td>0.164</td>
<td>0.178</td>
<td>0.211</td>
<td>0.49</td>
<td>0.58</td>
<td>0.5</td>
<td>49</td>
<td>34</td>
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</table>
minor shrinking, and the curve is almost linear. The standard deviation for Ap horizons is higher than for B horizons, which leads to the conclusion that we have more extreme values in the Ap horizons.

For the last parameter $V_0$, the Ap horizons showed higher values of the specific volume of the dry soil than the B horizons due to an absence of structure in the later. For these silty soils, $K_{sw}$ is a good indicator of the soil structure. The lower the $K_{sw}$, the lower the swelling capacity which means higher value for macropores volume, hence, higher value of $V_0$. For weakly structured soil, $K_{sw}$ value will be high, $V_0$ will be low which leads to low value of macroporosity.

### 3.2. Discriminant analysis

Discriminant analysis using SAS® 9.1 was performed on the parameters used in characterizing the soil mapping unit to investigate the uniqueness of these units. We refer to the soil mapping units with their pedostructure parameters as hydro-functional soil mapping unit. The uniqueness of the characterization by the soil shrinkage curve, the soil water potential curve, and the two curves combined, were investigated.

#### 3.2.1. Discriminant analysis by soil horizon

Table 2 shows the results of the discriminant analysis conducted using shrinkage curve parameters alone for Ap and B horizon samples, respectively. The main parameters of the shrinkage curve ($K_{sw}$, $V_0$, and $W_{sat}$) successfully discriminate the soil mapping units. For Ap horizons, six of the seven HoA samples are grouped under HoA, while one sample is grouped under SwA. Four of the SwA samples are grouped under SwA, two under MsC2, and the seventh sample is grouped under HoA. For MsC2, the results are not as good, only one MsC2 sample is grouped under MsC2, and three samples are grouped under each of HoA and SwA. This is probably due to relatively steep slopes and consequently greater erosion in the MsC2 map unit, resulting in more variability in the thickness of loess on these soils relative to the SwA map unit, and the possibility that in some areas the original surface horizon has been eroded away and the current surface is actually the top of the Bt horizon. Subsurface horizons generally discriminate better between the different soil types than surface horizons. Six HoA samples are in the HoA group, all MsC2 samples are put under SwA, and four SwA samples are put under HoA. In general it is noted that the discriminant analysis results are lower between MsC2 and SwA because these two soil type share the same parent material and same landuse.

The results for using the potential curve alone in the discriminant analysis are shown in Table 3. For the Ap horizons, five of HoA, three MsC2, and five SwA are grouped under the correct soil type. The results are better for the B horizons: six HoA and MsC2 and four SwA are grouped in the correct group. The potential curve corresponds mainly to the macropores, which is related to the structure more than texture. Subsurface soils have more developed structure than the Ap horizons due to less manmade interferences. This fact explains why better results were obtained for B horizons.

The results using the soil shrinkage and soil water potential characterizing curves together are shown in Table 4. Using the two curves enhances the results, and the soil’s mapping unit uniqueness is more distinguishable. Six HoA, five MsC2 and SwA are grouped under the correct soil type, for the Ap horizon. Subsurface horizons showed better results with all HoA, six MsC2, and five SwA in the correct group. It was expected that there would be better results upon using the two curves together because the uniqueness found in both the micro and macropores are utilized.

#### 3.2.2. Discriminant analysis combining surface and subsurface horizons

The results of discriminant analysis for shrinkage curve, potential curve, and potential and shrinkage curves combining surface and subsurface horizons are shown in Table 5. Discriminant results for shrinkage curve combining surface and subsurface horizons are good but of lesser quality than results obtained after separating Ap and B horizons (Table 5). Combining the two horizons for the analysis might cause overlapping in the values for each parameter since each horizon has its own range. HoA is clearly discriminated from the other two soils, while MsC2 is the least discriminated soil. Nine out of the fourteen HoA samples are grouped under HoA, seven MsC2 are correctly grouped, and six of SwA are grouped correctly.

When using the potential curve, ten of HoA, seven of MsC2, and eight of SwA are grouped under their own soil type. The results are almost similar to those obtained by using the potential curve alone and separating Ap and B horizons. When using both the potential and shrinkage curves combining surface and subsurface horizons, eleven HoA, ten MsC2, and nine SwA are grouped correctly (Table 5). These results are better than using the shrinkage or potential curves alone but not as good as compared to separating Ap from B horizons. Miami and Starks soils have mixed results because they share the same parent material, and development environment. The main difference between them is the drainage class. Miami soils are better drained than Starks. The Hononegah soils have higher percent sand and are developed over sandy sediments. Overall, results of discriminant analysis and P5 characterization reflect the functionality of the pore space, which corresponds to the development of soil structure.

#### Table 2

<table>
<thead>
<tr>
<th>GROUP/horizon</th>
<th>Sw A – horizon</th>
<th>Ms C2 – horizon</th>
<th>HoA – horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sw A</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Ms C2</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>HoA</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Bt – horizon</td>
<td>0</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Table 3

<table>
<thead>
<tr>
<th>GROUP/horizon</th>
<th>Sw A – horizon</th>
<th>Ms C2 – horizon</th>
<th>HoA – horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sw A</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ms C2</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>HoA</td>
<td>4</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Table 4

<table>
<thead>
<tr>
<th>GROUP/horizon</th>
<th>Sw A – horizon</th>
<th>Ms C2 – horizon</th>
<th>HoA – horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sw A</td>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Ms C2</td>
<td>2</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>HoA</td>
<td>1</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

3.3. The hydro-functional soil mapping units vs. the SSURGO soil mapping units

The resulting hydro-functional soil mapping units are similar to the existing soil mapping units obtained from SSURGO at least for the three soil units tested (Figs. 1 and 2). The key difference between the hydro-functional soil mapping units and the SSURGO soil mapping units is that the hydro-functional units were defined by physically based quantitative attributes that describe the soil structure and soil–water interactions which generate all the physical properties of the soil medium. The fact that the three soil types used in this work had approximately the same boundaries after performing the four-step system hierarchy approach described showed that; (1) SSURGO soil data set consists of a detailed second order soil survey in which micromosaic is already taken into consideration; and (2) the hydro-structural soil properties matched well with the holistic approach used by pedologists when they defined the soil mapping units delineation and their qualitative characterization. It is expected that the hydro-functional mapping unit will be different than the existing mapping unit if a less detailed soil map was used. Upon using the SSURGO map with a scale of level four (for example), some of the micro-relief is not captured and thus the mapping unit does not show all the details within it.

Overall, the hydro-functional soil mapping units agreed to a high extent with the SSURGO soil mapping units. Still, further works should be made in this way by testing more soil units for estimating the uniqueness of the correspondence between the hydro-functional characterization and the existing soil mapping unit delineation.

4. Conclusions

This research shows the potential for coupling the pedostructure concept into existing SSURGO soil maps to overcome their lack of comprehensive quantitative attributes which put limitations upon their use directly in agronomic models, hydrologic models, and precision agriculture or decision support systems.

The work demonstrated four steps of a hierarchical systems approach to generating hydro-functional soil mapping units that comprise physically based and quantitative parameters extracted from continuously measured water potential and soil shrinkage curves. Due to time and cost constraints, the research was restricted to three soil units, but should be extended to all mapping units of the zone in study.

In spite of this limitation, it was found that the hydro-functional mapping units match the existing soil mapping units of the large scale SSURGO map of which the soil data set consists of a detailed second order soil survey in which micromosaic is already taken into consideration.

The discriminant analysis results reveal the potential of using the PS parameters including parameters of the shrinkage curve and the water potential curve together to differentiate and characterize the different hydro-functional soil mapping units. Addition of these hydro-structural parameters to the attributes of the soil mapping units makes them hydro-functional and potentially dynamic with the water cycle modeled by a soil water model like Kamel.

The results of this research are promising and can be considered as the first cornerstone in developing a new approach of physically-based characterization of the existing soil mapping units which takes into consideration the hydrostructural properties of the soil medium according to the pedostructure concept and the hierarchical system approach. The delineated soil units based on this approach can be termed as hydro-functional soil mapping units.

Acknowledgments

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