Soil Disturbance Evaluation: Application of ANFIS

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Abstract

In this work, an Adaptive Neuro-Fuzzy Inference System (ANFIS) applied for study the contiguous relations between soil disturbed indicators. Several ANFIS surfaces, which described the contiguous relations between individual soil disturbed indicators (DFSs), values of soil parameters and depth, as well as the contiguous relations between DFSs and combined indicator of soil disturbance (DFC), were obtained.

Keywords: ANFIS, soil disturbance indicators

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1. Introduction

Soil disturbance can be very detrimental to normal soil processes and can promote soil degradation. The impact of the disturbance can cause problems for plant growth for both seedling establishment and productive growth. Understanding the level of soil disturbance is important and can be essential for understanding the potential impact on soil health and for determining proper land management options for both ecological and farm management environments. However, methods for assessing soil disturbance are not well developed and require further development to be of practical use.

The relationships between soil disturbance indicators, soil parameter values, and soil depth requires the application of a non-linear system with poorly quantified associations, leading to many uncertainties about the relationships. Utilizing the application of an “Adaptive Neuro-Fuzzy Inference System” (ANFIS) technique provides a practical method to examine these relationships. ANFIS employs fuzzy if-then rules to model the qualitative aspects of human knowledge and reasoning processes without employing precise quantitative analyses (Jang, 1993).

Recently, ANFIS has been applied in many agricultural and environmental settings, and represents a useful framework to deal with various issues. For example: 1) estimating fluvial nutrient loads in watersheds (Marce, 2004); 2) predicting daily reference evapotranspiration (Cai et al., 2004); 3) modeling of crop yield predictions (Kurtener et al., 2005; Krueger et al., 2011); 4) complexity of the soil compaction processes and qualitative knowledge associated with site-specific soil compaction evaluation (de Araújo & Saraiva, 2003); 5) soil science (McBratney and Odeh, 1997); 6) estimating soil erosion (Akbarzadeh et al., 2009); daily irrigation water demand (Atsalakis & Minoudaki, 2007), wind forecasts (Potter et al., 2004); and 7) hydro-environmental research (Azamathulla et al., 2009).

Recent research by Torbert et al. (2015, 2016) has used a fuzzy indicator approach for the assessment of soil disturbance. The aim of this study was to utilize the application of ANFIS for assessment of soil disturbance. When dealing with soil disturbance, the absolute value of a soil element is likely not as important as the potential change in that element relative to the undisturbed condition. Development of methods are need which will allow for separation of the normal changes in soil depth and those due to changes due to soil disturbance. Utilization of ANFIS technique allow for these relationships to be developed.

This paper is organized into three section. Section 1 provides an explanation of the ANFIS technique. Section 2 employs ANFIS for defining the contiguous relationship between individual soil disturbance indicators and combined soil disturbance indicators. Finally, section 3 provides a summary of the conclusions.
2. Material and Method

The foundation of ANFIS is using Data Driven Fuzzy Modeling (DDFM) approach. A DDFM provides the opportunity to extract models starting from input-output data. The generated model is represented as a fuzzy inference systems (FIS) (Zadeh, 1973). The use of FIS is one of the most famous applications of fuzzy logic and fuzzy sets theory (Zadeh, 1967). The strength of FIS rely on their twofold identity. On the one hand, they are able to handle linguistic concepts while on the other hand, they are universal approximaters, able to perform non-linear mappings between inputs and outputs (Serge, 2001). ANFIS (Adaptive Neuro-Fuzzy Inference System) is combination of a Sugeno-type fuzzy inference system and an Artificial Neural Network (Jang, 1993).

In the work described in this manuscript, the ANFIS is applied for two tasks:

1) Definition of the contiguous relations between individual soil disturbance indicators (DFSs), values of soil parameters, and depth; and

2) Identification of the contiguous relations between DFSs and combined indicators of soil disturbance (DFC).

In framework of the first task, the following three conditions were considered:

- Evaluation of case where DFS decreases smoothly with depth.
- Evaluation of case where DFS increases with depth.
- Evaluation of case where DFS changes smoothly with points of max/min.

The FIS was generated by applying MATLAB Fuzzy Logic Toolbox (FLT) (http://www.mathworks.com/). The FLT tool enabled the creation and editing of FIS, either manually or automatically as driven by the data. The input data used in this study was from a soil disturbance study reported by Torbert et al. (2015, 2016), where soil disturbance was evaluated from experimental soil sample data using the fuzzy indicator approach. The experimental design and the development of DFS and DFC from measured soil components in this study are discussed in detail by Torbert et al. (2015, 2016). Briefly, for the experiment on soil disturbance, the soil samples were collected from geological locations with completely different climatic and soil conditions on US Military bases in Fort Benning, GA, and Fort Riley, KS, United States. The site selection included locating areas of potential archaeological importance that may be sensitive to soil disturbance. At each of these geological locations, four sites were selected to ensure a wide range of variability. Each site was then surveyed for obvious mechanized maneuver training disturbances (vehicle ruts and tracks, compacted staging areas, etc.) and sub-divided based on level of training disturbance and archaeological importance. This arrangement provided essentially four treatments per site: (1) archaeological site/no-training, (2) site/training, (3) non archaeological/no-training, and (4) archaeological/training. For this study, the DFS previously developed for pH, Ca, Cr, N, Ni, Mn, and Pb for soil disturbance were used.
3. Results and Discussion

3.1. The contiguous relations between DFSs and depth

By using ANFIS several FISs, which defined the contiguous relations between DFSs and depth were built. In this case, the number of membership functions = 44, the type of membership functions was Gaussian, and the number of epochs = 30. The training errors changed from 0 to 0.5*10^-6 in this study.

The ANFIS surfaces described by these relationships are presented in figures 1-10. These ANFIS are presented as they differed between the archaeological sites and the non-archaeological sites. Also, they are also presented as they change with relationship to increasing depth.

3.1.1. DFS decrease with depth (case of archaeological sites)

The ANFIS surfaces describing some cases where the DFS decrease with depth within the case of archaeological sites are presented on figures 1 - 4. The decreasing relationship was observed for soil pH and Ni at the Fort Riley location and for soil Cr and Ni for the Fort Benning location.

Fig. 1. ANFIS surface described by the contiguous relationship between DFS of soil pH, soil pH, and soil depth for archaeological sites at Fort Riley.
Fig. 2. ANFIS surface described by the contiguous relationship between DFS of Ni, concentration of Ni, and soil depth for archaeological sites at Fort Riley.

Fig. 3. ANFIS surface described by the contiguous relationship between DFS of Cr, concentration of Cr, and soil depth for archaeological sites at Fort Benning.
3.1.2. DFS decrease with depth (case of non-archaeological sites)

The ANFIS surfaces describing some cases where the DFS decrease with depth within the case of non-archaeological site is presented in figure 5. The decreasing relationship was observed for soil N at the Fort Riley location.
3.1.3. DFS increase with depth (case of archaeological sites)
The ANFIS surfaces describing some cases where the DFS increases with depth within the case of an archaeological site is presented in figure 6. This condition was observed for soil Mn at the Fort Benning location.

3.1.4. DFS increase with depth (case of non-archaeological sites)
The ANFIS surfaces describing some cases where the DFS increases with depth within the case of non-archaeological site is presented in figure 7. This condition was observed for soil pH at the Fort Riley location.

3.1.5. DFS change with points of max/min (case of archaeological sites)
The ANFIS surfaces described did not always follow a continuous relationship of increasing or decreasing with depth. In some case it was observed that while there was a smooth transition, the relationship developed were surfaces that moved from points of maximum and minimum as soil depth changed. Some of the cases where the ANFIS surfaces described the DFS change between points of max/min are presented in figures 8-9.

![Fig. 6. ANFIS surface described by the contiguous relationship between DFS of Manganese, concentration of Manganese, and soil depth for archaeological sites at Fort Benning.](image)
Fig. 7. ANFIS surface described by the contiguous relationship between DFS of soil pH, soil pH, and soil depth for non-archaeological sites at Fort Riley.

Fig. 8. ANFIS surface described by the contiguous relationship between DFS of Pb, concentration of Pb, and soil depth for archaeological sites at Fort Riley.
3.1.6. DFS change with points of max/min (case of non-archaeological sites)

The ANFIS surfaces describing some cases where the DFS changes with points of max/min increases with depth within the case of non-archaeological sites is presented in figure 10. This condition was observed for soil Ni at the Fort Riley location.
3.2. The contiguous relations between DFC and two DFSs

In the research described by Torbert et al. (2015, 2016), soil disturbance factors complex were calculated by combining DFS for various soil component measurements. Further efforts were undertaken to understand the interactions of different soil components as impacted by soil disturbance by examining the possibility of combining DFS and DFC. By using ANFIS, several FISs which defined the contiguous relationship between DFC and two DFSs were built. Input variables of the designed FISs and training errors are given in Table 1. The number of membership functions = 33, the type of membership functions was Gaussian, and the number of epochs = 30. The ANFIS surfaces described by these relationships are presented in figures 11-14.

3.2.1. Case of archaeological sites

The ANFIS surfaces describing some cases where contiguous relationship between DFC, and two DFSs with depth within the case of an archaeological site are presented in figures 11 and 12. The ANFIS surfaces describing the relationship between DFS of soil Cr, DFS of soil Ni, and DFC shown in figure 11, and for DFS of soil Cr, DFS of soil Pb, and DFC are shown in figure 12 for archaeological sites at Fort Benning.

3.2.2. Case of non-archaeological site

By using ANFIS several FISs, which defined for the contiguous relationships between DFC and two DFSs were also built. Input variables of the designed FISs and training error are given in Table 2. Number of membership functions = 33, type of membership functions is Gaussian, number of epochs = 30. ANFIS surfaces described these relations are presented on figures 13-14.

![ANFIS surface described by the contiguous relationship between DFS of Cr, DFS of Ni, and DFC for archaeological sites at Fort Benning.](image-url)
Fig. 12. ANFIS surface described by the contiguous relationship between DFS of Cr, DFS of Pb, and DFC for archaeological sites at Fort Benning.

<table>
<thead>
<tr>
<th>Input variables</th>
<th>Training error</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFS of Cr and DFS of Ni</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>DFS of Cr and DFS of Pb</td>
<td>$10^{-7}$</td>
</tr>
</tbody>
</table>

Table 1. Input variables of the designed FISs and training error for archaeological sites

<table>
<thead>
<tr>
<th>Input variables</th>
<th>Training error</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFS on Cr- and DFS on Pb</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>DFS on Pb- and DFS on Ca</td>
<td>$0.1*10^{-3}$</td>
</tr>
</tbody>
</table>

Table 2. Input variables of the designed FISs and training error for non-archaeological sites
Fig. 13. ANFIS surface described by the contiguous relationship between DFS of Cr, DFS of Pb, and DFC for non-archaeological sites at Fort Benning.

Fig. 14. ANFIS surface described by the contiguous relationship between DFS on Pb, DFS on Ca, and DFC for non-archaeological sites at Fort Benning.
The ANFIS surfaces describing the relationship between DFS of soil Cr, DFS of soil Pb, and DFC shown in Figure 14 and for DFS of soil Pb, DFS of soil Ca, and DFC are shown in Figure 15 for non-archaeological sites at Fort Benning.

3.3. Discussion

By using ANFIS the contiguous relationships between soil disturbance indicators, values of soil parameters, and soil depth were evaluated. Individual soil disturbance indicators which are called "Disturbance Factor Simple (DFS)" could either decrease or increase smoothly with soil depth. For example, several ANFIS surface generated showed a smooth decrease of DFS with soil depth (cases of archaeological sites are shown in figures 1-4, and a case of non-archaeological sites are shown in figure 5). Other ANFIS surface generated showed a smooth increase of DFS with soil depth (cases of archaeological sites are shown in figure 6, and cases of non-archaeological sites are shown in figure 7). In other cases, the DFS was found to change with points of maximum and minimum as soil depth changed. This phenomenon was illustrated in figures 8-9 for cases of archaeological sites, and in figure 10 for cases of non-archaeological sites.

In previous research, Torbert et al. (2016) observed that DFSs may be useful for the assessment of change due to soil disturbance with depth. The research presented in this manuscript agrees with this previously reported research. The ANFIS surfaces obtained in this study and shown in figures 11-14, demonstrated that the contiguous relationship between combined indicator of soil disturbance DFC and two individual soil disturbance indicators. In some cases, these relationships are described by the rather monotonous ANFIS surfaces (for example, figure 12, which shows the case of archaeological sites and figure 13, which shows the case of non-archaeological sites). In other cases, these relationships are described by the surfaces with points of maximum or minimum (for example, figure 11 which shows the case of archaeological sites, and figure 14, which shows the case of non-archaeological sites). Observation of the ANFIS surfaces shows that in some cases DFC has a low sensitivity to some predictors. For example, from figure 13 it follows that there is low a sensitivity of DFC to DFS for Pb.

Conclusions

Soil disturbance assessment in a changing environment is important for solving ecological and farm problems. In this work, we considered the application of an Adaptive Neuro-Fuzzy Inference System (ANFIS) for decisions of two problems: 1) definition of the contiguous relationship between individual soil disturbed indicators (DFSs), values of soil parameters, and soil depth, and 2) identification of the contiguous relationship between DFSs and combined indicator of soil disturbance (DFC).
References


