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Quality evaluation of restored soils with a fuzzy logic expert system

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ABSTRACT

Due to landscaping, mining and construction activities on previously cultivated land, more and more soils are excavated, translocated, deposited and restored. In many cases restored soils show signs of structural degradation such as overcompaction and water logging. There is a lack of methods to evaluate and assess the physical quality of restored soil. In this study a fuzzy logic expert system was developed which allows us to evaluate the potential plant productivity of restored soils based on measured physical soil parameters. The system is based on the statements of a group of soil experts relating physical soil quality to packing density, penetration resistance, air capacity and saturated hydraulic conductivity according to their personal experience or expertise. From these statements we derived fuzzy membership functions and inference rules. The expert system was applied to evaluate 10 restored sites in comparison to nearby non-restored reference soils. The physical soil quality had remained unchanged or decreased after restoration at most investigated sites. Only two horizons showed clearly improved soil conditions after restoration. The validity of the fuzzy logic expert system is demonstrated by comparing the results with evaluations of the same soils using two other indicators of the physical soil quality for plant production: the least limiting water range (LLWR) and the *S*-parameter (i.e. the slope of the water retention curve at the inflection point). The physical soil quality assessment with the fuzzy logic expert system was highly correlated with both the LLWR ($r^2 = 0.80$) and the *S*-parameter ($r^2 = 0.70$). These results show that fuzzy logic expert systems may provide a suitable tool to assess physical soil quality, taking proper account of the vagueness and ambiguity necessarily involved in this task.

1. Introduction

Soil restoration on former construction, gravel exploitation and open-cast mining sites and after leveling of agricultural land is of increasing importance and is a cornerstone of sustainable resource management. Environmentally sound restoration of land for agricultural use requires that unpolluted and biologically active soil material is used (Harris et al., 1996). Current state-of-the-art restoration technology includes the separate excavation and storing of top- and subsoil material to enable restoring according to the original layering of this material (Häusler and Salm, 2001). However, paying attention to the quality of the soil material and respecting the original layering alone does not guarantee a successful restoration of soil for agricultural use (Barnhisel, 1988). It is also crucial that the packing and subsequent management of the soil lead to adequate physical quality (Beaudet-Vidal et al., 1998). Inadequate restoration procedures and over-use of freshly restored soils often leads to over-compaction, water logging and insufficient aeration, which are difficult to remediate. In order to improve the success of soil restoration, it is necessary to monitor the development of the structure-related physical properties of restored soils. Several indicators are available to assess the physical quality of soils (da Silva and Kay, 1997; Lipiec and Håkansson, 2000; Dexter, 2004a). But there is a lack of an integrated method to assess and evaluate the physical quality of restored soils based on a set of several easily measurable parameters (Friedli et al., 1998).

Recently, the awareness that soil and land evaluation are an important basis for sustainable land use and management has increased and led to the introduction of "soil quality" as a basic concept of soil monitoring (Larson and Pierce, 1994). According to this concept, soil simultaneously performs a multitude of different functions and all these functions contribute to soil quality. Karlen and Andrews (2000) defined soil quality as "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation". Thus, the concept of soil quality is based on a holistic view of soil and its functions within the ecosystem. Numerous soil parameters have been suggested as indicators for soil quality. Doran and Parkin (1996) proposed a list of basic indicators of soil quality, which they termed *minimum data set* (MDS). The MDS comprises a variety of physical, chemical and biological soil parameters that are related to the different soil functions. Soil quality is evaluated on the basis of these indicators in terms of the capacity of a soil to perform soil functions.

At present, despite many proposals, no consistent procedure exists how to implement the soil quality concept, as defined by Larson and Pierce (1994), in practice. The application of the concept is faced with

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