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Biodiversity and soil quality in agroecosystems: the use of a qualitative multi-attribute model

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Abstract In ecological impact assessment, special emphasis is put on soil biology and estimating soil quality from the observed biological parameters. The aim of this study is to propose a tool easy to use for scientists and decision makers for agroecosystems soil quality assessment using these biological parameters. This tool was developed as a collaboration between ECOGEN (www.ecogen.dk) soil experts and decision analysts. Methodologically, we have addressed this goal using model-based Decision Support Systems (DSS), taking the approach of qualitative multi-attribute modelling. The approach is based on developing various hierarchical multi-attribute models that consist of qualitative attributes and utility (aggregation) functions, represented by decision rules. The assessment of soil quality is based on two main indicators: (1) soil diversity (assessed through microfauna, mesofauna and macrofauna richness) and (2) soil functioning (in terms of leaching, comminution, mineralisation and plant growth). Here we address the methodological aspects of the model and its development, and describe the components of the model (attributes, value scales, decision rules and weights). We present initial results of its application to the assessment of crop management on soil quality in the case of using conventional and *Bt*-maize at three field sites in France and Denmark. Our finding was that soil quality was unaffected even though several input attributes were changed. We also analyse the sensitivity of the model and discuss its current and potential contribution to soil quality management.

Key words: soil quality, decision support systems, agroecosystems, GM plants

Introduction

An assessment of the impact of introducing new technologies, like GM plants, should ideally include some measure of soil health or quality. Conceptually, soil health and quality are similar with soil quality being a measure of whether a soil is ‘fit for purpose’ (Carter *et al.*, 1997) We have taken the definition of soil quality proposed by Eijsackers (1998), ‘degree of excellency with a relative nature’, as applicable to cropping systems. Thus, while striving for the best possible quality, the definition is also dependent on soil-type and land-use context.

Our purpose, within the ECOGEN project (www.ecogen.dk) was to develop a computer-based decision support systems (DSS) for the assessment of ecological impacts of using GM crops. A special emphasis was put on soil biology and thus a model was developed to predict soil quality from the observed biological parameters (Andersen et al. 2007, Cortet et al. 2007, Griffiths et al. 2007). The main aim was to produce a soil quality score based on soil biodiversity and function – tailored to determine effects of different maize (*Zea mays* L.) cropping systems on these.

In this paper, we describe a model for the assessment of the impact of GM and non-GM cropping systems on soil quality. The model has been developed in collaboration between ECOGEN soil ecology experts and decision analysts. We address the methodological aspects of the model and its development, describe the components of the model (attributes and decision rules) and present the initial results of its application to the assessment of impacts to soil in the case of using conventional and *Bt* maize at field sites in France and Denmark.

Material and methods

Soil quality model

The model consists of hierarchically structured variables called attributes. All the attributes in the model are qualitative rather than numerical: they can take only discrete symbolic values. The aggregation of values in the model is defined by decision rules (Bohanec 2003).

Model structure

Soil quality is assessed on the basis of soil diversity and soil functioning. In the model, this is reflected so that the hierarchy of attributes is split into two main parts (Figure 1): the smaller subtree on the left assesses soil diversity using indicators of species richness, whereas the larger part on the right assesses soil functioning using indicators which mostly depend on the biomass of soil organisms. The techniques for the sampling, extraction, enumeration and identification of soil organisms are detailed elsewhere (Cortet *et al*., 2007; Griffiths *et al*., 2007; Krogh *et al*., 2007).

Attribute value scales, decision rules and weights

To each attribute fits a value scale, decision rules and weights. A complete description of these parameters is given by Bohanec *et al*., (2007). Briefly, four types of qualitative value scales are used in the model, (i) the prevailing and the simplest being the three-valued scale “low, medium, high”. This means that most basic attributes can take only one of the three values: low, medium, or high. By convention, the value medium is assigned to an attribute whenever the corresponding numerical measurement of that attribute lies within the ±15% interval around its average value; (ii) the attributes “Leaching”, “Comminution” and “Mineralisation” use a three-valued scale “slow, medium, fast”, which is used in the same way as the previous scale; (iii) for “Soil Quality”, “Soil diversity”, “Soil functioning”, “Decomposition”, and “Plant growth”. this is a 5-valued Likert scale 1, 2, 3, 4, 5, ordered from bad (1) through intermediate (3) to good (5); (iv) the attribute “Bacteria/Fungi ratio” is measured using the three-valued qualitative scale “fungi dominant”, “balanced”, “bacteria dominant”.

The aggregation of attributes in the model is defined through decision rules. For each aggregate attribute in the model, there is a set of if-then rules that define the value of that attribute depending on the values of its immediate descendants in the model. The decision rules were defined by soil ecology experts using the DEXi software. DEXi does also calculate attribute weights from decision rules (Bohanec and Zupan 2004). In this case, weights do not define the relationship between the attributes, but rather conveniently represent an approximation of this relationship, which is actually defined by decision rules.

Results and discussion

Sensitivity Analysis and assessment of ECOGEN data

To determine how sensitive the model was to changes in attributes we determined the fewest changes required to increase or decrease the soil quality score. Some scenarios indicated we could improve soil quality (from 3 to 4) by enhancing only three basic attributes. Conversely, soil quality could be reduced to 2 or 1 by impairing only 3 or 4 basic attributes, respectively.

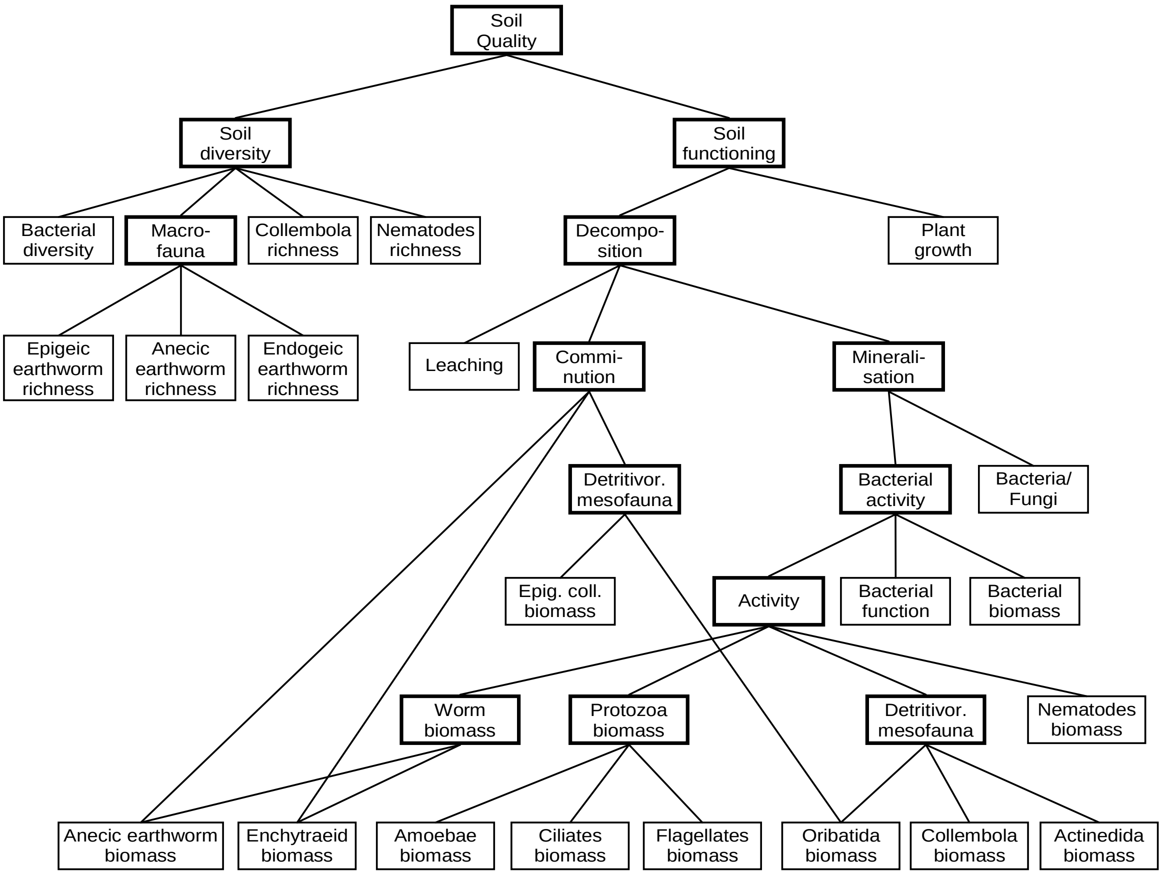

Figure 1. Soil Quality model. Emphasised and non-emphasised boxes represent aggregate and basic attributes, respectively.

We tested the model using ECOGEN data collected in 2003 from eight cropping systems on three locations: Foulum in Denmark, and Varois and Narbons in France (for site details see Andersen *et al*., 2007). For each location, the “conventional” system (involving conventional maize and ploughing, if applicable) was taken as a reference, with all the remaining systems, including those using Bt maize, being described and evaluated in comparison with this reference.

The evaluation results indicated that all the management options gave the same soil quality value of 3. However, looking at the results at the lower level of the model, it is clear that the use of Bt-maize in Foulum positively affects Soil functioning (with ploughing) and Soil diversity (when using minimum tillage). More specifically, minimum tillage positively affects Nematode richness, Detritivorous mesofauna and Protozoa biomass, leading to better Activity. The use of Bt-maize reduces Protozoa biomass, but improves Comminution due to Anecic earthworm biomass. However, at Varois and Narbons, the use of Bt-maize reduced many faunal populations without affecting the higher level outcomes of Soil functioning, diversity or quality.

Thus, changing the attributes in the model showed that it was possible to affect soil quality by altering only 2 or 3 basic attributes by more than 15%, showing that soil quality could be particularly sensitive to altered environmental conditions. In reality, when field data was used to run the model, even though up to 11 basic attributes were affected, there were no changes to the soil quality score. In some cases there were opposing changes operating, for example mineralisation was slower but comminution faster, that tended to cancel each other out. This model seems to bear out the perceived wisdom that soils are generally resistant to change and the opposing effects of the observed changes offers an explanation of the mechanism behind that resistance.

Overall, the contribution of developing such a model is threefold. First, by drawing from various disciplines, the model encodes knowledge about the relevant soil quality factors, their interrelationships and how they are influenced by environmental conditions. The model, consisting of attributes and decision rules, can be easily communicated and discussed among experts. Second, the model is operational in the sense it can be used for the assessment, comparison, and 'what-if' analysis of realistic scenarios. Third, the model can be used in a way to generate and propose desirable characteristics of management options, thus possibly contributing to the development of new agricultural practices. We have successfully produced a soil quality score based on biological diversity and function, tailored to determine the effects of different cropping systems. Although soil physical effects and effects through the addition of organic matter are excluded at present the model could be expanded to include other parameters. As such the model could be considered a biological sub-model for more global soil quality scores.

Implementation

A simplified version of the model is available through the web page called ESQI (ECOGEN Soil Quality Index, http://kt.ijs.si/MarkoBohanec/ESQI/ESQI.php).

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