

Assessing agricultural soil quality on a global scale

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Abstract

Food insecurity due to limited and degraded soil resources is a threat of the 21st century. The aim of the paper is to analyse potentials and deficiencies of current approaches for assessing agricultural soil quality consistently over a range of spatial scales. The analysis includes both the description of methods of soil quality evaluation and results of field tests across Eurasia. We found that the soil moisture and thermal regime are the main constraints to the soil productivity potential on a global scale. However, most taxonomic soil classification systems provide insufficient information on soil functionality. Visual soil assessment methods have been developed as diagnostic tools for the recognition and evaluation of the morphological and functional status of soil. They offer the potential for use in extension, monitoring and modelling the management-induced changes of agricultural soil quality. A straightforward overall soil functional assessment framework based on soil indicators may explain most of crop yield variability of cereals. Such a system which includes the soil thermal and water regime and management induced and inherent aspects of agricultural soil quality is the Muencheberg Soil Quality Rating. This system could serve as a functional supplement to the World Reference Base for Soil Resources, ranking and controlling agricultural soil quality on a global scale.

Key Words

Soil quality, indicator, crop yield, visual soil assessment, Muencheberg Soil Quality Rating

Introduction

The function of soils to provide food, fibre, and further essential goods for humans is closely associated with the main global issues of the 21st century like food security, demands of energy and water, carbon balance and climate change (Lal 2009). A growing global community of land users and stakeholders seeking to achieve high soil productivity in the context of a sustainable multifunctional use of soils and landscapes will demand assessment tools for agricultural land worldwide. A crucial question arises: Are adequate operational tools available to assess the functional status of the agricultural soil resource consistently over spatial scales? The aim of the study was to detect potentials, deficiencies and gaps in knowledge of current approaches for assessing soil quality and the productivity potential of soils. Conclusions for further work on assessing and evaluating the functional status of the soil resource should be drawn.

Methods

We analysed available methods for assessing soil quality and its productivity potential by different criteria like field method suitability, performance and crop yield relevance over different scales. Field analyses were performed to test the visual soil assessment methods of Shepherd (2000), Ball *et al.* (2007). Different soil profiles were also analysed in agricultural landscapes of Eurasia. Soils were classified according to the World Reference Base for Soil Resources (WRB 2006) and functionally assessed by the Muencheberg Soil Quality Rating (M-SQR, Mueller *et al.* 2007). Field soil data were surveyed according to FAO (2006) guidelines for soil description. Crop yields and management intensity data were taken from agricultural research reports.

The New Zealand Visual Soil Assessment (VSA) method (Shepherd 2000) is a multi-parameter technique based on scoring of soil by different criteria. Measuring the disaggregation of soil after a drop-shatter test is the key criterion for assessing soil structure and helps minimise the subjective handling of the soil prior to assessment. The Muencheberg Soil Quality Rating (M-SQR, Mueller *et al.* 2007) has been developed as a

potential international reference base for a functional assessment and classification of soils (Figure 1). It focuses on cropland and grassland and is based on productivity-relevant indicator ratings which provide a functional coding of soils. Two types of indicator are identified. The first are basic and relate mainly to soil textural and structural properties relevant to plant growth. The second are hazard-based, relating to severe restrictions of soil function. The sum of weighted basic indicator ratings and ratings of the most severe (active) hazard indicator, yield an overall soil quality rating index. Indicator ratings are based on a field manual and utilize soil survey classifications (FAO 2006), soil structure diagnosis, and local or regional climate data.

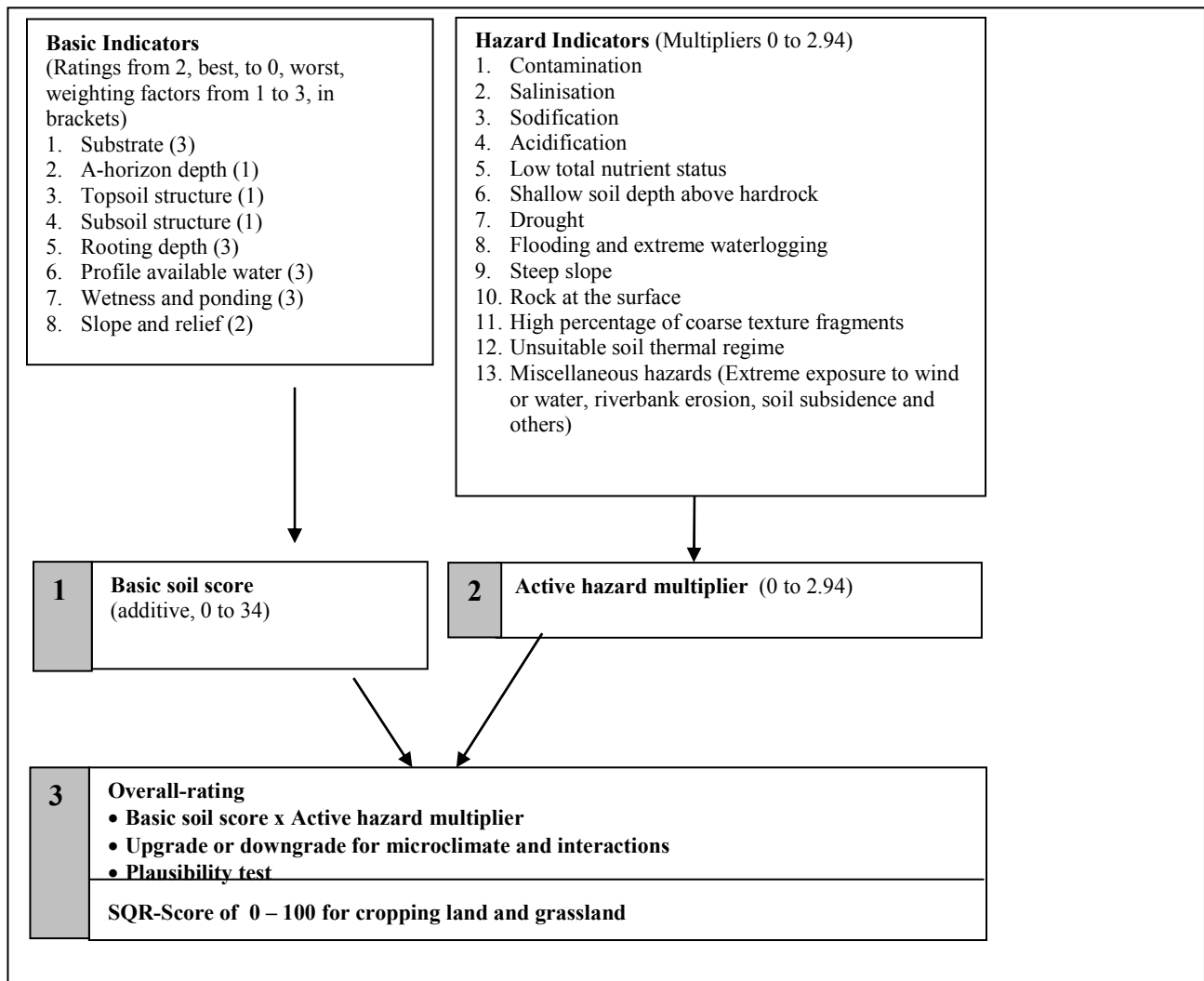


Figure 1. Indicator system of the Muencheberg Soil Quality Rating (Mueller *et al.* 2007).

Results

The performance of visual soil assessment methods

Visual soil assessment methods define macro-morphological features of soil structure that can be detected and evaluated in the field. Soil structure is a criterion of agricultural soil quality. It is particularly vulnerable to change by management and degradation processes like compaction and erosion, and its preservation is key to sustaining soil function. Soil structural features meet the farmers perception of soil quality (Shepherd 2000; Batey and Mc Kenzie 2006) and are correlated with measured data of physical soil quality and crop yield (Mueller *et al.* 2009). Visual assessment of soil structure may serve as a diagnostic tool for the recognition and evaluation of the morphological and functional status of soil. This offers semi-quantitative information for use in extension and monitoring or even modelling (Roger-Estrade *et al.* 2009). Over the past decades, several methods have been evolved. One of the most accepted methods is that of Peerlkamp (1967). It has a conjoint scale referring to type and size of aggregates and pores. The main advantages of this method are speed and minor soil disturbance, providing comparative statistical analyses both in large fields and also in small plots of long-term trials. However, the scoring framework has potential for subjective errors. In a study relating soils data derivable from visual scoring to crop growth, types and sizes of aggregates and

abundance of biological macropores were the most reliable criteria relating to measurement data. In addition, differences in soil management or effects of compaction may be detected by visual assessment of the soil (Batey and McKenzie 2006; Mueller *et al.* 2009). In the same study, unfavourable visual structure scores were associated with increased dry bulk density, higher soil strength and lower infiltration rate, but correlations were site-specific (reference required). Visual soil structure assessments may thus form an important part of overall soil characterizations (FAO 2006; WRB 2006, Mueller *et al.* 2007). Visual methods based on, or supplemented by illustrations, have clear advantages for the reliable assignment of a rating score based on visual diagnostic criteria. Illustrated methods like the updated Peerlkamp method (Ball *et al.* 2007) and the Visual Soil Assessment (Shepherd 2009) are particularly effective and reliable to apply.

Comparison of some methods of assessment of overall soil quality

Specific soil and land evaluation schemes exist on a national basis. Their soil data inputs differ, evaluation ratings are not transferable and not applicable in international studies. From current available overall soil assessment schemes, the multi-indicator based Canadian Land Suitability Rating System (LSRS, Agronomic Interpretations Working Group 1995) and the Muencheberg Soil Quality Rating (M-SQR, Mueller *et al.* 2007) meet best the criteria for a worldwide comparison of overall soil quality and productivity potentials for cropping cereal-dominated rotations. They should be tested and compared, and evolved towards a functional supplement to the World Reference Base for Soil Resources.

Relevance of soil quality assessment methods for crop yield

Visual soil structure assessment may explain only part of crop yield variability, as the influence of inherent soil properties and climate on crop yield is dominant, particularly over larger regions. Attributes of the WRB 2006 database attributes such as reference soil groups and texture qualifiers may thus provide important information on the yield of cereals and grass. However, if the classes of soil thermal and moisture regimes are not taken into consideration, less than 50% of the crop yield variability in the supra-regional scale can be explained by WRB reference soil groups and qualifiers only (Table 1).

Table 1. Coefficient of determination (B) of multiple regressions between grain yield of cereals and soil parameters.

Reference soil groups (RSG) and land use	Variant of classification	B
All RSG, high-input farming (n=352)	1) Soil attributes only (Qualifiers of WRB 2006)	0,20**
	2) Soil attributes and thermal and moisture regime	0,61***
	3) M-SQR-score (Muencheberg Soil Quality Rating)	0,78***
Phaeozems, Chernozems und Kastanozems, high-input farming (n=54)	1) Soil attributes only (Qualifiers of WRB 2006)	0,00
	2) Soil attributes and thermal and moisture regime	0,65***
	3) M-SQR-score (Muencheberg Soil Quality Rating)	0,74***
All RSG, organic and low-input farming (n=43)	1) Soil attributes only (Qualifiers of WRB 2006)	0,36**
	2) Soil attributes and thermal and moisture regime	0,63***
	3) M-SQR-score (Muencheberg Soil Quality Rating)	0,87***

Soil moisture and thermal regimes which are climate-controlled are, like pedogenesis, the main constraints to potential soil productivity on a global scale. However, most taxonomic soil classification systems, including the World Reference Basis for Soil Resources, and even many national soil rating frameworks, provide insufficient information on soil functionality, including the productivity function on that scale. Figure 2 shows clear differences in crop yield between soils of mesic and frigid to cryic temperature regimes. Within the mesic temperature regime, sandy soils (Arenosols) have a significantly lower crop yield potential. Overall soil quality rating systems which include information on climate, textural and structural properties, may explain between 70 and 87% of the crop yield variability (Table 1).

Conclusion

The Muencheberg Soil Quality Rating has potential as a reference method of rating potentials and limitations of soils for cropping and pastoral grazing at different scales. It can serve as a crop yield estimator for cereals on a global scale. Regarding assessing agricultural soil quality and the productivity function of soils, it could also be a useful supplement to the WRB 2006 soil classification.

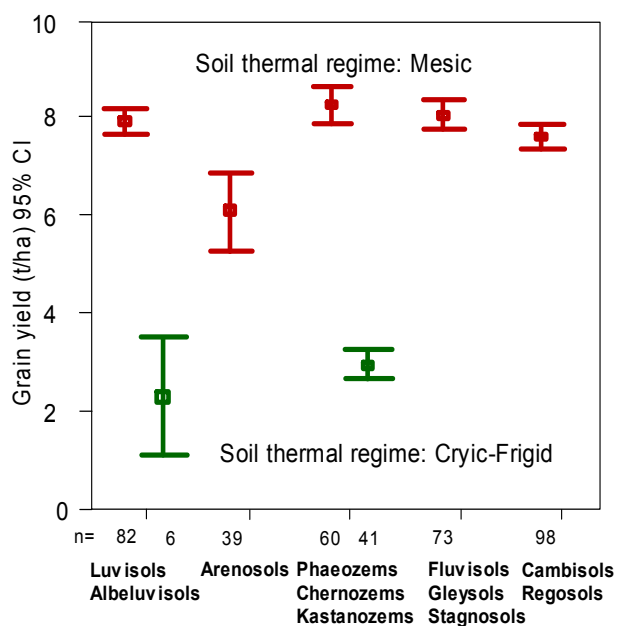


Figure 2. Grain yields of cereals in Eurasia stratified by soil thermal regimes and Reference Soil Groups of the WRB 2006. Sites are mainly located in Germany, western Siberia and northern China. Cereals are wheat, rye, oats or barley, whichever had the highest local crop yield.

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