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Effects of agricultural management practices on soil quality: A review of long-term experiments for Europe and China

Zhanguo Bai[a,*], Thomas Caspari[a,1], Maria Ruiperez Gonzalez[a], Niels H. Batjes[a], Paul Mäder[b], Else K. Bünemann[b], Ron de Goede[c], Lijbert Brussaard[c], Minggang Xu[d], Carla Sofia Santos Ferreira[e], Endla Reintam[f], Hongzhu Fan[g], Rok Mihelič[h], Matjaž Glavan[h], Zoltán Tóth[i]

[a] ISRIC – World Soil Information, P.O. Box 353, 6700 AJ, The Netherlands
[b] Department of Soil Sciences, Research Institute of Organic Agriculture FiBL, Ackerstrasse 113, CH-5070, Frick, Switzerland
[c] Department of Soil Quality, Wageningen University & Research, P.O. Box 47, 6700 AA, Wageningen, The Netherlands
[d] Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences (CAAS), Beijing, 100081, PR China
[e] Research Centre for Natural Resources, Environment and Society (CERNAS), College of Agriculture, Polytechnic Institute of Coimbra, P-3040-316, Coimbra, Portugal
[f] Estonian University of Life Sciences, Kreutzwaldi 1, 51014, Tartu, Estonia
[g] Soil and Fertilizer Institute, Sichuan Academy of Agricultural Sciences, Chengdu, 610066, PR China
[h] University of Ljubljana, Biotechnical Faculty, Jamnikarjeva 101, 1000, Ljubljana, Slovenia
[i] Pannonia University, Georgikon Faculty, Keszthely, Hungary

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ABSTRACT

In this paper we present effects of four paired agricultural management practices (organic matter (OM) addition versus no organic matter input, no-tillage (NT) versus conventional tillage, crop rotation versus monoculture, and organic agriculture versus conventional agriculture) on five key soil quality indicators, *i.e.*, soil organic matter (SOM) content, pH, aggregate stability, earthworms (numbers) and crop yield. We have considered organic matter addition, no-tillage, crop rotation and organic agriculture as "promising practices"; no organic matter input, conventional tillage, monoculture and conventional farming were taken as the respective references or "standard practice" (baseline). Relative effects were analysed through indicator response ratio (RR) under each paired practice. For this we considered data of 30 long-term experiments collected from 13 case study sites in Europe and China as collated in the framework of the EU-China funded iSQAPER project. These were complemented with data from 42 long-term experiments across China and 402 observations of long-term trials published in the literature. Out of these, we only considered experiments covering at least five years. The results show that OM addition favourably affected all the indicators under consideration. The most favourable effect was reported on earthworm numbers, followed by yield, SOM content and soil aggregate stability. For pH, effects depended on soil type; OM input favourably affected the pH of acidic soils, whereas no clear trend was observed under NT. NT generally led to increased aggregate stability and greater SOM content in upper soil horizons. However, the magnitude of the relative effects varied, *e.g.* with soil texture. No-tillage practices enhanced earthworm populations, but not where herbicides or pesticides were applied to combat weeds and pests. Overall, in this review, yield slightly decreased under NT. Crop rotation had a positive effect on SOM content and yield; rotation with ley very positively influenced earthworms' numbers. Overall, crop rotation had little impact on soil pH and aggregate stability − depending on the type of intercrop; alternatively, rotation of arable crops only resulted in adverse effects. A clear positive trend was observed for earthworm abundance under organic agriculture. Further, organic agriculture generally resulted in increased aggregate stability and greater SOM content. Overall, no clear trend was found for pH; a decrease in yield was observed under organic agriculture in this review.

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[*] Corresponding author.
E-mail address: Zhanguo.Bai@wur.nl (Z. Bai).
[1] Current address: Landcare Research, 54, P.O. Box 69040, Lincoln, 7640, New Zealand.

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1. Introduction

Soil is increasingly recognized as a non-renewable resource on a human life scale because, once degraded it's regeneration is an extremely slow process (Camarsa et al., 2014; Lal, 2015). Given the importance of soils for crop and livestock production as well as for providing wider ecosystem services for local and global societies, maintaining the soil in good condition is of vital importance. To manage the use of agricultural soils well, decision-makers need science-based, easy-to-apply and cost-effective tools to assess changes in soil quality and function.

The European Commission, the Government of China and the Government of Switzerland co-funded the research project "*Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience*" (iSQAPER), which aims to develop an interactive soil quality assessment tool (SQAPP) that accounts for the impact of agricultural land management practices on soil properties and functions. The ultimate aim is to provide agricultural land users with options for cost-effective agricultural management activities which enhance soil quality and crop productivity.

The concept of soil quality includes assessment of soil properties and processes as they relate to the ability of soil to function effectively as a component of a healthy ecosystem (Bünemann et al., 2018). Specific functions and subsequent values provided by ecosystems are variable and rely on numerous soil physical, chemical, and biological properties and processes, which can differ across spatial and temporal scales (Doran, 2002; Nannipieri et al., 2003; Van Diepeningen et al., 2006; Spiegel et al., 2015). As such, selection of a standard set of specific properties as indicators of soil quality can be complex and varies among agricultural systems and management purposes. According to Islam and Weil (2000), soil quality is best assessed by soil properties that are neither so stable as to be insensitive to management, nor so easily changed as to give little indication of long-term alterations.

Understanding interacting effects of agricultural management practices on soil quality indicators (SQI) is essential for the development of SQAPP. Such effects can be best analysed from data of agricultural long-term experiments (LTE), where soils are experimentally manipulated to identify the key drivers of soil change. These trials allow to study changes over time of soil properties under various types of treatment (e.g. plough/no-tillage) and their respective intensities (e.g. ploughing frequency).

The present study has been performed to analyse and summarise the data of a large range of LTEs. Our hypothesis was that sufficient data for promising soil quality indicators can be extracted in order to show trends over time as a basis for further, generic decision-making on recommended agricultural practices.

2. Data and methods

2.1. Selection of soil quality indicators and agricultural management practices

Based on an earlier review by Bünemann et al. (2018) in the iSQAPER project framework, and work by Spiegel et al. (2015), we have initially chosen six soil quality indicators. Main considerations in making this selection were:

- Changes in soil quality and fertility are gradual and significant effects of land use and management generally cannot be measured within at least five years after their introduction; hence, long-term experiments (LTEs) are of critical importance. Focus will be on "dynamic" over "static" indicators as only the former can reflect changes within a reasonable time span.
- Most indicators are soil and site specific (*e.g.* soil organic matter content and pH), so it is essential that experiments have been done under comparable conditions (*e.g.* LTEs with split-plot design, or at least with neighbouring parcels) under identical soil and climate conditions.
- It is necessary to distinguish between short-term effects and long-term changes in soil quality indicators.
- Indicators can be related to potential changes in soil functions and soil threats.
- It is important not only to identify the most appropriate bio-physical indicators, but also to ensure that farmers and land managers can easily understand and relate to these indicators so that they may be used to support on-farm management decisions.

The selected soil quality indicators were: soil organic matter (SOM) content, pH, aggregate stability, water-holding capacity and (number of) earthworms. Yield, although not a soil property, is also considered here as it is a good measure for soil quality and a primary concern to farmers.

Five agricultural management practices were chosen as "promising": organic matter addition, no-tillage, crop rotation, irrigation, and—at the system level—organic agriculture. For each LTE, we compared results with respect to the corresponding "standard practice" (reference): no organic matter input, conventional tillage, monoculture, non-irrigation, and conventional farming.

2.2. Data collection and literature review

LTEs are indispensable for assessing effects of agricultural management practices on changes in soil quality. We have collated data of 30 long-term experiments from the 13 iSQAPER project partners in Europe and China. Data collated for each LTE included: location, climate, land use, soil data, trial factors, management systems, assessments done, sample storage and analysis. The average duration of the LTEs under consideration was 19 years (range: 5–34 years). The earliest LTE began in 1964 and most of these LTE's are still ongoing. Details on the trials included are provided as Supplementary information in Table S1.

The above data were complemented with analytical data from 42 long-term agricultural experiments across China covering over 30 years of observations and various management practices (Xu et al., 2015a, 2015b).

To augment our database, we performed an extensive literature review, including over 900 publications and reports using web-based search engines Google Scholar, ScienceDirect, ISI Web of Science, ResearchGate, and Scopus. Publications in Chinese were retrieved using the China Knowledge Resource Integrated (CNKI) database (http://eng.oversea.cnki.net/kns55/). Key search terms used included organic matter addition (crop residue, straw return, green manure, farmyard manure, compost, slurry), crop rotation, no-tillage, organic agriculture, organic farming, and combination with the chosen soil properties and yield.

The resulting publications were documented using an open source reference manager (Mendeley.com) and subsequently screened for their relevance for the present review. Key elements of the selected studies (402 observations) were entered into a Microsoft Excel database. The corresponding data and literature references are documented in Supplementary Table S2.

2.3. Data analysis and visualization

Effects of management practices on the selected soil quality indicators were assessed on the basis of both the iSQAPER LTE data (Supplementary Table S1), and the data extracted from the literature review including analytical results from the LTEs of China (Supplementary Table S2).

For the LTE's, we calculated response ratios (RR) for each indicator under a paired practice. For example, SOM content under NT (Treatment 2) was divided by SOM content under conventional tillage