Hans H. Ruthenberg-Graduierten-Förderpreis 2016/

Hans H. Ruthenberg Award for Graduates 2016

Steffen A. Schweizer "Evaluation of soil physical properties under long-term organic and conventional agricultural systems in Central India"

University of Hohenheim, 2015

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Summary

Problem statement and motivation

Vertisols are clay-rich soils that are widely cultivated with cash crops, have a high cation exchange capacity and a high water holding capacity that enables crops to survive longer in case of drought in semiarid regions. However, the large agricultural yield potential of Vertisols is limited by their structural properties: low root permeability and hydraulic conductivity, shrinking and swelling, and a narrow soil moisture range for tillage operations. In addition, the clayey soil structure of Vertisols bears a high risk of degradation through slaking or compaction. In India the monsoon rainfalls threaten Vertisols due to a high rain intensity and low infiltration into the soil resulting in high water erosion through surface runoff.

To sustain the soil fertility of Vertisols, to minimize their erosion risk and to increase their crop growth potentials a higher input of biomass is advocated e.g. through organic farming systems. However, as pointed out by Seufert et al. (2012), the agricultural success of organic farming in countries of the tropics and subtropics is highly dependent on specific management practices and the scientific evidences of its ecological consequences are scarce. To compare organic and conventional farming systems, the Research Institute of Organic Agriculture (FiBL) established a long-term experiment in India in cooperation with a local partner, BioRe Foundation. The long-term experiment is situated in Kasrawad, Madya Pradesh and was started in the year 2007. A previous economic study of this experiment has shown that the organic systems were economically viable during the first four years after conversion, although the yields of the organic systems were equal or lower than the conventional systems (Forster et al. 2013). But what are the ecological effects of the farming systems on soil structure and interrelated soil properties?

Research objective

To understand how organic and conventional farming influence the soil structure of a Vertisol I analyzed both soil structural· properties and soil functions in the long-term

experiment in Kasrawad:

In the first part of my master thesis I measured how long-term organic farming systems affected soil structural properties in comparison to conventional farming by (i) increasing soil organic carbon, (ii) stabilizing aggregates, (iii) increasing pH and electrical conductivity, and (iv) loosen soil and increase cracking. In the second part of my master thesis I measured whether long-term organic farming systems (i) increase infiltration, (ii) decrease surface runoff, and (iii) decrease plowing time. In addition, the impact of fertile soil structure on the sustainable use of the soil resources in a Vertisol was identified in an interdisciplinary chapter.

The biomass input to the soil was much higher under organic farming than under conventional farming. Consequently, we assumed that soil organic carbon (SOC) would increase in soils under organic systems compared to conventional systems, resulting in more stable and bigger soil aggregates, lower bulk density, and wider cracks. Such soil structure would then permit faster and cheaper plowing as well as higher infiltration that leads to lower surface runoff reducing the erosion risk. However, due to fertilization of the organic systems with composted biomass and watering of the same with river water, a potential salt accumulation could occur. Therefore, soil chemical properties like pH value and electrical conductivity were also analyzed for their interaction with soil structure.

Methodological approach

I analyzed the soil below a long-term experiment in its 7th year, which comprises a two-year crop rotation of cotton-soybean/wheat in four farming systems (biodynamic, organic, conventional, and conventional with genetically modified Bt-cotton). The organic systems were fertilized with composted organic manure, whereas the conventional systems received an integrated fertilization of synthetic fertilizer with a smaller amount of farmyard manure. On site, cracking was analyzed by photogrammetry analysis and bulk density was measured by core sampling. To determine infiltration, double ring infiltrometers were welded by a local mechanic. A drip irrigation was mounted onto a 2 m high construction with a Boyle-Mariotte flask to simulate rainfall whereas the surface runoff was collected at all four sides of the analyzed 1 m^2 area. At the University of Hohenheim soil organic carbon was analyzed by an elemental analyzer and pH as well as electrical conductivity were determined in a soil water suspension. At the University of Freiburg dynamic image analysis (QICPIC method) was improved and adapted in order to analyze size and shape of the aggregates. The QICPIC method provided an automatic size analysis of spherical particles in a fast water stream by rear illumination with a pulsed laser light. In combination with wet sieving and sonication, this QICPIC method allowed the assessment of both waterstable and sonication-stable aggregates.

Research findings

Both organic systems demonstrated 1.8 times wider cracking ($p<0.05$) and 2 % looser subsoils (20-40 cm) ($p<0.05$) than the conventional systems in the wheat strip. In addition, the organic systems indicated 1.1 g kg-1 (5.1 Mg ha^{-1}) more soil organic carbon (0-40 cm) than the conventional systems, although these differences were not statistically different ($p=0.16$). The dynamic image analysis of aggregate size and shape through QICPIC was successfully improved and adapted to the clayey soil properties. This analysis revealed that in organic topsoils more water-stable microaggregates <110 µm developed ($p<0.05$) that were also rounder if sized 30-90 µm ($p<0.05$). Such size trends towards smaller soil aggregates in organic systems is related to preferential interaction of the added biomass with claysized structural units. In addition, the pH (H20) within organic topsoil was 8.3, which was 0.14 units higher than in conventional systems ($p<0.0001$). In the conventional systems urea application probably decreased the pH due to its acidifying turnover. The higher pH and a non-increased electrical conductivity within the organic topsoils compared to conventional topsoils suggested increased sodicity that could also lead to higher dispersibility and thus smaller water-stable soil aggregates. This was shown by significant correlations of high pH in organic systems with increased microaggregates ($p<0.01$), lower infiltration ($p<0.01$) and higher wet surface runoff ($p<0.1$). The proposed relationship of aggregate size with other soil properties was supported by increased exchangeable sodium and potassium data collected by FiBL after submission of my master thesis. Therefore, pH had a major influence on soil structure and its functions, whereas the expected influence of soil organic carbon on soil structure was not detected.

As shown in the second part of my thesis I could also distinguish differences in soil structural functions between organic and conventional farming: The organic topsoils showed a lower infiltration of simulated rain water ($p<0.01$) which was related to clogging of pores by smaller aggregates. Such decreased infiltration was also shown through the independent analysis of a surface runoff that was higher on organic topsoils compared to conventional ($p<0.05$). These detrimental effects of reduced infiltration and increased surface runoff pose major challenges to the sustainable management of soil fertility on Vertisols. A positive effect was, however, a faster and cheaper plowing in the organic systems than in conventional systems by 9 € ha-1 ($p<0.01$).

Conclusion and impact

The influence of soil chemical properties and preferential interaction of soil minerals with added biomass to small units led to smaller aggregates in organic systems that clogged the soil pores, halting infiltration of rainwater and raising surface runoff. The identification of such detrimental soil processes and knowledge about their relation with soil chemical properties enables foresighted soil protection by amendment through adaptation of compost management. Especially on clay-rich Vertisols, protecting and improving soil structure through sustainable management is critical to achieve higher yields and sustain soil resources by combatting soil erosion, improving crop growth and increasing water availability. Therefore, protecting the fertile soil structure has a high potential to sustain the agro-ecological base for food supply and local income of rural smallholder farmers.

In an interdisciplinary chapter I linked the soil analyses of my master thesis to the concept of economical and environmental benefits from an intact soil. Major challenges of the local population at the study location while working towards obtaining these benefits from soil were detected. Within the setup of the long-term experiment the local partner BioRe collaborates with the farming community at grass root level enabling the integration of scientific innovations into local consultancy activities to improve food security and rural livelihoods.

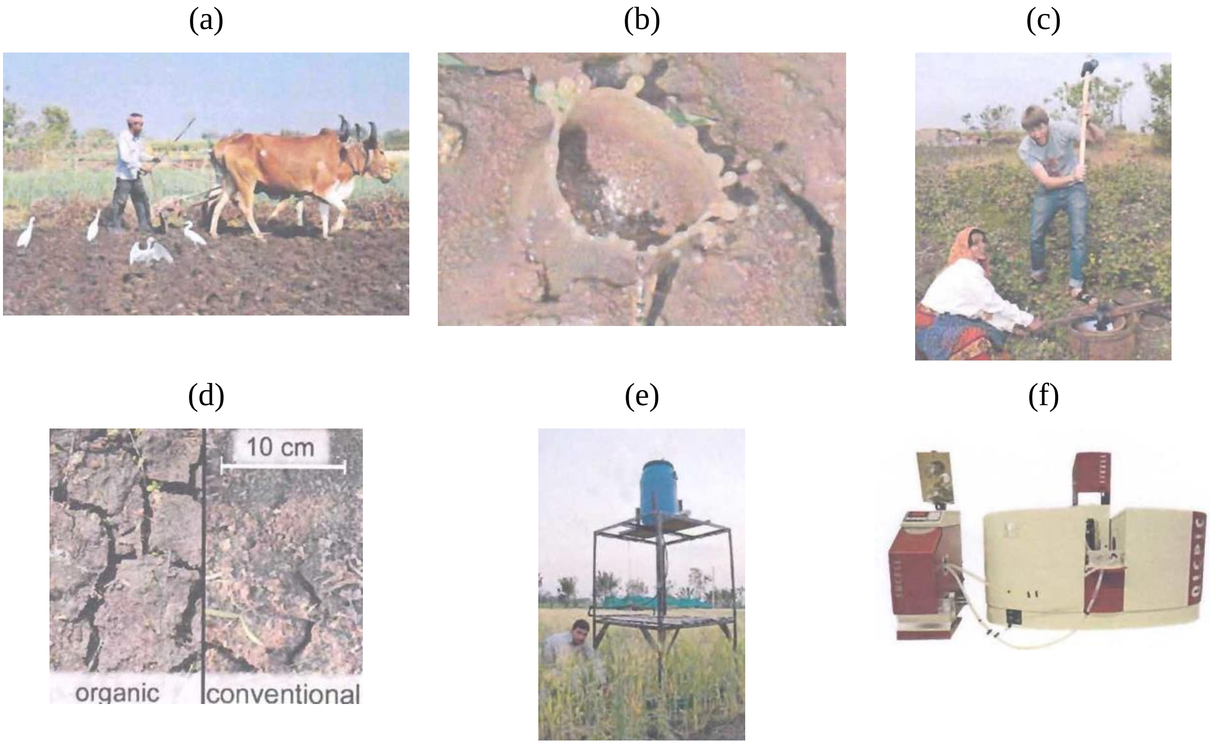

Figure: (a) traditional bullock-drawn land management on analyzed long-term experiment, (b) impact of artificial rain drops on the soil surface showing soil disaggregation, (c) installation of infiltrometers, (d) comparison of average cracks visible at the surface of organic and conventional systems, (e) rain simulator constructed out of drip irrigation by applicant, (f) QICPIC machine with disperser and sensor unit.

References

Forster, D., C. Andres, R. Verma, C. Zundel, M.M. Messmer and P. Mäder (2013): Yield and economic performance of organic and conventional cotton-based farming systems -Results from a field trial in India. PLoS ONE 8(12).

Seufert, V., N. Ramankutty and J.A. Foley (2012): Comparing the yields of organic and conventional agriculture. Nature 484(7397), 229-232.