Ecological Engineering 107 (2017) 137–143

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Various effects of land tenure on soil biochemical parameters under organic and conventional farming – Implications for soil quality restoration

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ARTICLE INFO

Article history:
Received 2 May 2017
Received in revised form 3 July 2017
Accepted 6 July 2017
Available online 18 July 2017

Keywords:
Land tenure
Agricultural management
Soil enzyme
Soil quality
Ecosystem restoration

ABSTRACT

Land tenure insecurity is one of the worldwide problems that often leads to soil degradation. We tested whether owner-operators maintain a higher level of soil quality and biochemical activity than tenant-operators and how this effect is modified by the agricultural system (organic vs. conventional) in arable fields. We selected 45 plots with cambisol soil based on a factorial design of owner-operator vs. tenant-operator and organic vs. conventional management. On all tested plots, the crop was wheat in shortly after harvest. We measured total carbon in soil and a set of 8 soil enzymes: acid phosphatase, β-glucosidase, α-glucosidase, cellobiohydrolase, β-xylosidase, chitinase, glucuronidase and arylsulfatase. These enzymes participate in the main geochemical nutrient cycles in soils.

Differences in the activity of 4 out of these 8 enzymes and differences in the weighted means of the total enzyme activity show a joint effect and indicated higher biochemical activity of the soil under conventional farming in plots farmed by owners. However, when organic farming was practiced, no obvious differences in enzymatic activity were found between soils farmed by owners or by tenants. The total carbon showed a similar pattern, although not significant. Generally, we conclude that farmer's motivation for making investments in soil health is driven by tenure security, especially in cases where the farm economy depends on profit from crop yields. However, the positive features of tenure security can also be ensured by effective agroecological standards, strict rules, higher levels of subsidies and other incentives that are typically provided for organic farming. We propose that changes in agricultural policies may not only stop land degradation in various parts of the world but also support ecosystem restoration process.

1. Introduction

Willingness to manage farmland in a sustainable manner is significantly affected by the relationship between the farmer and this natural resource, whether it is in terms of social or economical bonds (Kristensen et al., 2004; Yami and Snyder, 2015). The level of tenure security is extremely diverse throughout the world. It is affected by the political system, cultural and ethical traditions, land law and policy, enforcement of rules, community characteristics, market imperfections, competition for land, pressure on resources, and other factors (Yami and Snyder, 2015). Tenure insecurity as an immediate cause most frequently leads to five land degradation types: water and wind erosion (Sklenicka et al., 2015), a reduction in organic matter (Jacoby et al., 2002), soil compaction, and nutrient leaching/depletion (Scherr, 2000). It is highly likely that tenure insecurity can also cause other land degradation types, in particular, loss of vegetation cover, a decline in species diversity, alien plant invasion, water table drawdown, and others. In China, land tenure security and government subsidies have been recognised as a crucial factor of people's participation in forest conservation and rehabilitation projects in rural areas (Mullan et al., 2011; Rao et al., 2016; Salant and Yu, 2016) and similarly in Vietnam, the privatization of forests has significantly increased the afforestation rate (Nguyen et al., 2010). These findings suggest, that high levels of tenure security may contribute not only to land conservation but also rehabilitation of degraded areas.

This issue is most strongly accentuated in connection with developing countries, particularly in Africa, where it is most often associated with food security issues or even with the survival of poor farmers and their families (Meshesha et al., 2012). However,

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http://dx.doi.org/10.1016/j.ecoleng.2017.07.006
0925-8574/

tenure insecurity is also becoming a significant problem in countries with developed economies, where its impact is predominantly discussed in connection with the environmental impacts of agriculture. In the context of the transition countries of Central and Eastern Europe, this issue is proving to be key to defining sustainable land use and preventing farmland degradation (Swinnen, 2002), depending on the different ways of transformation from socialist agriculture in each country, including the transformation of land rights towards the conditions of market economy (Lerman, 2001).

The Czech Republic is a unique example of a country with a problematic level of tenure security and, at the same time, an extremely high level of land ownership fragmentation. On the one hand, there are almost 3.5 million landowners. On the other hand, there is an extremely concentrated system of farmland use, where this land is actually farmed by just 30 thousand users (Sklenicka et al., 2015). In consequence, approximately 78% of the land is currently farmed on the basis of lease contracts of variable lengths, and less than a quarter of the land is farmed by its owners. The reluctance of tenants to invest in the land and in the landscape has been confirmed by frequent monitoring of the quality of farmland in the Czech Republic. In the past 25 years, ongoing large-scale soil degradation has been observed. Above all, there has been a significant decrease in the natural fertility of the soil, and in the individual indicators that determine this fertility. In this case, weak tenure security may act as an immediate cause of land degradation (Sklenicka, 2016).

Soil quality or soil health, and their development in time, are primary indicators of sustainable land management (Doran and Zeiss, 2000), and they are generally largely affected by land degradation (Zhang et al., 2006; Zeithaml et al., 2009). The criteria for these indicators relate mainly to their utility in defining ecosystem processes and in integrating physical, chemical, and biological properties, their sensitivity to management and climatic variations, and their accessibility and utility to agricultural specialists, producers, conservationists, and policy makers (Doran and Parkin, 1996).

Microbial community parameters are often used as indicators of soil biological activity, since soil microbes react quickly to the actual soil conditions in the soil. In addition, the diversity of soil microbiota and the diversity of the enzymes they produce also reflect the past practices and indicate the rate of recycling of biogenic elements (Balota et al., 2014; Doran and Zeiss, 2000; Schloter et al., 2003; Das and Varma, 2010). It has often been commonly used as indicator of effect of agricultural management on soil microbial community (Bandick and Dick, 1999; García-Ruiz et al., 2008; Gianfreda et al., 1996; Pajares et al., 2011; Schloter et al., 2003) and also a measure of the mine rehabilitation success (Jamro et al., 2014; Kumar et al., 2015).

There is a large number of soil enzymes, each of which has a specific function and catalyzes a specific chemical reaction. Enzyme diversity is therefore of major importance, because the chemical transformations of substrates in the soil will only be complete when the whole set of enzymes is present. In our study we used assays for 8 enzymes that figure in 6 important biochemical pathways in soil. These enzymes are presented in Table 1.

In this study we test how the farming practices and the relationship of the farmer to the land he manages affect the activity of selected soil enzymes and the amount of SOM. We hypothesize that a farmer who owns the land he is managing will look after the soil better than farmers who are tenants, resulting in higher numbers of soil microorganisms and consequent increased activity of soil enzymes and amount of SOM. We also hypothesize that organic farming supports a higher amount of SOM and biomass of soil biota. At the same time, we hypothesize a different effect of land tenure security on organic farming systems and on conventional farming systems and we presume that the effect of land tenure is more pronounced when conventional farming systems are employed.

Table 1
An overview of analyzed enzymes, their abbreviations (Abbrev.), which macromolecule breakdown it mediates (Biochemical pathway) and substrate used for analysis, based on 4-methyluumbellyferyl molecule (Substrate).
References: Bandick and Dick, 1999; Burke and Cairney, 1997; Deng and Tabatabai, 1997; Fan et al., 2012; Ganeshamurthy and Nielsen, 1990; Klose et al., 1999; Makoi and Ndakidemi, 2008; Parham and Deng, 2000; Saiya-Cork et al., 2002

Enzyme	Abbrev.	Biochemical pathway	Substrate: 4-methylumbellyferyl-
chitinase	N	Chitin	N-acetylglucosaminide
β-glucosidase	G	Cellulose	β-D-glucopyranoside
cellobiohydrolase	C	Cellulose	N-cellobiopyranoside
acid phosphatase	P	Esters,anhydrides $-PO_4$	phosphate
α-glucosidase	αG	Starch	α-D-glucopyranoside
arylsulfatase	S	Esters– SO_4	sulphate potassium salt
β-xylosidase	X	Xylans	β-D-xylopyranoside
glucuronidase	U	Xylans	P- D-glucuronide

2. Material and methods

2.1. Data collection

We used the Land Parcel Identification System (LPIS), which registers all production blocks and their users in the Czech Republic, and the Land Register, which contains all land parcels and their owners, to select 45 production blocks of arable land (fields) and identify whether they are owned by the farmer or rented. These fields were in central and western Bohemia, at elevations ranging between 250 m and 450 m, mean annual temperature ranging between 7 °C and 9 °C, and mean precipitation between 600 mm and 700 mm. All of the fields were between 0.1 ha and 20 ha in size, on Dystric Cambisol soil type with clay loam texture and wheat as crop plant. 20 fields out of the 45 were under organic farming management, and out of these 8 were managed by a tenant and 12 by the owner. 25 fields were under conventional management, out of which 14 fields were managed by the owner and 11 by a tenant. To determine whether a block was under organic agriculture and whether it was farmed by the owner or by a tenant, we compared the data from LPIS with data from the Land Register.

For each field, we noted the type of crops and the phase in the cultivation cycle at the time of measurement. On each field we demarcated a 10 × 10 m square, 20 m from one edge of the field and at least 20 m from the other edges. Inside this square, we selected 5 sampling points, at least 2 m apart, evenly distributed in and between the rows, if rows were present (2 sampling points in the rows, 2 between the rows and 1 on the transition). At each of these points, we took a composite soil sample from the top 20 cm for soil enzyme activity analysis. The soil samples were then kept at 4 °C until the measurements were performed 12–24 h later. The sampling was done during August-September 2015.

2.2. Laboratory analyses

2.2.1. Bulk density and total soil carbon

Soil bulk density was measured using the Kopecky rings – 100 cm^3 soil probes. The lid was removed from the probes on one side and the probes with soil were weighed and then placed in an oven and dried at 100 °C for 24 h and then weighed again. Afterwards soil was tipped out and the probes were weighed without soil. The soil moisture was established at the same time gravimetrically.