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

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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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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.

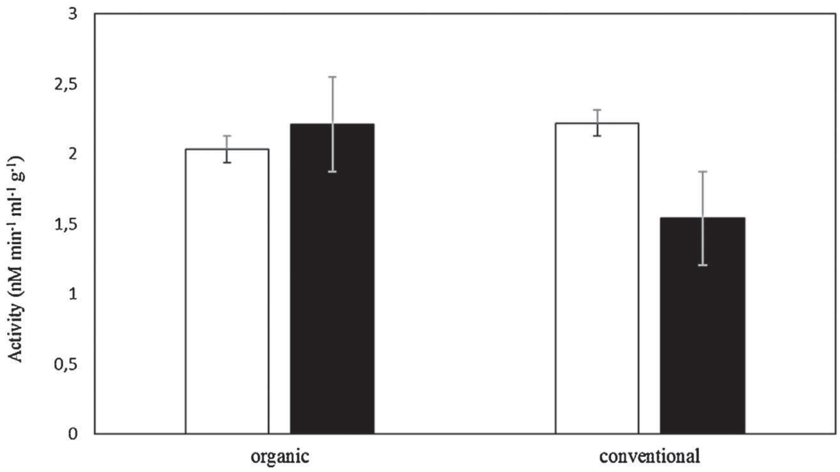

Fig. 1. Weighted means of activity of all enzymes in fields with different management and tenancy. White columns represent fields managed by owner, black columns represent field managed by tenant. Error bars denote standard errors of mean. Current effect: F (1, 41) = 3.2872, p = 0.078.

Soil organic matter (SOM) was measured as total amount of soil C by the modified Walkley-Black method (Mylavarapu, 2009) in 1 g of the oven-dried soil sample.

2.2.2. *Enzyme assays*

0.5 g of each soil sample was mixed with 50 ml of 50 mM sodium acetate buffer, pH 5.0. The solution was then homogenized using Ultraturrax IKA (Labortechnik, Germany). The activity of 8 enzymes common in soils was measured spectrophotometrically, in 3 replicates from each sample, so in total there were 3 × 5 replicates per field. We added 8 substrates (each to different wells) based on *p*-nitro-phenol, 4-methylumbelliferone, which is fluorescent in its pure form, in solution with dimethyl sulfoxide (DMSO), a cell growth inhibitor. The fluorescence of the substrate was measured after 5 min and 125 min of incubation at 40 °C, and was compared with the calibration curve of different concentrations of MUF substrate to obtain the enzyme activity of the sample. The mean value of the three replicates on each plate were counted, and these were then converted to dry weight of soil. The detailed method is described in Baldrian (2009). The substrates used for assessing individual enzyme activity are shown in Table 1.

2.3. *Statistical analyses*

The mean values obtained from 5 samples from each field were used for statistical analyses. Prior to the analyses, univariate Pearson correlations were computed among all variables to eliminate those that would correlate strongly ($r > 0.6$). However, neither of the variables could be omitted, as the r values varied between 0.09 and 0.41. The Lillefors normality test was used for assessing the normality of the data. Factorial ANOVA was used for a comparison of the effect of the two categorical factors and for the weighted means of the activity of all enzymes. Weighted means of the total enzyme activity in each field were counted by sum of particular enzyme activity divided by the mean activity of this enzyme in all fields. The Fisher posthoc test was used to compare the differences between individual combinations of factors. These analyses and the graphical presentation of the data were performed in STATISTICA 9.0 (StatSoft, Tulsa).

3. Results

The soil water content ranged between 3 and 15% of the total soil weight, the soil bulk density ranged between 1.03 and 1.1 Mg m^{-3} and was similar in all fields The total soil carbon was ranging between 1.6% of dry weight (in a conventional field managed by owner) and 4.1% (in an organic field managed by tenant)

Table 2
The mean values of all measured variables ± standard errors in the 2 management types (organic vs. conventional) and in fields managed by owner or tenant (line subject).

management	Organic		Conventional	
subject	Owner	Tenant	Owner	Tenant
variable				
P	20.79 ± 2.85	22.10 ± 3.46	18.95 ± 2.64	15.27 ± 2.97
G	11.60 ± 1.39	14.19 ± 1.7	13.46 ± 1.29	8.46 ± 1.45
aG	0.5 ± 0.1	0.76 ± 0.13	0.66 ± 0.1	0.43 ± 0.11
C	2.84 ± 0.48	3.15 ± 0.59	3.58 ± 0.45	2.05 ± 0.51
X	1.26 ± 0.21	1.52 ± 0.21	1.79 ± 0.2	1.05 ± 0.22
N	0.78 ± 0.11	1.02 ± 0.14	1.05 ± 0.1	0.55 ± 0.12
U	0.22 ± 0.07	0.34 ± 0.08	0.35 ± 0.06	0.24 ± 0.07
S	0.37 ± 0.08	0.39 ± 0.1	0.34 ± 0.07	0.28 ± 0.08
weighted means	7.92 ± 0.98	8.92 ± 1.2	8.94 ± 0.91	6.21 ± 1.02
total carbon	2.24 ± 0.18	2.36 ± 0.24	2.05 ± 0.19	2.08 ± 0.19
bulk density	1.09 ± 0.16	1.07 ± 0.11	1.04 ± 0.21	1.05 ± 0.18

All the soil parameters measured are summarized in Table 2.

The sum of the activity of all enzymes was highest for the fields under organic management performed by the tenant (42.9), followed by organic fields managed by the owner (40.4); however, due to the differences in the activity of individual enzymes, weighted means were used to compare the total enzyme activity between individual types of fields. The weighted means of the total enzyme activity was highest in fields under conventional management managed by the owner, and was lowest in conventional fields managed by the tenant, as shown in Fig. 1. The differences between individual types of fields were marginally significant – $F(1, 41) = 3.287$, $p = 0.078$. The Fisher post-hoc test showed also a marginally significant difference between conventional fields managed by the owner and by a tenant; the difference between organic fields managed by owner and tenant was not significant (Fig. 1).

The activities of enzymes had a normal distribution at a 90% level of probability, and some enzymes also had a normal distribution at a 95% level (acid phosphatase, alpha-glucosidase, glucuronidase) (Lillefors test of normality). The highest activity was measured for acid phosphatase and beta-glucosidase, with activities ranging from 5 nM/min/ml to 45 (for acid phosphatase) and from 5 nMmin^{-1}ml^{-1} to 26 nMmin^{-1}ml^{-1} (for beta-glucosidase) per gram of soil, as an average value for the sampled fields. The activity of other enzymes was below 5 nMmin^{-1}ml^{-1}g^{-1}. The lowest levels – less than 1 $nMmin^{-1}ml^{-1} g^{-1}$ – were in glucuronidase and in arylsulfatase.

The activity of acid phosphatase was 25% higher in organic fields than in conventionally farmed fields, though the result was not statistically significant. Glucuronidase activity reached similar values for organic fields managed by a tenant and for conventional fields managed by the owner (the mean values were 0.34 and 0.35, respectively). Glucuronidase activity in organic fields managed by the owner was 52% lower than in fields managed by a tenant. The opposite trend was measured for conventionally-farmed fields – the activity was lower by 43% where the farmer was a tenant. The arylsulfatase activity was 22% higher in organic fields than in conventional fields, and was 20% lower in conventionally-managed fields farmed by a tenant, but the result was not significant.

The activity of β-glucosidase, α-glucosidase, β-xylosidase and N-acetyl-glucosaminidase all followed a similar trend. The activity was lower in organic fields managed by the owner than in fields managed by a tenant, and the opposite trend was measured for conventionally farmed fields – there was lower activity where the farmer was a tenant (Fig. 2), and these results were statistically significant.

The posthoc tests showed significant differences between owner management and tenant management only for conventional agriculture. In cellobiohydrolase, the trend was also present but the result was only marginally significant ($p = 0.085$).

4. Discussion

The soil bulk density values were similar in all fields and correspond with the bulk density in Cambisols with clay loam structure from other studies (Martins et al., 2012). The total carbon content didn't show significant differences between management types or tenant x owner relationship, although there was a tendency towards higher carbon in soils with organic management. This corresponds with the fact that the fertilizers organic farmers use have a higher carbon content (Tuomisto et al., 2012). Organic carbon content of the soil has been widely used as a soil quality measurement, however, its response to actual management practice is often slower than the biochemical activity, which is closely linked to soil microorganism community (Marinari et al., 2006; Smith, 2004), therefore we believe that the activity of enzymes involved in the C-cycle may be better indicators of the current practice than the total carbon content in soil.

The fact that only the interaction of land tenure with farming system shows significant differences, and not the factors as single predictors, confirms the importance of examining this combination. The significant differences in activity in 4 (G, aG, X, N) out of 8 enzymes and the differences in the weighted means of the total enzyme activity show a joint effect, where higher biological activity in the case of conventional farming is indicated in soils managed by owner-operators, whilst in the case of organically managed soils the variability of enzymatic activity is not statistically significant for plots farmed by a tenant and by the owner. The rest of the enzymes followed a similar pattern, although the results were not statistically significant.

Because the soil biochemical activity is highly dependent on character and amount of organic matter – the substrate for reactions (Snajdr et al., 2013), the crop type and the amount of crop residue left on the field is one of the major limiting factors for soil enzyme concentration (Bending et al., 2002). For this reason, crop rotation with various types of crops will support a more diverse community of microorganisms and consequently a higher diversity and activity of enzymes (Bending et al., 2002; Dick, 1994; Miller and Dick, 1995). The study of Sklenicka et al. (2015) indicates that owner-operators tend to use a more diversified crop rotation system and are significantly more willing to adopt soil conservation measures. Our current study shows that this is reflected by the soil biochemical activity, although it does not neccessarily have a significant impact on long-term soil health indicators, such as SOM.

Intense tillage has been recognized to have a negative impact on soil organic matter and also on soil enzymes (Andrade et al., 2002; Bending et al., 2002; Deng and Tabatabai, 1997). This may be the reason why, in the fields farmed organically in our study, the soil enzyme activity was similar to or lower than in the fields under conventional management farmed by the owner. Reduced options for chemical weed elimination in organic farming are generally substituted by mechanical weed removal techniques, such as disc harrowing (García-Ruiz et al., 2008). Shortly after tillage or disc harrowing, enhanced biochemical activity of the soil and proliferation of the microbial communities occur, because the organic matter, mixed with mineral soil and exposed to air, presents an easily-available source of energy. However, it quickly becomes mineralized and prevents the organic carbon from being transformed into humic substances and being incorporated into stable soil aggregates (Andrade et al., 2002) and may have a long-term negative impact on the soil microbial community (Deng and Tabatabai, 1997; Gianfreda et al., 1996). This may be happening in some organic farms in the Czech Republic, as the subsidies from the government attract farmers that often don't have a strong relationship to the land and are motivated only by an easy income (Malá, 2011; Pechrová and Vlašicová, 2013).

The fact that tenure security didn't have effect on soil enzyme activity within organic farms is most probably caused by relatively strict agro-ecological standards and norms, which must be fulfilled in order for the farm and its products to be certified (Scialabba and Hattam, 2002) and also by government subsidies which apply to owners and tenants the same (Malá, 2011; Pechrová and Vlašicová, 2013).

Acid phosphatase had a higher activity at organic farms, which is probably related to a widespread use of leguminous plants as green manure in organic agriculture. Leguminous crops have been reported to have a positive effect on the activity of phosphatase, most probably due to higher demand of leguminous plants for phosphorus (Yadav and Tarafdar, 2001). The enzymes that figure in the carbon cycle (G, aG, C, U, N) are more closely linked to the organic matter content of soils, as the stable soil organic molecules are formed by more than 50% of carbon. Most of these enzymes had significantly higher activity in fields managed by the owner, indicating that there are larger permanent pools of organic matter in these soils than in the fields managed by a tenant. Exo-chitinase (N-acetylglucosaminidase) showed the greatest differences in activity between fields managed by the owner and by a tenant, indicating that the management performed by owner-operators supports a greater amount of fungi in soils. A higher fungi: bacteria ratio is generally reported for soils with less disturbance and with lower nutrient input (Bardgett et al., 1996), as most soil fungi are comparatively slow-growing organisms, specializing in decomposition of large organic molecules. In soils with high disturbances these organisms are easily outcompeted by more flexible and faster-growing bacteria (Lavelle and Spain, 2001). The arylsulfatase activity was very low in the sampled soils and showed differences due to tenure or management type, although it has been reported to correlate with the soil organic matter content (Deng and Tabatabai, 1997). In our study, however, this effect was probably outweighed by the extremely dry and hot climatic conditions at the time of sampling.

The generally low enzyme activity values measured during our study, in comparison with values obtained by other authors (Bending et al., 2004), can be explained by the fact that the sampling was performed at the highest aboveground biomass stage, when the soil nutrient supply is at its minimum. In addition, the

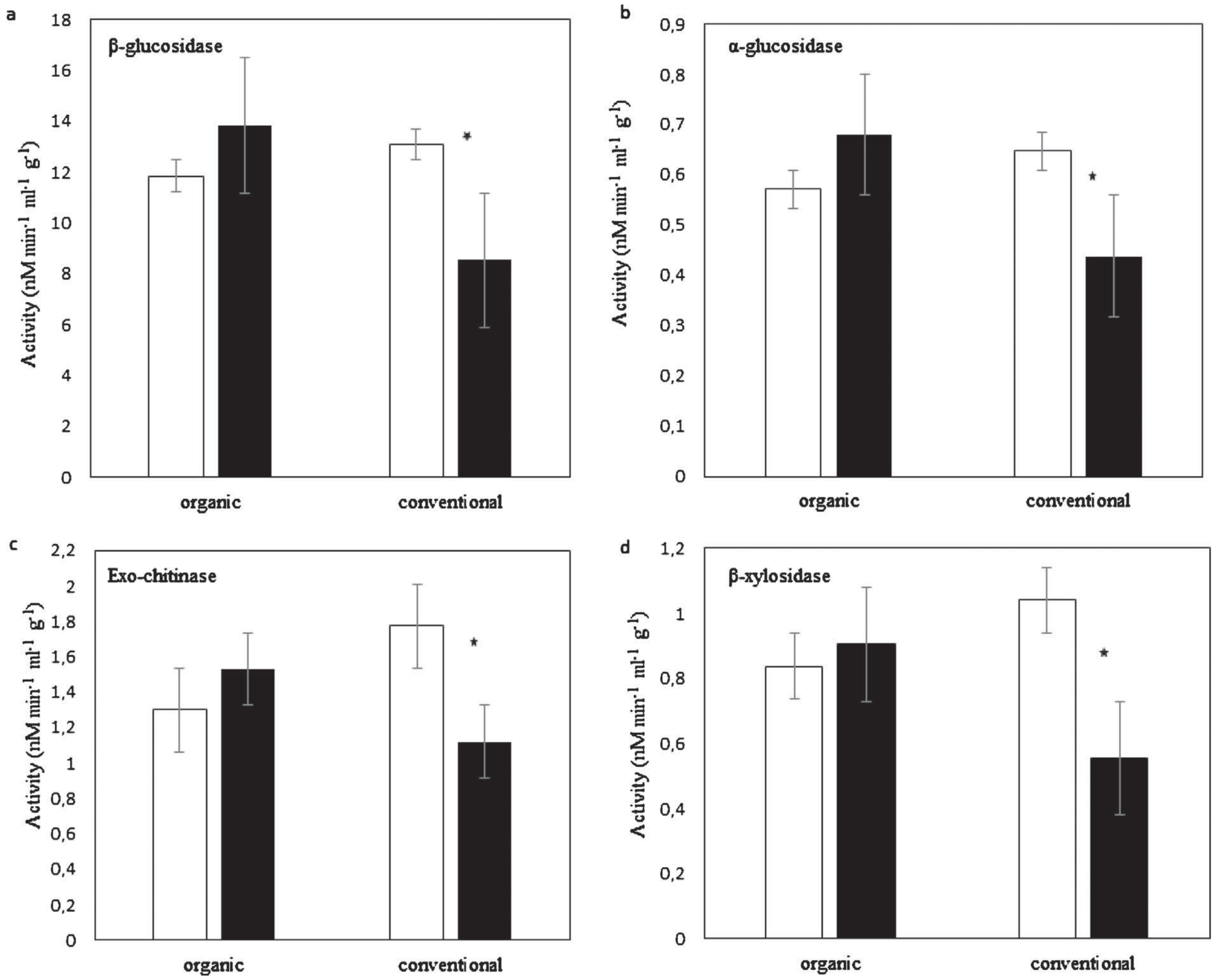

Fig. 2. Activity of 4 enzymes – β-glucosidase (a), α-glucosidase (b), *exo*-chitinase (c) and β-xylosidase (d), in relation to management and tenancy. Organic/conventional signs type of management, white columns cover fields managed by owner and black columns fields managed by tenant. The stars sign significant differences between treatments. p = 0.015; 0.03; 0.035; 0.004 respectively for enzymes: G; aG; X; N. Vertical error bars denote standard error of mean.

low moisture content of the soil presumably had a negative effect on the microbial biomass and on the consequent biochemical activity in all fields that were studied (Debosz et al., 1999; Steinweg et al., 2012). However, sampling at this time of the year enabled us to eliminate the effect of most chemical inputs, which are generally applied at the start of the vegetation season or at the enhanced growth peried.

Lumley (1997) and Walters et al. (1999) consider that the motivation of owners for long-term investments lies in the phenomenon of a "desire to own land". In traditional agricultural societies, voluntary soil conservation was the key to long-term survival (Pregill and Volkman, 1999).

However, farmers that farm on rented land do not have this security (Sklenicka et al., 2014). In the conditions of the Czech Republic, where the average period of tenancy on the fields studied here is 5 years, the farmer, under threat of termination of the contract, is driven towards a preference for investments with a short-term effect, for example, the use of mineral fertilizers rather than organic fertilizers. This insecurity also tends to lead to maximization of profits, and to a disregard for the unsustainability of approaches with a negative impact on the biological activity of the soil. Where no further incentives are offered, our results therefore confirm the findings of other authors who have studied the effect of land tenure security. The results of a study by Myyrä et al. (2007) confirm that when they feel insecure about the extension the lease farmers rapidly decrease their investments in the soil and, as a consequence, their yields decrease rapidly. Fraser (2004) showed that farmers who own their land more often than farmers who are renting the fields plant crops that improve the soil quality, namely perennials and forage legumes. Nowak and Korsching (1983) found a more pronounced negative impact of agriculture on groundwater supplies and on groundwater quality in the case of rented farmland, in comparison with land managed by the owner.

5. Conclusions

Land tenure security is an important factor that not only affects the economic behavior of the farmer, but can also have an indirect effect on the health of the soil. Lower motivation of farmers to invest in soil conservation practices is likely to result in soil degradation, followed by overall lower biological activity. The activity of soil enzymes has the potential to reflect these changes; the lower activity of most enzymes in soils managed by tenants under the conventional agricultural system indicates a decrease in nutrient recycling processes in these soils, as well as an overall decline in soil quality. The effect of land tenure was not obvious within organically managed fields. This can be interpreted as evidence that, within organic farming systems, the farmer's behavior tends to be affected by other incentives, including government subsidies. We propose that land ownership has a potential to reduce land degradation and this should be taken into account when new policies are being made. We also suggest that the policies increasing tenure security play an important role during land rehabilitation projects.

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Trends of soil degradation: Does the socio-economic status of land owners and land users matter?

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ABSTRACT

Land degradation results from natural and from socio-economic factors. However, the socio-economic factors are less adequately understood than the natural factors. In this study, we focus on the impact of the socio-economic status of land owners and land users on soil degradation trends in the Czech Republic over a period of 14–20 years. The trends were monitored using several indicators: soil porosity, cation exchange capacity (CEC), base saturation (BS), and Cu + Zn levels. We have focused on those characteristics of land owners and land users (76% of the land owners included in the study rent out their land) which can be determined without conducting labour-intensive and relatively expensive demographic surveys, therefore, can be used quite easily in subsequent evaluations, e.g. by land conservation authorities. Generally, the influence of land user characteristics has been shown to be more significant than the influence of land owner characteristics. The most significant degradation-promoting characteristics of land users are large farm size and non-family character of the farm. Degradation-promoting characteristics of land owners include older age, absence of post-secondary education, and renting out of their land. The probability of soil degradation is also marginally increased by the owner's gender (male) and by greater distance of the owner's place of residence from the plots studied here.

1. Introduction

What explains two agricultural areas with very similar natural conditions, yet in one area the soil is degrading, while in the other it is improving? While there is increasing research on land and soil conservation evidenced in recent literature (Collard-Dutilleul and Breger, 2014; Malucelli et al., 2014; Trolard et al., 2016) and in policy (European Commission, 2011; Decoville and Schneider, 2016), many of the processes leading to soil degradation are not yet fully understood. And the extent of soil degradation is influenced not only by the natural (i.e. environmental, biophysical) characteristics of a locality, but also by a number of factors that can collectively be referred to as socio-economic (Lambin et al., 2001; Boardman et al., 2003).

1.1. Land owner and land user characteristics

Research has shown the motivation of land owners and land users to promote sustainable use of their land can be affected by a number of socio-economic factors. For example, the effect of individual characteristics of land owners and land ownership on soil degradation has been examined in several studies. Petrzelka et al. (2013) found absentee landowners are less likely than resident owners to be engaged in active management, conservation practices, and decision making on their land. Sklenicka et al. (2015) found tenants (those renting from the landowner) apply erosion control measures on land they rent from absentee owners to a much lesser extent than do those farming their own land. A greater responsibility to the land by operating land owners in comparison with tenant farmers has been confirmed by other studies (e.g. Nowak and Korsching, 1983; Gillis et al., 1992; Hu, 1997; Praneetvatakul et al., 2001). This study takes place in the Czech Republic, where almost 80% of agricultural land in the Czech Republic is farmed by tenants. In this respect, the Czech and Slovak Republics have the highest level among the EU Member States (Eurostat) of alienation of land owners from their land (Sklenicka et al., 2014).

Another factor co-determining farming sustainability is land ownership fragmentation, which, in its extreme form, has been identified as

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an underlying cause of soil degradation (Sklenicka et al., 2014; Sklenicka, 2016). Other authors explain the sustainability of land owners' behaviour by socio-economic indicators such as occupation, age, income and education (Barbier, 1997; Salmon et al., 2006; Côté et al., 2015), by lifestyle indicators such as habits and personal and family values (Côté et al., 2015; Song et al., 2014), and by social norms or community knowledge (Hoffman and Todd, 2000; Taddese, 2001).

A separate group of studies has focused on the effect of the characteristics of land users on the sustainability of farming practices. Most of these studies have focused on farm characteristics, such as size or income. Tavernier and Tolomeo (2004) found that the operators of farms in lower income brackets (defined by annual sales), valued sustainable farming practices that contribute to soil conservation, such as agroforestry or crop diversification. Similarly, D'Souza and Ikerd (1996); Thompson (1986); Krojerova-Prokesova et al. (2008) and Novotný et al. (2017) have argued that the operators of smaller farms are better stewards of the environment, and use their land less intensively than farmers on a larger scale. However, Liu et al. (2007) found that smaller farm size in Kenya led to maize being grown in rainy seasons in order to maintain sufficient production for the land user's family, and this in turn led to soil degradation.

When examining various demographic characteristics, researchers suggest a tendency towards sustainable lifestyle/farming by those with a higher education (e.g. Ervin and Ervin, 1982; Skaloš et al., 2015). The authors of these studies consider the main causes behind this phenomenon to be a higher level of consciousness and personal responsibility among more educated people, resulting both from more advanced environmental education and from other influences of further education on their social responsibility and critical thinking. When examining other demographics, Sidibé (2005) found no relationship between the age or wealth of land users and their use of soil conservation practices, while Temesgen et al. (2008) noted that repeated ploughing and cross ploughing, leading to soil degradation, were more frequently practised by more experienced, thus older, farmers. Finally, Boserup (2017) has emphasized that family farms have strong motivation to protect soil in order to pass it on to the next generations in good condition.

The brief discussion above shows some studies have linked selected characteristics of land owners or land users to their preference for, or use of, sustainable farming practices. However, to the best of our knowledge, no previous studies have linked these characteristics to directly-monitored soil degradation or soil conservation trends. Our study is an attempt to start filling this critical gap in the research, with a focus on rented lands.

1.2. Soil degradation indicators

Soil degradation is defined as a change in the soil health status, resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries (FAO, 2018).

The process of soil degradation is associated with the loss of various aspects of soil quality and soil function - physical, physico-chemical, chemical and biological - which are generally closely connected to each other; a decrease in one function usually affects other characteristics of the soil (Sklenicka et al., 2004). However, the indicators respond differently to different agricultural practices and on different time scales. It is therefore important to select a number of indicators to be able to estimate the full extent of soil degradation (Walmsley and Sklenička, 2017).

Soil porosity is one important indicator of soil quality as it relates to soil structure and of the level of soil compaction. Reduced soil porosity indicates increased compaction, which can be avoided by good timing of operations (i.e. not putting heavy equipment in the field when the ground is wet) and by investing in modern farm equipment, or by remediation operations (direct drilling, subsoil ripping). Soil compaction may also be alleviated by high organic matter content (SOM; Capowiez et al., 2012; Arthur et al., 2013; Défossez et al., 2014). SOM is connected to cation exchange capacity (CEC) – the ability of the soil to bind nutrients. Loss of organic matter generally results in a decrease in negatively-charged binding sites, which will show as a decrease in CEC (Tiessen et al., 1994; MacHmuller et al., 2015). Decreasing CEC may also be related to the loss of clay particles from soils, most often caused by erosion or weathering during intensive agriculture (Jackson and Sherman, 1953; Chichester and Richardson, 1992).

Soil acidification is a second important indicator of soil quality, and a common type of soil degradation in the Czech Republic. In addition to naturally occurring acidification resulting from the leaching of alkalis from the soil by rain, several anthropogenic factors contribute to this process, including; acid rains; acid production by crops due to the use of ammonia-rich fertilizers; use of grain crops (which produce low amounts of basic cations); reduced CEC and washing-out of clay particles from the soil (resulting in reduced buffering capacity of the soil– (Rowell and Wild, 1985; Helyar and Porter, 1989; Guo et al., 2010)). One indicator of soil acidification is soil pH or base saturation (BS), which expresses how many binding sites of the soil complex are taken up by basic cations, as opposed to acidic cations (mainly H^+).

Related to soil acidification is presence of Zinc (Zn) and Copper (Cu), important micronutrients in soil. However, the concentration of these metals in soil has been increasing above levels that are useful to plants, as a result of pollution from industry, inorganic fertilizer use, sewage sludge application and the use of animal waste as a fertilizer (Cu and Zn are present in the mineral salts fed to animals (Mantovi et al., 2003; Micó et al., 2006)). Cu is also present in many pesticides (Trewavas, 2001). High concentrations of these metals may negatively affect some soil organisms and in that way have an indirect effect on soil function (Giller et al., 1998; Ciarkowska et al., 2014).

Soil porosity and acidification are affected by both long-term and short-term land management practices (ISPRA, 2018), and are amongst the soil properties that are most strongly detrimentally affected with soil degradation in Europe (Pražan and Dumbrovský, 2010). Using these soil quality indicators, we test selected characteristics of land owners and land users on soil degradation trends, expressed by changes in the indicators. We aim to determine whether it is possible to define two basic archetypes of land owners and land users, with regard to specific characteristics: (1) owners or users whose land follows a degradation trend during the observed period; and (2) owners or users whose land follows a sustainable or improving trend over the observed period.

2. Material and methods

2.1. Field sampling design and soil characteristics

Our data on soil properties and indicators was obtained from the Central Institute for Supervising and Testing in Agriculture (CISTA), part of the Monitoring of Agricultural Soils program conducted in the Czech Republic from 1993–2013. The research plot selections aimed to capture all major climatic areas that occur in the Czech Republic as well as the major soil types (Fig. 1). The plots were selected in an irregular network as unconnected sites from the whole area of the Czech Republic. The proportion of major genetic soil types was selected on the basis of a special pedological description (detailed in the Complex Soil Survey of the Czech Republic).

The monitoring plots are defined as rectangles 25 × 40 m in size, with an area of 1 000 m^2. Each plot is defined by its geographical coordinates, landscape morphology, and the nature of the soil and climate. The plots are located on parcels belonging to private persons or legal entities that manage the land in a manner characteristic of agriculture in the particular climatic area of the Czech Republic. Within these plots, 4 × 8 disturbed and undisturbed samples (for physical and chemical analyses) were taken in a randomized cross design to form 4 composite samples. Undisturbed soil samples and disturbed soil samples were collected to determine selected physical and physico-chemical and

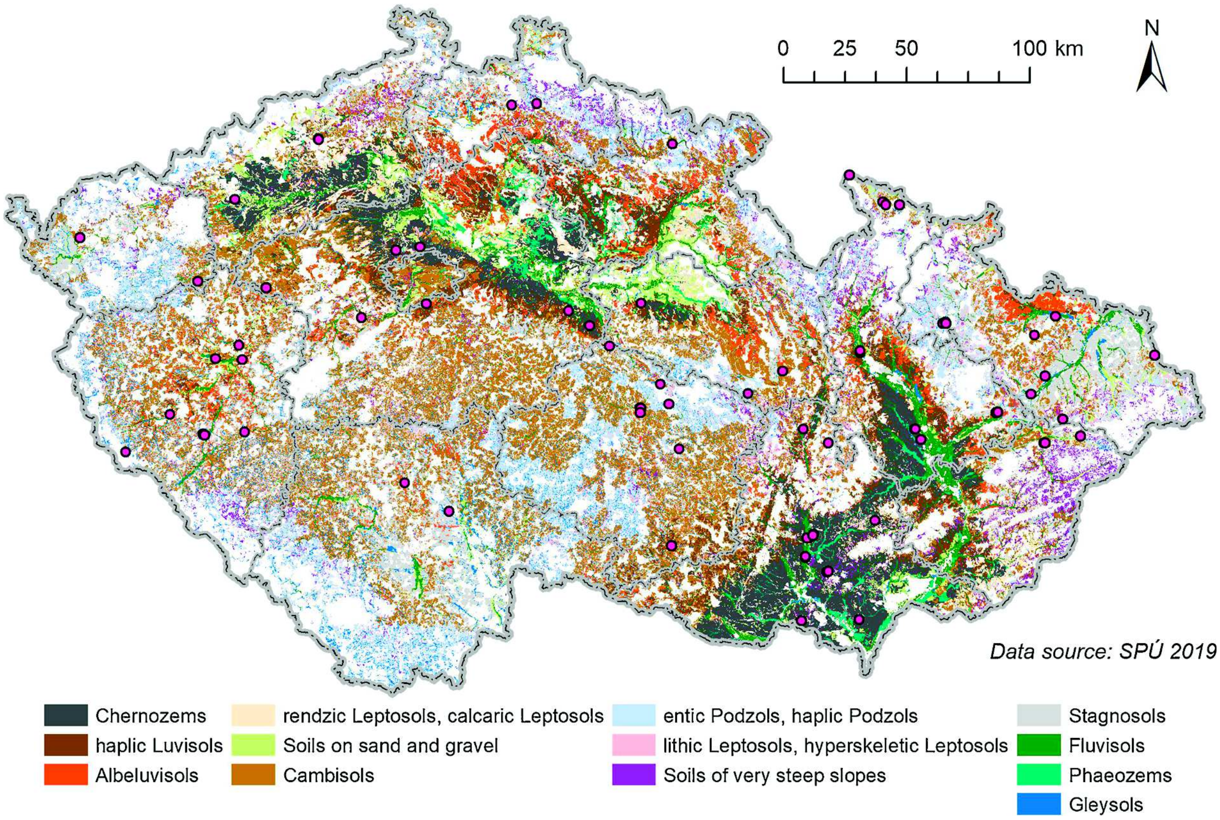

Fig. 1. Location of soil samples within the Czech Republic according to main soil types. The samples used in the study represent all 10 climatic regions. Data on soil types is provided by State Land Consolidation Office (SPU, 2019).

chemical properties of the soils. The sampling was conducted diagonally; in each case, the samples were taken from up to four different horizons located in the topsoil (up to 25 cm) and the subsoil (35–60 cm).

The initial sampling was performed in the years 1993–1999 on 59 monitoring plots. Sampling was repeated at each plot within 14–20 years from the date of initial sampling (thus in years 2010–2013). As each plot contained measurements from multiple soil horizons, our dataset contained a total of 191 start-end measurements pairs from matching plots and soil horizons.

All soil analyses were conducted in the CISTA National reference laboratory, using methods accredited according to ISO 17,025. Table 1 lists all soil indicators that entered our analyses, Table 2 presents their descriptive statistics. For each soil indicator (*P*, *CEC*, t_{CEC}, *BS*, *Zn*, *Cu*), we coded an increase in its value between the initial measurement and the repeated measurement as 1 (upward trend), and a decrease in its value as 0 (downward trend); the resulting upward-trend indicators constituted the dependent variables in the statistical analyses.

2.2. Land plot, owner and user characteristics

Our study focuses on those characteristics of land owners and land users which can be determined without conducting labour-intensive and relatively expensive demographic surveys, and therefore, be replicated quite easily by those working on soil conservation. The study uses land owner and land user data available from open sources, such as the Land Register, the Land Parcel Information System (LPIS), databases of national statistical bureaus and others.

Land plot, owner and user characteristics are all explanatory variables. Table 3 gives an overview of the variables and their measurement units.

For all 59 monitoring plots, data on the associated land use plot were obtained from the LPIS, which is a system to identify land use for a given country, utilising orthophotos to extract spatial information of each land parcel to provide an actual identification of the land cover and the management of the crops.

Our study only includes plots where the owners and users remained the same across the entire observed period. All owner and user characteristics were measured at the beginning and the end of the observed

Table 1
Soil indicators: abbreviations, units of measurement, relation to soil degradation type, and analyses used to obtain the values. The ISO numbers refer to soil analyses registered with the International Organization for Standardization.

Indicator	Unit	Abbrev.	Relation to soil degradation	Analysis
Effective cation exchange capacity	*cmol.* kg^{-1}	*CEC*	↓ of *CEC* marks lack of binding plots for nutrients; is connected with loss of SOM and clay	ISO 11260
Maximum potential CEC	*cmol.* kg^{-1}	t_{CEC}	Same as above; t_{CEC} expresses maximum CEC at the ideal pH	ISO 11260
Soil porosity	%	*P*	↓ of *P* generally means an increase in soil compaction, loss of structure	Undisturbed soil samples
Base saturation	%	*BS*	↓ of *BS* indicates soil acidification	ISO 11260
Cu content	*mg.* kg^{-1}	*Cu*	↑ of *Cu* indicates ↑ use of pesticides, animal manure or pollution from industry	ISO 11466
Zn content	*mg.* kg^{-1}	*Zn*	↑ of *Zn* content indicates ↑ use of inorganic fertilizers, animal manure or pollution from industry	ISO 11466

Table 2
Soil indicators: descriptive statistics. The unit of observation is a measurement at a specific monitoring plot and horizon; the "Increase" portion of the table relates to the dummy variables describing an upward trend of the respective soil indicator at the given plot and horizon, the "%" column indicates the proportion of plot-horizons with an upward trend.

	Initial observation (start)						Repeated observation (end)					Increase	
	n	Mean	SD	Min	Max	Skew	*n*	Mean	SD	Min	Max	*n*	%
CEC	178	151.96	85.04	17.95	503.30	0.97	179	142.88	76.22	14.00	506.00	174	0.47
t_{CEC}	178	190.35	76.87	32.50	537.50	0.74	179	175.06	76.49	29.90	629.00	174	0.33
BS	178	152.46	83.32	9.00	437.50	0.61	179	136.04	74.79	0.10	349.00	174	0.35
P	168	44.70	6.14	27.14	65.47	0.16	178	45.54	6.40	31.37	83.77	165	0.55
Cu	177	23.62	28.64	1.44	276.80	5.62	179	23.46	23.12	2.47	233.00	173	0.59
Zn	177	84.40	104.41	14.62	795.60	5.16	179	100.58	152.57	5.21	985.00	173	0.66

period. Data on land ownership were obtained from the Czech Office of Surveying, Mapping and Cadastre (COSMiC) and from the title deeds. Additionally, in response to a direct request, farmers provided information about the annual income of their farms, and the Association of Private Farming of the Czech Republic (APFCR) provided information that allows us to distinguish between family farms, (farm owned and operated by a family) and others.

For the sake of statistical analyses, the data on land plots, owner and user characteristics have all been merged into a single dataset. In cases where a land plot was associated with multiple owners (a majority case, as we had 309 owners of 59 land plots), their characteristics have been averaged to provide a single value for each plot.

2.3. Statistical analyses

We began by examining for the presence of outlying observations using the BACON algorithm (Billor et al., 2000). All cardinal variables (*plot acreage*, *number of parcel owners*, *distance from the place of residence*, *years of ownership* and *age*) were entered; and monitoring plots marked as outliers were removed from further analyses.

We then conducted logistic regression to assess the impact of land owner and land user characteristics on soil degradation, measured by the upward-trend indicators. Given the large number of explanatory variables, we ran two series of regressions, one with land owner characteristics and the other with land user characteristics among the covariates. All regressions, however, shared the same control variables; land plot characteristics (plot acreage and arable land) initial value (the starting value of the soil indicator whose trend is currently being studied as the dependent variable), and a set of dummies indicating the observation's soil horizon.

As each monitoring plot contained multiple measurements of the dependent variables (taken from different horizons), to account for pseudo-replications of the land plot, owner and user characteristics, which all had a single value per monitoring plot, we based our statistical inference on cluster-robust standard errors, with each cluster representing a monitoring plot (this procedure also makes statistical inference robust to heteroskedasticity). Finally, we obtained variance inflation factors (VIFs) to detect possible multicollinearity problems. All statistical analyses were performed in Stata 14.2 (StataCorp, TX).

3. Results

The procedure for outlier detection marked two of the 59 monitoring plots as outliers. All 8 measurements of the dependent variables taken from these plots were removed from the analysis, reducing the total number of start-end observations to 183. This number was further reduced by incomplete data. The number of non-missing values for each dependent and explanatory variable is given in Tables 2 and 4, respectively; the tables also present descriptive statistics for all variables.

In order to reduce strong positive skewness, the following covariates were logarithmically transformed in all regressions: *plot acreage*, *number of parcel owners*, *distance from place of residence*, *years of ownership*, *farm size*, and the *initial value* of the *Zn* and *Cu* soil indicators. Tables 5 and 6 present the results of logistic regressions that included land user and land owner characteristics; a combination of two sets of explanatory variables and six dependent variables yielded 12 different model specifications, each presented in a single column in the tables.

In all but one case (Table 5, last column), the omnibus test for joint significance of all variables confirmed the significance of the estimated model as a whole (the p-value in the last row in Tables 5 and 6). The McFadden R-squared values varied from 0.076 to 0.342, indicating very uneven (and overall rather low) goodness of fit. The maximum VIF across all regressions and all variables was 2.493, implying that covariate intercorrelation was not an issue.

Table 3
Land plot, owner and user characteristics: variable definitions and sources.

Variable	Description	Source
Land plot characteristics		
Plot acreage	Acreage of the land plot of the monitoring plot	LPIS
Arable land	Land use indicator (arable land vs. permanent grassland)	LPIS
Land owner characteristics		
Number of parcel owners	Number of ownership parcels within the land use plot	LPIS, COSMiC
Restrictions on property rights	Existence of other material rights to the parcel, especially mortgage, pre-emptive right, easement, etc.	COSMiC, deeds
Farming owner	Whether the plot is farmed by the owner of the studied plots within the plot – comparison of data from LPIS and COSMiC	LPIS, COSMiC
Distance from place of residence	Distance (km) of the monitoring plot from the land owner's place of residence	COSMiC
Years of ownership	Length of ownership or co-ownership of the studied plot within the plot	COSMiC, deeds
Owner = legal entity	Dummy variable distinguishing legal and natural persons	COSMiC
Female	Dummy for gender (natural persons only)	COSMiC
Age	Age in years (natural persons only)	COSMiC
Post-secondary education	Dummy variable for owners with post-secondary education (natural persons only)	COSMiC
Land user characteristics		
Farm size	Total acreage of the farm operating on the monitoring plot	LPIS
Family farm	Dummy variable indicating family farms	APFCR
Sales 300k + EUR	Dummy variable indicating farms with sales above EUR 300,000	Farmers' responses

Table 4
Land plot, owner and user characteristics: descriptive statistics. For plots with multiple owners, owner characteristics have been averaged to produce a single value per plot.

	n	Mean	SD	Min	Max	Skew
Land plot characteristics						
Plot acreage	57	23.59	24.48	1.31	100.60	1.52
Arable land	57	0.70	0.46	0	1	−0.88
Land owner characteristics						
Number of parcel owners	57	1.70	1.06	1	6.09	2.18
Restrictions on property rights	57	0.23	0.31	0	1	1.15
Farming owner	57	0.10	0.22	0	1	2.84
Distance from place of residence	57	33.99	42.35	0.19	191.91	1.76
Years of ownership	57	13.61	7.48	1	40.50	1.04
Owner = legal entity	57	0.31	0.34	0	1	0.85
Female	50	0.41	0.32	0	1	0.06
Age	50	60.06	8.61	40	80	−0.15
Post-secondary education	50	0.26	0.31	0	1	1.07
Land user characteristics						
Farm size	57	637.86	492.83	98	2416	1.65
Family farm	57	0.30	0.46	0	1	0.88
Sales 300k + EUR	57	0.58	0.50	0	1	−0.32

Out of the set of control variables present in all 12 models, the *initial value* stood out as a variable that was almost always significant (with the exception of the models explaining *Zn*) and had a consistent effect across all models. This effect is of little interest, however, as it only confirms the rather obvious idea that the probability of further growth diminishes as the value of a soil indicator increases. The plot characteristics (*plot acreage*, *arable land*) are insignificant in the results. The horizon dummies were significant only in the models for *Cu* and *Zn*, suggesting the adverse effects of pesticides and industrial pollution are stronger in the upper layers of the soil.

The statistical significance of the land user and land owner characteristics fell short of our expectations. Largely significant and consistent results have been found only for the *farm size* variable, and to a lesser extent for *post-secondary education* and *age* of the owner. For other variables, some significant effects have also been found, but only in isolated models, reducing the credibility of the findings and making them difficult to generalize. We discuss these results in detail below.

4. Discussion

The original aim of this study was to establish archetypes of land owners and land users on the basis of whether their land tends to be degraded or to be farmed sustainably. While our findings are inconclusive to some degree, we discuss those characteristics that have been confirmed as significant.

The results have confirmed that the influence of land users and their basic characteristics is more significant than the influence of land owners. This finding is not surprising, given the previous discussion regarding the high amount of agricultural land in the Czech Republic that is farmed by tenants. In our experience, there are two instruments that can particularly help non-farming land owners to prevent degradation of their land.

The first instrument is careful choice of the land tenant. The owner should not select the tenant solely on the basis of the highest rent offer, but should also responsibly consider the sustainability of the tenant's farming methods, verified by references commenting on the tenant's previous activities on other plots. This instrument places relatively high demands on the awareness and the involvement of the land owner, in hopes they prefer tenants who farm responsibly, even at the cost of lower income from land rentals. However, in the Czech Republic, practice clearly shows that land owners almost always prefer higher rents, regardless of the sustainability of the tenants' management practices. Land owners tend to choose short-term gains, even at the risk of long-term losses.

The second indirect instrument to deter degradation of soil is continuous control of the tenant's farming methods on soil quality. This control must be secured by a tenancy agreement, such as written into the lease, that specifies enforceable remediation or compensation for any soil degradation, or termination of the contract on the grounds of unsustainable management practices or direct damage to the owner's property.

These two instruments are aimed at compensating for the tenant's lack of personal interest in and motivation for maintaining soil quality – a phenomenon that is frequently observed. It is in the tenant's interest to maximize his or her profits within the timespan of the tenancy agreement. By contrast, the land owner's interest is in maintaining or improving the soil quality in the long term (Bechmann et al., 2008). The owner's motivation, unlike the tenant's, lies not only in the instantaneous yield of the land, but also in maintaining and increasing the value of the land for the benefit of his successors, or in order to gain a better price when the land is sold (McConnell, 1983).

The desire to maintain or increase the value of the land is a key driver of sustainable land use by owner-operators as they want to pass the soil on to the heirs in unchanged or improved condition (Boserup,

Table 5
Land user characteristics as potential predictors of an upward trend in selected soil characteristics (results of logistic regressions).

Soil indicator:	*CEC*	t_{CEC}	*BS*	*P*	*Cu*	*Zn*
Farm size, logged	−3.157** (1.102)	−2.155** (0.794)	−2.051** (0.795)	−1.109 (1.258)	1.266 (0.979)	1.439 (0.925)
Family farm	0.801* (0.377)	−0.112 (0.353)	0.0265 (0.380)	−0.0257 (0.589)	−0.0347 (0.554)	0.958 (0.583)
Sales 300k + EUR	0.0360 (0.507)	0.175 (0.406)	0.384 (0.451)	−0.343 (0.672)	−0.764 (0.616)	−0.279 (0.588)
Plot acreage, logged	0.375 (0.357)	0.690 (0.374)	−0.00371 (0.348)	0.0457 (0.365)	0.665 (0.426)	0.469 (0.398)
Arable land	0.123 (0.406)	−0.000833 (0.353)	0.195 (0.350)	−0.590 (0.574)	−0.0374 (0.507)	0.190 (0.426)
Initial value	−1.044*** (0.264)	−0.629** (0.219)	−0.656** (0.208)	−2.410*** (0.486)	−0.583* (0.247)	−0.0533 (0.439)
Horizon 2	−0.194 (0.503)	0.956* (0.482)	−0.00982 (0.442)	−0.917 (0.469)	−0.699 (0.386)	0.213 (0.435)
Horizon 3	0.491 (0.545)	0.889 (0.560)	0.330 (0.474)	−0.812 (0.469)	−0.736 (0.417)	−0.410 (0.421)
Horizon 4	−0.385 (0.590)	0.947 (0.638)	0.245 (0.550)	−0.142 (0.666)	−1.404** (0.487)	−1.205* (0.529)
Observations	174	174	174	165	173	173
McFadden's R^2	0.254	0.131	0.091	0.249	0.076	0.077
AIC_c	200.7	213.9	226.3	191.8	237.9	226.3
Maximum VIF	2.409	2.406	2.407	2.314	2.493	2.423
Mean VIF	1.478	1.482	1.480	1.484	1.483	1.472
p(land user char.)	< 0.001	0.021	0.027	0.166	0.570	0.237
p(land plot char.)	0.505	0.160	0.848	0.572	0.224	0.436
p(horizon dummies)	0.358	0.236	0.860	0.136	0.032	0.015
p(all variables)	< 0.001	0.002	0.001	< 0.001	0.017	0.067

Notes: (i) Standard errors, in parentheses, are made robust to clustering at the level of individual monitoring plots. (ii) * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. (iii) The last four rows show p-values of Wald tests for joint significance of the indicated variables.

Table 6
Land owner characteristics as potential predictors of an upward trend in selected soil characteristics (results of logistic regressions).

Soil indicator:	*CEC*	t_{CEC}	*BS*	*P*	*Cu*	*Zn*
Number of parcel owners, logged	2.139 (1.214)	−1.908 (1.238)	−2.105 (1.208)	0.123 (1.617)	−2.122 (1.402)	2.132 (1.939)
Restrictions on property rights	1.297 (0.954)	−0.617 (1.193)	−0.684 (0.760)	0.474 (0.958)	−2.851** (0.901)	−0.445 (1.079)
Farming owner	4.134*** (1.136)	1.992 (1.380)	2.525 (1.329)	−1.855 (1.914)	−1.802 (1.734)	0.589 (1.657)
Distance from place of residence, logged	0.194 (0.356)	0.201 (0.305)	−0.0727 (0.314)	−0.670 (0.494)	0.430 (0.516)	1.084* (0.470)
Years of ownership, logged	−0.896 (0.670)	−0.137 (0.652)	−0.830 (0.754)	−0.226 (0.816)	−0.986 (0.874)	−0.276 (0.896)
Owner = legal entity	−0.302 (1.087)	−1.554 (1.223)	−0.866 (0.789)	1.299 (1.302)	3.407* (1.406)	1.437 (1.423)
Female	−0.0440 (0.615)	1.627* (0.687)	0.123 (0.636)	−0.825 (0.899)	1.598 (0.891)	0.113 (0.923)
Age / 25	0.479 (0.600)	0.186 (0.652)	−0.530 (0.494)	−1.704* (0.738)	2.047** (0.723)	1.507* (0.650)
Post-secondary education	1.749 (0.909)	0.446 (0.842)	0.467 (0.543)	3.111* (1.210)	−0.365 (1.031)	−1.922* (0.823)
Plot acreage, logged	0.586 (0.464)	0.867 (0.449)	0.114 (0.398)	0.348 (0.475)	0.914 (0.501)	0.248 (0.587)
Arable land	0.00293 (0.472)	0.153 (0.534)	0.611 (0.469)	−0.821 (0.687)	0.792 (0.579)	0.410 (0.622)
Initial value	−0.843*** (0.235)	−0.660* (0.268)	−0.601* (0.245)	−2.696*** (0.449)	−1.344*** (0.341)	−0.559 (0.535)
Horizon 2	−0.117 (0.490)	1.226* (0.496)	0.213 (0.484)	−0.994 (0.563)	−1.158* (0.541)	0.292 (0.482)
Horizon 3	0.750 (0.506)	0.985 (0.608)	0.604 (0.512)	−0.552 (0.591)	−1.013 (0.616)	−0.319 (0.483)
Horizon 4	−0.334 (0.677)	1.242 (0.732)	0.621 (0.654)	−0.117 (0.884)	−2.015** (0.707)	−1.755** (0.624)
Observations	152	152	152	146	151	151
McFadden's R^2	0.177	0.150	0.116	0.342	0.260	0.158
AIC_c	207.7	200.9	208.6	168.7	187.4	200.8
Maximum VIF	1.767	1.774	1.768	1.781	1.859	1.902
Mean VIF	1.449	1.455	1.450	1.418	1.489	1.504
p(demographic char.)	0.135	0.120	0.663	0.007	0.004	0.010
p(other owner char.)	0.001	0.393	0.099	0.752	0.017	0.113
p(plot char.)	0.356	0.120	0.229	0.436	0.039	0.455
p(horizon dummies)	0.136	0.100	0.604	0.316	0.029	0.004
p(all variables)	<0.001	0.001	0.019	<0.001	0.001	<0.001

Notes: (i) Standard errors, in parentheses, are made robust to clustering at the level of individual monitoring plots. (ii) * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. (iii) The last four rows show the p-values of Wald tests for joint significance of the indicated variables.

2017). However, it is also possible to promote some sustainable land management practices relatively effectively on rented land by implementing well-adjusted agro-environmental standards for the payment of subsidies to users (Sklenicka et al., 2015). Nevertheless, only owner-operators have control over the entire range of options for affecting soil quality, positively or negatively, and can motivate the tenants to make long-term investments in soil conservation by increasing their tenure security (Gebremedhin and Swinton, 2003).

4.1. Impact of land user characteristics on soil degradation

User characteristics are significant in the indicator models of *CEC*, t_{CEC} and *BS*. Two of the three predictors of the influence of land users on soil degradation were significant in at least one of the tested models. The most significant predictor of the influence of land users on land degradation was farm size, significant for three indicators of land degradation (*CEC*, t_{CEC} and *BS*). In all three cases, degradation trends are more likely to appear if the land is farmed by large-scale users (users with a larger overall farmed area). Conversely, land farmed by smaller users is more likely to be farmed sustainably, i.e. maintaining or improving the soil quality. The same trend was also estimated for the remaining three dependent variables, although not confirmed as statistically significant.

The impact of farm size on the sustainability of land management should be seen rather as an indirect expression of several underlying land user characteristics (Tavernier and Tolomeo, 2004; Skaloš et al., 2017). On the one hand, large farms operate far more often on rented land while, on the other hand, these farms far more often have the character of joint-stock companies, limited companies, or cooperatives, i.e. legal entities which intrinsically reduce the motivation for soil conservation, as the majority of the companies' employees lack the connection to the land that would arise from ownership. This statement is supported by studies which have found significantly more frequent degradation of soils farmed by large agricultural holdings than in the case of smaller farms (e.g. D'Souza and Ikerd, 1996; Sklenička, 2002; Morgan, 2005). However, other studies have pointed to the greater effectiveness of soil conservation measures in the case of larger farms (e.g. Ervin and Ervin, 1982; Moudrý and Šímová, 2013). We believe that these differences are caused mainly by differences in the definition of "large farms" in individual studies. While in our study this term is used to categorize farms ranging in size from hundreds to thousands of hectares, in other studies farms of tens of hectares are categorized as large. These contradictory results are also surely influenced by tenure status, i.e. large farmers operate on their own land or on rented land. Most large agricultural holdings moreover belong to land users who do not reside in the municipality where the land is located.

Whether the plot is farmed within the framework of a family farm is only significant in the *CEC* model. According to the results of this model, family farms are more likely to foster sustainable trends, whereas non-family tenant farms are more susceptible to soil degradation. The motivation for family farms to be operated sustainably is straightforward and obvious, given by the need or the tradition to pass the soil on to the heirs in unchanged or improved condition (Boserup, 2017). Reasons why family farm operators are more motivated to invest in soil conservation include a higher level of land tenure security (Soule et al., 2000; Fraser, 2004), a greater probability that these farmers have received a relevant education and have benefitted from the transfer of professional skills from generation to generation, as well as the fact that these farmers usually live in the immediate vicinity of their land (resident owners) and are more likely to be engaged in active management of their land. Finally, the characteristics describing the tenants' level of income were not confirmed as a significant characteristic in any model.

4.2. Impact of land owner characteristics on soil degradation

Land owner characteristics are significant overall in models for indicators *P, Cu* and *Zn*. Six of the nine predictors of the influence of land owners on soil degradation were significant in at least one of the tested models. The most frequent significant predictors of soil degradation were the age and the education of the owner. These characteristics have been confirmed as significant for three indicators of soil degradation (*P, Cu* and *Zn*). All three indicators show a trend of soil degradation in the case of older land owners and land owners without post-secondary education. One possible explanation for our findings is that there has been greater emphasis on environmental education in recent years, while older generations were raised and educated in times when production was accentuated at the expense of sustainability. Our results are also confirmed by the finding of work in the Great Lakes Region of the US when older farmers indicate they are near retirement, thus, unwilling to change their practices to more updated conservation practices.

The remaining three characteristics, tenure, gender, and residence, have been confirmed as significant predictors of soil degradation in only one of the tested models. Tenure status was highly significant in the *CEC* model, where plots farmed by tenants were more susceptible to soil degradation than plots farmed by the owners themselves. The greater responsibility shown by operating land owners in comparison with tenant farmers has also been confirmed by other studies (e.g. Nowak and Korsching, 1983; Gillis et al., 1992; Hu, 1997; Praneetvatakul et al., 2001).

The last two characteristics (gender and distance of the plot from the owner's place of residence) were found to be less significant. The results of our study indicate that women tend to be more responsible land owners than men. It has been suggested that for women land means survival, while for men it signifies power (Deere and León de Leal, 2001). In the case of distance from the place of residence, we have confirmed the negative role of absentee landowners, as discussed by Petrzelka et al. (2013). The characteristics of land owners which describe the size of their holding, length of land ownership, restrictions on ownership rights, and whether the owner is a legal entity were not significant in any of the models tested.

5. Conclusions

The study presented here analyzed trends over 14–22 years for possible indicators of soil degradation. Degradation/sustainable trends have been detected on the basis of differences in the values of indicators between the beginning and the end of the reference period.

The influence of land user characteristics has been confirmed as more significant than the influence of the land owner characteristics. Land users with large farms, and with non-family type farms, are especially prone to have higher soil degradation. Older land owners without post-secondary education and who rent out their land are also particularly likely to impact soil degradation in a detrimental manner. The trend of soil degradation is also marginally increased by male gender of the owner and by greater distance of the land owner's place of residence from the land.

We are aware that our findings cannot be generalized, even in the European context, far less so for countries in other continents with fundamentally different historic, political and socio-economic conditions. However, there is minimal published research which links these individual and farm characteristics to directly-monitored soil degradation or soil conservation trends. Our study begins to address filling this gap in the research. In addition, the approach used here is valuable in its ability to define real trends, not just the immediate values of the selected indicators.

More research on the causes or conditions underlying farmland degradation is crucial in order to formulate general principles for the sustainable use of farm land. Recognition of the influence of the characteristics of land owners and land users that are available from open sources can help to identify plots or entire areas that are at increased risk of soil degradation. Detailed research on the role of the profile of land owners and land users, or of the individual characteristics of these actors, can contribute to the design of measures that will begin to effectively address the socio-economic causes of soil degradation.

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Owner or tenant: Who adopts better soil conservation practices?

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ABSTRACT

Land tenure security is widely considered to be a fundamental factor in motivating farmers to adopt sustainable land management practices. This study aims to establish whether it is true that owner-operators adopt more effective soil conservation measures than tenant-operators, and whether well-designed agro-environmental instruments can provide sufficiently strong motivation to compensate for the differences between these two groups.

An analysis of the level of adoption of four types of erosion control measures on 263 blocks of arable land endangered by water erosion in the Czech Republic has proved that all measures were adopted by owners significantly more frequently than by tenants. Compared to tenants, owners applied wide-row crops in crop rotation schemes 2.4 times less frequently in the last 5 years, while they applied soil-improving crops 1.9 times more frequently. Contour farming was adopted 1.8 times more often by owners, and the slope length in production blocks farmed by owners was on an average 2.4 times shorter than in blocks farmed by tenants. However, the study has also shown that, in cases where conservation measures are supported by incentives based on Good Agricultural and Environmental Conditions (GAEC) standards cross compliance, the differences in the approach to soil conservation between owners and tenants were minimized or eliminated, due to the adoption of responsible practices by tenants. The study has proved that a well-designed system of environmentally determined subsidies can compensate otherwise substantial differences in the attitude of owners and tenants towards soil conservation.

1. Introduction

The well-known saying "No one washes a rented car", attributed to several different authors, encapsulates the basic idea investigated in this study. As long as there are countries where farmland is operated mostly by tenants (e.g. 11 of the 28 EU countries), it is important to ask whether the tenants take responsible care of this natural resource. In the spirit of the above saying, a negative answer can be presumed. However, this answer needs to be verified on the basis of real data. We should know whether differences do exist between owners' and tenants' farming practices, and, if so, how significant these differences are. We should also know how farmers' decisions are affected by motivational tools, such as the European GAEC cross-compliance standards, which support sustainable management practices on farmland. Are well designed subsidy policies able to compensate the differences between owners and tenants?

Soil erosion as a physical process has been consistently studied for the last two centuries (Dotterweich, 2013) by scientists from backgrounds as diverse as geography, agronomy and engineering (Boardman et al., 2003). However, the causes of this physical process are firmly rooted in the socio-economic, political and cultural environment in which the land users operate (Stocking and Murnaghan, 2001), which is a fact not taken into account in the majority of soil erosion studies (Boardman, 2006).

Farmers' decisions to employ practices leading to soil conservation, rather than to soil degradation, can be divided into three categories according to their motivation: farmers' voluntary decisions based on their values, decisions motivated by economic incentives, and decisions determined by legal restrictions. In traditional agricultural societies, voluntary soil conservation was the key to long-term survival, and episodes of increased soil degradation generally marked a significant setback to the human population (e.g. Pregill and Volkman, 1999). In some parts of the world, such as the Mediterranean uplands (McNeill, 2002), this effect was less

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pronounced as the soils are degraded more slowly. In other places, notably the tropics, soil degradation tends to be much faster, leading to an immediate and dramatic effect on agricultural yields. Therefore, unless sustainable alternatives were found, the populations quickly ceased to grow (Henley, 2008). In the Central European region, farming within traditional small-scale field patterns (Sklenicka et al., 2009; Skaloš et al., 2012) was relatively effective in soil conservation (Kovář et al., 2011).

In the present day, a number of methods are available to increase short-term agricultural production, regardless of possible long-term effects on the soil quality. The decision to employ soil conserving practices, at the expense of immediate financial gain, is therefore a complex one, influenced by a number of factors. Some authors (e.g. Löw and Míchal, 2003) argue that "ties to the land" are critical in the farmer's decision to protect the soil, and that land which has been owned and farmed by a family for several generations is much more likely to receive long-term erosion control measures. Similarly, Stocking and Murnaghan (2001) note that security of land tenure affects farmers' decisions in a similar way, and Hardin (1968) discusses the "tragedy of the commons", pointing out that common property resources are the most vulnerable to degradation. Ervin (1982) has also demonstrated better use of soil conservation practices by owner operators than by tenants. On the other hand, Boardman et al. (2003) state that in the developed world, there is no evidence that owners conserve soil better than tenants. They hypothesize that this could be due to the high level of land tenure security for tenants.

Stocking and Murnaghan (2001) also emphasize the role of the location of impacts of soil conservation measures. Practices which incur benefits or eliminate costs on-site (on the farmer's land) are much more likely to be employed voluntarily than those with an impact that occurs off-site (McConnell, 1983). For example, silting of rivers and water bodies, and also mud floods, are perceived as a cost to society, not to the individual farmer (Schuler et al., 2006), and are therefore less likely to be mitigated voluntarily by farmers.

Off-site impacts are therefore often the primary concern of prevention and mitigation measures employed by governments and conservation agencies (Evans, 2002; Fullen et al., 2006; Kutter et al., 2011). These include (1) mandatory measures, which regulate environmental damage using reinforcement mechanisms such as fines or withdrawal of farming subsidies; (2) voluntary incentive-based measures, which provide financial incentives to provide environmental benefits beyond the level established by mandatory measures; and (3) awareness-raising measures, aiming to educate land users in best management practices (Kutter et al., 2011). Frequently, a combination of these approaches is used to achieve optimal results (Anderson and Thampapillai, 1990). It also needs to be noted that schemes which are formally based on incentives can in some cases have restrictive aspects. For example, 40% of farmers who participated in the first stage of the Sloping Land Conversion Program in China felt that their participation was imposed on them by the authorities (Wang and Maclaren, 2012).

In the EU, incentive-based measures have a long tradition, and overviews by Boardman et al. (2003) and Fullen et al. (2006) report mostly measures of this type. Boardman et al. (2003) state that farmers in the developed world are predominantly influenced by economic incentives, and Myers and Kent (1998) note that the extent of this influence has in some cases contributed to environmental degradation.

Voluntary incentive-based measures often form parts of regional development policies. These policies have formed a basis for many cases of conservation success in Europe, including a substantial reduction in soil erosion due to a change from autumn to spring ploughing in Norway (Lundekvam et al., 2003), mitigation of harmful sheep grazing practices in Iceland (Arnalds and Barkarson, 2003), and greater farmer involvement in soil conservation schemes in Belgium (Verstraeten et al., 2003) and the Netherlands (Spaan et al., 2010). In recent years, a large proportion of soil conservation incentives have been paid within the EU Agri-environmental programmes and as Natural Handicap payments to farmers in less favoured areas (Kutter et al., 2011). Although the acceptance of these programmes is often ambiguous (Macilwain, 2004), measures facilitated by the incentives have already contributed significantly to soil conservation in the EU (e.g. Van Rompaey et al., 2001; Schuler and Sattler, 2010).

Mandatory soil conservation measures have traditionally been embodied in the legal systems of the individual EU countries, and there was a high level of spatio-temporal variability in the 20th century. For example, while Western European countries such as Germany, the United Kingdom and Denmark have fewer but more stable mandatory soil conservation regulations (Boardman and Poesen, 2006), post-communist countries such as the Czech Republic, the Slovak Republic and Hungary experienced a rapid change from heavily regulated to almost unregulated land management in the 1990s (Dostál et al., 2006; Cebecauer and Hofierka, 2008). While the mandatory measures implemented under communist regimes were production-oriented rather than conservation-oriented, and had many negative impacts on soils and on the landscape, rapid deregulation without adequate replacement also contributed to soil degradation in many places (Janeček et al., 2002).

In 2005, the EU Common Agricultural Policy was supplemented by mandatory cross-compliance standards to prevent negative environmental impacts of agriculture. The issue of water soil erosion is addressed mainly by the Good Agricultural and Environmental Conditions standards GAEC 1 and GAEC 2, applied to agricultural parcels listed in the Land Parcel Identification System as arable land. The following summary lists the conditions of GAEC 1 and GAEC 2 valid in the Czech Republic and relevant for the purposes of this study.

GAEC 1 defines soil conservation measures on arable parcels with a slope greater than 7°. Applicants for farming subsidies on this type of land are required to sow a subsequent crop after harvest or to apply one of the following measures: (1) The stubble of the harvested crop is left on the block of land or part thereof at least until November 30th, unless this is contrary to GAEC 2 requirements on plots strongly endangered by erosion. (2) The land remains ploughed or tilled for the purposes of water absorption at least until November 30th, unless this is contrary to GAEC 2 requirements on plots strongly endangered by erosion. These measures are minimum requirements leading to a reduction in soil erosion and runoff, as well as to a decreased risk of flooding and related damage.

The main aims of GAEC 2 are to protect soil against water erosion and to reduce both direct impacts of erosion and indirect impacts caused by flooding and muddy floods. The GAEC 2 standard addressing the issue of erosion on strongly endangered soils was accepted on January 1st 2010, and since July 1st 2011 the standard has been extended to slightly endangered soils. The issue of soil erosion is addressed by regulating the crop species grown on vulnerable land and the agrotechnology that may be used.

Applicants for farming subsidies (direct payments within Pillar 1) on land classified as strongly endangered by erosion are required through cross-compliance not to grow wide-row crops on this land, i.e. maize, potatoes, beetroot, broad beans, soy, sunflower and sorghum. Cereals and rape seed crops are to be planted using soil protective technologies. For cereal crops, these measures are not required where the crop is sown into protective clover or grass-clover undersow. On slightly endangered soils, the applicant is required to grow wide-row crops only with soil protective technologies. These conditions do not need to be met where the area of endangered soil is less than 0.40 ha, provided that the wide-row crops rows are oriented along contour lines, with maximum divergence of 30°, and that below the endangered area there is an adjacent belt of agricultural land at least 24 m in width, which interrupts all drain lines intersecting the endangered area with wide-row crops. On this belt, the applicant is required to establish grassland, perennial fodder crops or other crops with the exception of wide-row crops.

The goal of this study is to answer two fundamental questions: (1) Do land-owning farmers treat their own property more responsibly than tenant farmers? (2) Do agri-environmental instruments that support sustainable farming practices (in our case, GAEC) provide sufficiently strong motivation to compensate any differences between owners and tenants?

2. Material and methods

2.1. Data collection

The basic spatial unit, to which all variables are related, is a production block registered in the Land Parcel Identification System (LPIS). The 263 production blocks used in this study were chosen by stratified random selection within the Czech Republic. The selection includes only blocks which are endangered by water erosion and are in the Slightly Endangered or Strongly Endangered categories, according to the GAEC typology. The primary classification into these categories within LPIS was performed using the USLE method with modified *C* and *P* factors (Wischmeier and Smith, 1978) by the Research Institute for Soil and Water Conservation in Prague for the Ministry of Agriculture. The stratification of random selection consisted of applying predetermined criteria to provide equal representation for each of the country's 13 administrative units (the Prague Capital Region is excluded from our study, as the proportion of farmland in this region is negligible), for both types of land users (owners and tenants), for various size categories of farms, and also for the five growing regions that occur in the Czech Republic, based mainly on climatic and soil conditions.

In order to avoid data sets of spatially correlated data, the minimum distance between two nearest blocks was set to 5 km. This also guarantees that no more than 1 block is situated in any municipality. Other types of erosion risks are not considered in this study, as they are only a marginal cause of land degradation in the Czech Republic.

The explained variables indicate four ways in which a farmer can affect erosion control of arable soil (Table 1). Two of these variables reflect the inclusion or exclusion of crops relevant for soil erosion in crop rotation within a 5-year period, i.e. on the one hand wide-row crops (WIDEROW) that increase soil loss, including maize (*Zea mays*), potatoes (*Solanum tuberosum*), beetroot (*Beta vulgaris*) and sunflower (*Helianthus annuus*), and on the other hand soil-improving crops (IMPROVE), which have a positive impact in this sense, and among which we have included clovers (*Trifolium* spp.), alfalfa (*Medicago sativa*), hairy vetch (*Vicia villosa*), Hungarian vetch (*Vicia pannonica*), common vetch (*Vicia sativa*), blue lupin (*Lupinus angustifolius*) and pea (*Pisum sativum*). The values for these two variables were established based on personal interviews with farmers. Each of the crops listed above was recorded as "used" if it was included in the crop rotation as a main crop or as a catch crop, as defined by GAEC, on the respective production block at least once in the years 2009–2013.

The next two explained variables express the farmer's choice to interrupt the runoff strip length on the slope of the production block using agrotechnical, technical or combined measures (slope length of production block – LENGTH, m), and to reduce water erosion by contour farming (CONTOUR). Contour farming involves preparing the land, planting, and cultivating a crop along the contours of a field to reduce erosion, increase water infiltration, and control runoff water. The values of both of the variables were derived from a combination of a digital elevation model (Fundamental Base of Geographic Data of the Czech Republic on scale of 1:10,000) and orthophotographs. The lines of the uninterrupted slope were created and measured to obtain LENGTH values for each production block. Contour farming was recorded where in at least 75% of the area of the block arable land was cultivated along contour lines, with maximum divergence of 30°.

The explained variables were tested for the effects of two predictors. The first was Character of Farming Subject (FARMING), which indicates whether the farming subject is himself the owner of the farmed blocks, or whether the subject is a tenant. To determine whether a block is farmed by the owner or by a tenant, we compared the data from LPIS with data from the Land Register. Cases where these two alternatives are combined, and where one production block includes both parcels owned by and parcels rented by the farming subject were omitted. The second predictor, taken from the LPIS database, expressed the slope of the production block (ANGLE,°) classified into two categories, as slopes up to 7° and slopes above 7°. This division reflects the GAEC erosion control standards. In slopes up to 7°, only GAEC 2 erosion control standards are relevant, whereas in slopes above 7° both GAEC 1 and GAEC 2 principles are applied. The version of GAEC 1 and GAEC 2 valid in 2009–2013 has been used in this study.

2.2. Statistical data processing

For each of the tested farming approaches (response of the farmers) we analyzed a separate model, in which we were particularly interested in the effect of interaction (stated as the third term in the model) between two fixed predictors, farming subject (owner versus tenant) and Mean Slope Angle of Production Block ($\leq 7°$ or $>7°$), suggesting that there may be different trends in farming approaches on steep slopes versus moderate slopes between owners and tenants. In the analysis of farming approaches, including applications of wide-row crops, soil-improving crops and contour farming, we used generalized linear models with a binomial distribution of the response variables (GLM_{binom}). We analyzed the effects of predictors on the slope length of the production block using a general linear model with a log transformed explained variable to approach its normality ($GLM_{gaussian}$). The models were performed in R release 3.0.3 (R Development Core Team, 2010). $P = 0.05$ was adopted as the level of statistical significance.

Because disproportions in block sizes and numbers of blocks with steep slopes between owners and tenants might cause the results to be misinterpreted, we first checked the differences in block sizes and the proportion of blocks with steep slopes between owners and tenants. All values (results) are presented as mean + SE (standard errors) unless stated otherwise.

3. Results

We found highly significant differences in mean block size between owners and tenants (66.4 ± 23.7 ha and 148.4 ± 45.1 ha, respectively, *t* test: $t = 4.60$, df = 261, $P < 0.0001$), while the proportion of blocks with steep slopes did not differ significantly between owners and tenants (Fisher's Exact Test, $P = 0.07$). We therefore controlled the effect of predictors for block size in the models (i.e. block size was included as first in the models and is not further presented in the results).

The single predictor FARMING was significant in all four tested models (Table 2). As shown in Fig. 1, there were substantial differences in the behaviour of owners and tenants in all cases. The results show that while in the last 5 years owners had included wide-row crops (WIDEROW) in crop rotation schemes on just 23.6% of the production blocks, tenants had included these crops in 52.1%

Table 1
Description of the variables used in the study.

Variables	Abbr.	Data type	Data source	Standards of GAEC
Explanatory variables				
Farming subject	FARMING	Owner/tenant	LPIS; Land Register	
Mean Slope Angle of Production Block	ANGLE	≤7°/>7°	DEM; LPIS	
Explained variables				
Wide-row crops in crop rotation	WIDEROW	Yes/no	Survey with farmers	Yes, in slopes >7°
Soil-improving crops in crop rotation	IMPROVE	Yes/no	Survey with farmers	Yes, in slopes >7°
Slope length of production block	LENGTH	Total slope length [m]	DEM; LPIS	No
Contour farming	CONTOUR	Cultivation following contour lines ± 30° yes/no	DEM; LPIS; orthophotographs	No

of cases. On the other hand, soil improving crops (IMPROVE) were included by owners on as many as 69.9% of the blocks, whereas tenants used them in just 37.4% of cases. Contour farming (CONTOUR) was applied as a soil conservation measure by owners on 48.3% of the blocks, whereas tenants applied this measure on just 26.8% of the blocks. The uninterrupted slope length (LENGTH) was (mean ± std. deviation) 113 ± 69 m on blocks farmed by owners, while on blocks farmed by tenants the uninterrupted slope length was on an average 2.4 times longer (275 ± 253 m).

The second predictor – ANGLE – was significant for two explained variables (Table 2), both describing the use of crops relevant for soil conservation in crop rotation schemes in the last 5 years. Wide-row crops (WIDEROW) were used on slopes up to 7° on 59.5% of production blocks, whereas on slopes over 7° they were used in 21.9% of cases. On the other hand, soil improving crops (IMPROVE) were grown on 24.3% of blocks on slopes up to 7° and on 73.7% of blocks on slopes above 7°.

The interactions of the two tested predictors (Farming:Angle) were highly significant only for one explained variable – WIDEROW. In addition, in the case of IMPROVE the effect of the interaction was marginally non-significant ($p = 0.062$; Table 2). The results show that on slopes up to 7°, tenants used wide-row crops (WIDEROW) in 71.9% of the production blocks, whereas owners used these crops in just 23.5% of cases. On slopes above 7°, the proportion of blocks where wide-row crops were grown was approximately the same for both groups (tenants = 22.7%; owners = 23.7%; Fig. 2).

On slopes up to 7°, tenants only used soil improving crops (IMPROVE, Fig. 3) on 14.9% of the blocks, whereas owners applied these crops 3.8 times more often (on 55.9% of the production

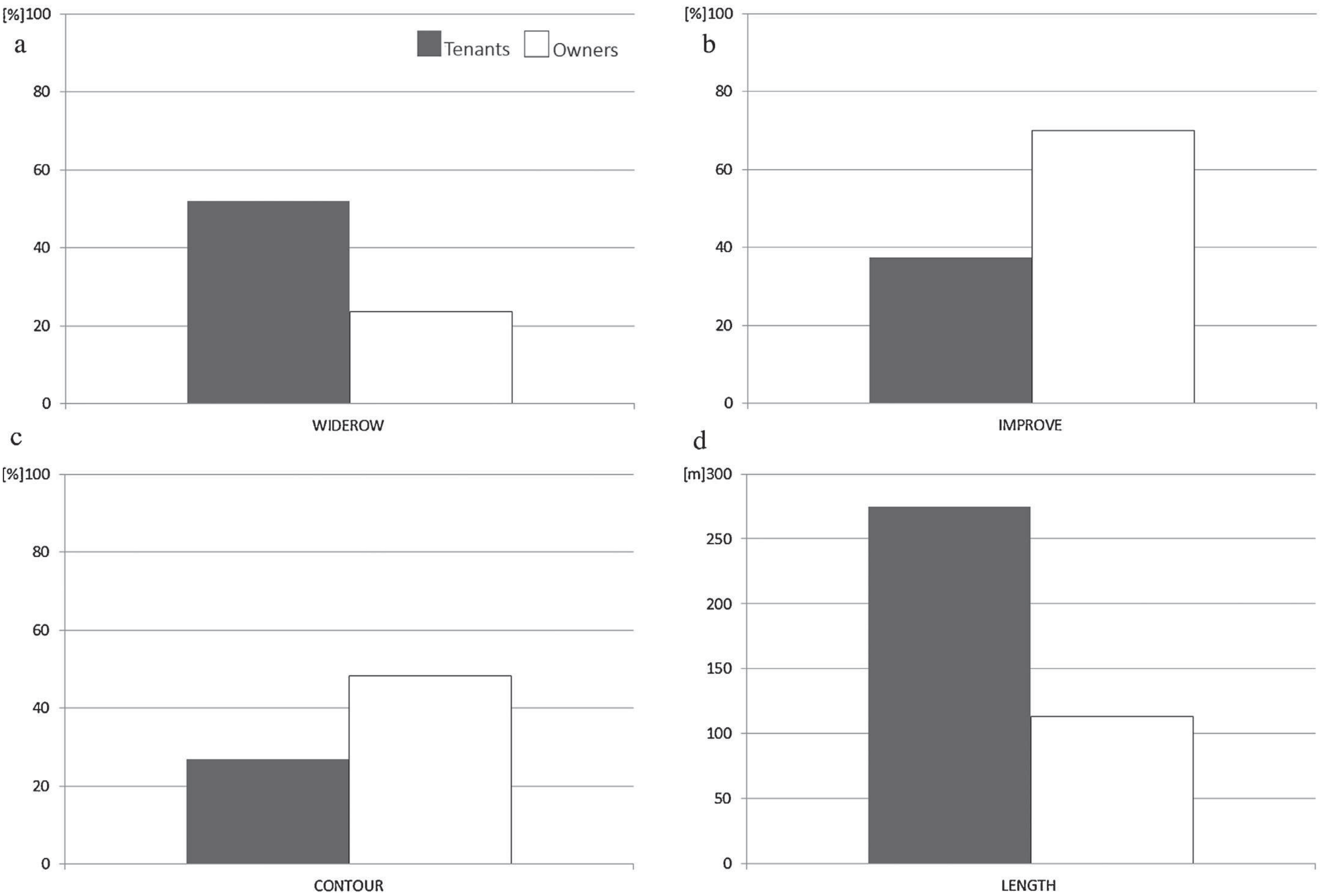

Fig. 1. Significant differences ($P < 0.0001$) in the adoption of four tested soil conservation measures between owner-operators and tenant-operators on all tested production blocks of arable land (a) wide-row crops, (b) soil improving crops, (c) contour farming, and (d) slope length. In all four cases, owner-operators appear to adopt conservation measures significantly more responsibly.

Table 2
Results of models analyzing the effects of farming subject (FARMING), Mean Slope Angle of Production Block (ANGLE) and their interaction on (A) wide-row crops in crop rotation (WIDEROW), (B) soil-improving crops in crop rotation (IMPROVE), (C) slope length of production block (LENGTH), and (D) contour farming (CONTOUR). The overdispersion in binomial models was 1.14 (model A), 1.03 (model B), 1.18 (model D).

Factor	Estimate	SE	χ^2	Df	*P*
A. WIDEROW					
Farming	−2.07	0.459	15.19	1	<0.0001
Angle	−2.18	0.347	34.83	1	<0.0001
Farming:Angle	2.22	0.655	11.34	1	0.0008
B. IMPROVE					
Farming	1.84	0.435	17.68	1	<0.0001
Angle	2.57	0.364	63.13	1	<0.0001
Farming:Angle	−1.24	0.650	3.49	1	0.062
C. CONTOUR					
Farming	1.90	0.429	45.96	1	<0.0001
Angle	0.32	0.335	1.99	1	0.158
Farming:Angle	0.26	0.620	0.18	1	0.675
D. LENGTH					
Farming	−0.35	0.079	4.07	1	<0.0001
Angle	−0.13	0.060	0.48	1	0.086
Farming:Angle	0.14	0.011	0.27	1	0.199

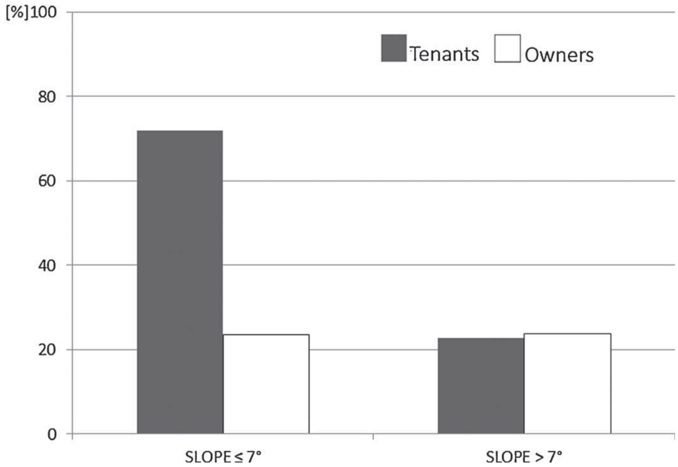

Fig. 2. The representation of wide-row crops in crop rotation schemes by owners and farmers in the last 5 years, presented separately for blocks on slopes below 7° and above 7°. The graph distinctly shows that the differences between owners and tenants that are significant on slopes below 7° are not evident on slopes above 7°, where the less frequent use of wide-row crops is due to subsidy payments.

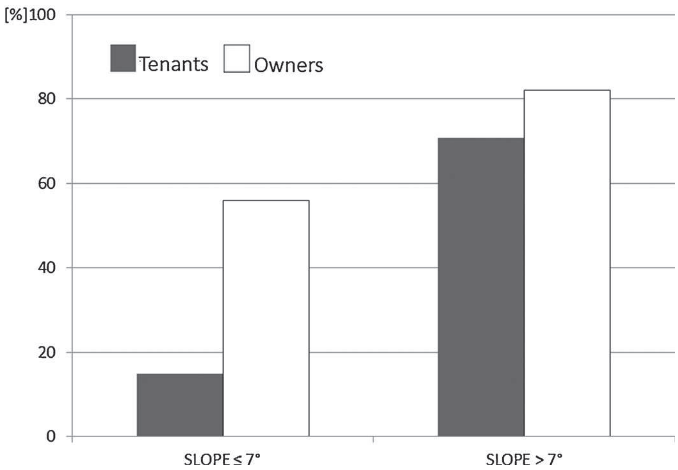

Fig. 3. The representation of soil-improving crops in crop rotation schemes by owners and tenants in the last 5 years, presented separately for blocks on slopes below 7° and above 7°. The graph distinctly shows that the significant differences between owners and tenants on slopes below 7° are not evident on slopes above 7°, where the more frequent use of soil-improving crops is due to subsidy payments.

blocks). On slopes above 7°, this difference was substantially smaller, with tenants using soil improving crops on 70.7% of the production blocks and owners in 82.0% of cases.

4. Discussion

Private ownership implies not only rights and freedoms, but also the owner's responsibilities in the management of the property, which transfer the decision-making to the lowest level, i.e. to the individual (farm). The owner's rights to enjoy the benefits of their investments create incentives towards effective utilization of the resources (Bechmann et al., 2008). However, the freedom to use property may be delegated by rent or lease contracts. In these contracts, the residual rights are maintained by the initial owner. Skogh (2000) considers these residual rights to be the essence of ownership. However, the concept of ownership itself always has to be understood in the context of an individual country and culture. Unlike in Europe, where ownership means a practically absolute right to dispose of the land freely, including unlimited land sale rights, in a number of African countries land cannot be sold outside of the community, and it therefore has no commercial value (Hesseling, 1998).

It is evident that the more rights and freedom the owner contractually delegates to the tenant, the fewer rights and the less freedom he retains. In the context of our study, it is not only the owner's right to benefits that are important, but above all his right to protect his property. These two rights, however, are often in contradiction. Not only the owner but also the tenant of the land is motivated by profit. However, the owner's motivation, unlike the tenant's, lies not only in the instantaneous yield of the land, but also in the value of the land as such, in maintaining and increasing this value for the benefit of his successors, or in order to gain a better price when the land is sold (McConnell, 1983). However, this value, which is a long-term attribute, can be reduced by the tenants in order to gain maximum short-term profit for themselves. The long-term (permanent) value of the land is protected not only by the contract between the tenant and the owner of the land, but also by a number of legislative, motivational, and also cultural and ethical measures, which the community (state) employs to protect its natural resources, on the one hand, and the tenure rights on the other hand. Moreover, the owner can motivate the tenant to make long-term investments in soil conservation by increasing tenure security (Gebremedhin and Swinton, 2003).

A number of studies have shown that insecure land tenure, caused mainly by short-term lease contracts, does not contribute to soil conservation (e.g. Nowak and Korsching, 1983; Soule et al., 2000; Fraser, 2004). Economic theories predict that enhancing tenure security should invite investments in erosion control and soil quality (Beekman and Bulte, 2012). Soil degradation occurs primarily where farmers perceive the land only as an economic asset (Assies, 2009).

4.1. Is the owner more responsible than a tenant?

In our study, we have selected four types of erosion control measures that can be employed by the farming subject (owner or tenant) to control the amount of runoff from the land. Two of these measures (wide-row crops and soil-improving crops), are required by cross-compliance under the GAEC standards in the Czech Republic. The remaining two measures (slope length and contour farming) are not directly mentioned in the GAEC standards. It is therefore up to the farming subject to decide whether to implement them. It can generally be said that all four types of measures tested in our study were adopted in a significantly more responsible way by owners than by tenants.

Wide-row crops were used in crop rotation systems on land endangered by erosion once or more times in the last 5 years 2.4 times more often on blocks farmed by tenants than on blocks farmed by owners. This occurred in spite of the fact that cover management is one of the measures that can be most easily adopted to reduce erosion (Renard et al., 1991). The responsible approach, according to which wide-row crops should be eliminated or at least minimized on blocks endangered by erosion, as these crops provide minimum cover to the topsoil, is in practice confronted by the economic interests of the farming subject (Fraser, 2004). Wide-row crops, in the Czech Republic mainly maize, are economically interesting crops, especially because in the present day they are grown not only for direct consumption or as fodder for cattle, but also used for biogas production and for other technical products. Entirely excluding these crops from the crop rotation system can therefore mean a significant economic sacrifice for the farmer.

Crops improving the soil against erosion provide relatively stable vegetation cover, protecting the soil from the impact of raindrops. At the same time, these crops improve the quality of the soil, making it more fertile and less prone to erosion. On the blocks tested in this study, soil-improving crops were used in crop rotation systems at least once in 5 years 1.9 times more often by owners than by tenants. To put it simply, we can state that, in our study, the exclusion of wide-row crops represents the farmer's desire not to contribute to soil degradation, while the use of soil-improving crops indicates a desire to improve the current state of the soil. Soil-improving crops are essentially a medium- to long-term investment in soil quality, rather than an economically attractive commodity bringing immediate profit. Soil-improving crops are therefore grown mostly by owners, who take the long-term perspective of the condition and fertility of the soil into consideration in view of their commitment to their own property. For tenants, the perspective may be limited to the length of the lease contract with the land owner, and it is therefore not lucrative for the tenant to "invest" in improving soil fertility at the expense of immediate profit. Farmers who engage in long-term soil conservation in this sense may sacrifice immediate income for the promise of better soil fertility and conservation (Fraser, 2004). However, tenants often lack security that they will be able to benefit from advantages brought by long-term investments, so they are motivated rather to maximize short-term production, often at the expense of deteriorating soil conservation and loss in soil fertility. These conclusions are confirmed by studies from countries all over the world, with various legal and political systems (e.g. Nowak and Korsching, 1983; Gillis et al., 1992; Hu, 1997; Praneetvatakul et al., 2001). In this sense, our results confirm these findings that compare owner-operated and tenant-farmed arable land.

Similarly, contour farming as a soil conservation measure proved to be significantly (1.8 times) more likely to be used on plots farmed by owners than on plots farmed by tenants. This finding is all the more interesting because the tenants in our study farmed on an average larger fields than owners, while according to Lichtenberg (2004) plot size is a significant factor positively determining the application of this erosion control measures. However, our results indicate that, in this case, land ownership is a far stronger motivation than the additional costs associated with the implementation of this measure, which can however bring a number of benefits, such as more effective water management, reduction of nutrient losses and consequent higher yields of agricultural crops (Quinton and Catt, 2004).

Finally, the results concerning the fourth tested type of measures – slope length – also indicate more responsible use of the land by owners. Blocks of arable land farmed by owners had 2.4 times shorter slope length than those farmed by tenants, while, notably, many studies found soil loss to be positively associated with slope length (e.g. Megahan et al., 2001; Xu et al., 2009), and the same relationship is confirmed by the widely used USLE cropland erosion prediction model (Wischmeier and Smith, 1978) and its revised version RUSLE (Renard et al., 1991). Shorter slope length usually means higher soil cultivation costs, as it involves more frequent turning of the tillage machinery on headlands, resulting in a higher proportion of non-working rides across the farmland (Gonzalez et al., 2004). The application of this measure therefore requires motivation strong enough to exceed the increased costs. In our case, this motivation is created by ownership, but not by the less secure land tenancy.

Some authors argue whether long leases provide the same incentives as land ownership to conserve the soil. Their works illustrate the crucial significance of the political, economic and legislative background of the individual countries in which these studies were performed. A certain role is also played by social norms, as is illustrated in a study by Beekman and Bulte (2012). While in many developing countries long-term lease of farmland often matches the security of ownership (Gebremedhin and Swinton, 2003; Ndah et al., 2014), or even exceeds it in some characteristics, such as resistance to urban development (Lee and Stewart, 1983), in countries with a developed free market, ownership is the form of land tenure that is most likely to guarantee long-term investments in soil quality. Some studies draw similar conclusions on house ownership, e.g. Buchanan (2012) states that owners are more responsible than renters, creating more stable neighbourhoods. In this sense Lumley (1997) and Walters et al. (1999) emphasis the significance of the "desire to own land" phenomenon as a motivation of owners towards long-term investments.

Our study regards ownership in the context of the Czech Republic as a more secure form of land tenure than tenancy. In this country, almost 80% of farmers farm on rented land, moreover with extremely fragmented ownership, which is one of the main drivers of such a high proportion of tenant-operated lands (Sklenicka et al., 2014). In comparison with Western Europe, both sale prices and lease prices of land in the Czech Republic are still relatively low (Sklenicka et al., 2013). Tenancy contracts are usually of unlimited duration, and they usually contain a 1- to 3-year notice period. This time limit does not motivate tenants towards long-term investments. The uncertainty of lease contracts in the Czech Republic currently derives mainly from the dynamically developing land sale and rental markets, with sale prices and lease prices of farmland growing by as much as tens of percent annually, in order to catch up with the several times higher price levels in Western Europe. Under these conditions, owners are not willing to guarantee long-term conditions of lease contracts. The diametrically different priorities and goals for owner-operated and tenant-operated land under such conditions are more than obvious.

4.2. Can agro-environmental instruments compensate the differences between owners and tenants?

Not only countries with a significant proportion of land farmed by tenants should take measures to ensure the sustainability of land use through long-term investment in soil conservation. There are essentially two methods for governments in these countries to address this matter immediately – by implementing legislative measures ensuring sufficient tenure security for land tenants, or by introducing a system of subsidies determined by environmental standards, addressing the farming subjects and therefore compensating or minimizing the differences between tenants and owners. Since the first method – legislative measures – may mean an undue restriction of owners' rights, the second method – a system of subsidies – is preferred, especially in countries with liberal market economies. For example, the member states of the EU have implemented a whole system of measures on national and regional levels

(GAEC), offering new incentives for the adoption of soil conservation practices (Kutter et al., 2011).

The results of our study confirm very high efficiency of the GAEC standards for two of the tested variables (wide-row crops and soil-improving crops), albeit the effect of the interaction for soil-improving crops was marginally non-significant. Both of these measures are defined on the national level within the GAEC standards. On slopes over 7°, the exclusion of wide-row crops, or the use of soil-improving crops, is required in order to qualify for the direct payments. Our results clearly show that on slopes below 7°, where these measures are not strictly required by the GAEC standards, the approach of owners, as defined by their application of these two measures, is far more responsible. On these blocks, owners used wide-row crops 3.1 times less often than tenants, whereas soil-improving crops were used 3.8 times more often by owners than by tenants. These numbers reflect the level of motivation of both groups of farmers to use soil conservation measures, without the effect of environmentally determined subsidies. In contrast, on slopes above 7°, the differences in the use of wide-row crops were fully compensated, and for soil-improving crops the differences were also almost eliminated. The statistical significance of the interaction Farming:Angle, together with the highly conclusive average values provide proof that implementation of the GAEC principles on slopes above 7° brings positive results and practically eliminates the differences between farming owners and tenants. The amount of direct subsidies at the time when the data was collected for this study was c. 200 EUR ha^{-1}, which represents on an average approximately 25% of the farmers' income per 1 ha of arable land in the Czech Republic. The absolute amounts of subsidies per hectare are the same in all regions of the country, but in less fertile areas the subsidies logically represent a significantly higher proportion of the farmers' income than in more fertile areas. The farmers' decision to accept GAEC conditions and collect direct subsidies is voluntary. Where the farmer does not meet the GAEC conditions in terms of erosion control, the direct payments are reduced by up to 5%. Our results show that although the threat of such a reduction provides sufficient motivation for most farmers to comply with the GAEC conditions, for a small proportion of farmers this motivation is insufficient and they would appear to consider the profit from production to be more financially attractive than the lost proportion of the direct subsidies.

The results of our study indicate that the rules are defined effectively, and that the level of subsidies is sufficiently motivating for these two types of measures on blocks strongly endangered by erosion on slopes above 7°. However, scientific debate needs to continue as to whether similar principles should also be implemented on less endangered production blocks on slopes below 7°. At the present time, there is a marked dichotomy in the application of erosion control measures, where tenants, as opposed to owners, are not motivated to make a long-term investment in soil conservation at the expense of short-term profit. If these cases are not regulated, there is a risk of ongoing soil degradation on more than 1/3 of the arable land in the Czech Republic. It is also necessary to revise the limits and conditions of GAEC cross compliance to include new indicators, in order to support additional soil conservation measures. This would not necessarily lead to an increased proportion of land that is declared vulnerable. Rather, the zoning should be fine-tuned to be more effective.

The remaining two measures (slope length of production block; contour farming) are not currently regulated by the Czech version of GAEC. The results of our study in these two cases confirmed significantly more responsible treatment of soil by owners than by tenants, without a statistically significant difference between slopes below 7° and above 7°. This is logical, since neither of these measures is strictly required or regulated by the GAEC standards, and we therefore cannot presume a significant difference in the motivation towards responsible farming on slopes slightly (up to 7°) and strongly (above 7°) endangered by erosion.

Although farmers' attitudes towards environmental policy instruments are often ambiguous (Davies and Hodge, 2006; Zeithaml et al., 2009), there is ongoing development and refinement of these instruments to include a wide complex of environmental principles, reflecting the assessment of the effectivity of these instruments in countries with varying political and economic orientations. For example, Amdur et al. (2011) examined the possibilities of developing market-oriented instruments of agri-environmental policy measures in Israel, and Zheng et al. (2015) evaluated experience from the efforts to minimize negative environmental impact of livestock production in China. Adequate subsidies and additional services also stand behind the willingness of Swedish landowners to facilitate ecosystem services by establishing new wetlands to reduce nutrient transport to the sea (Hansson et al., 2012). However, a well-adjusted system of subsidies based on agri-environmental schemes can only function well if it is based on adequate legal measures and on the ability to enforce these measures effectively (Prazan and Dumbrovsky, 2011; Dumbrovský et al., 2014).

The variety of political, economic, and also cultural conditions in individual countries and regions makes it impracticable to define general principles for soil conservation. The mutual interactions of restrictive and motivational measures need to be regularly evaluated, in order to keep fine-tuning the conditions under which soil conservation in a given country and region will be the most efficient.

5. Conclusions

Our study has used an analysis of the level of adoption of four types of erosion control measures to answer two fundamental questions: (1) Do land-owning farmers treat their own property more responsibly than tenant farmers? (2) Do agri-environmental instruments in support of sustainable farming practices provide sufficiently strong motivation to compensate the differences between owners and tenants?

The results have proved that all measures were adopted by owners in significantly more responsible ways than by tenants. Compared to the tenants, owners applied wide-row crops in crop rotation Schemes 2.4 times less frequently in the last 5 years, while applying soil-improving crops 1.9 times more frequently. Contour farming was adopted 1.8 times more often by owners, and the slope length in production blocks farmed by owners was on an average 2.4 times shorter than in blocks farmed by tenants.

Only two of the four tested types of measures, concerning the use of wide-row crops and soil-improving crops, are supported by subsidies based on the GAEC standards. Moreover, this scheme applies only to arable blocks strongly endangered by erosion, on slopes above 7°. The results have shown that in these cases the differences in the approach to soil conservation between owners and tenants were minimized or eliminated, due to the adoption of responsible practices by tenants. In the case of these two types of measures, the results can therefore be interpreted as proof of the efficiency of agri-environmental subsidy instruments, which introduce significant motivation for farmers to adopt soil conservation measures. Moreover, this motivation is sufficiently strong to eliminate the otherwise significant differences between owner and tenant farmers.

On a broader level, our study has discussed the role of land tenure security in achieving sustainable land use, since the results further demonstrate the need to fine-tune the national conditions for subsidy payments in the Czech Republic, mainly by extending the scope of the existing instruments to blocks with low and medium risk of erosion. Similarly, it is necessary to revise the limits and the conditions of GAEC cross compliance, and to include new indicators in these standards in order to support additional soil conservation measures.

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