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THE IMPACT OF FARMING AND LAND OWNERSHIP ON SOIL EROSION

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Abstract

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The aim of this paper was to compare two methods of farming, especially their effect on water soil erosion. The examined methods were (1) large-scale farming, where more than 50% of the land was leased, and (2) small-scale farming, where the land was almost exclusively privately owned. The research area was 8 cadastres in the district of Hodonín, South Moravia, Czech Republic. In these cadastres 48 land blocks representing both large-scale and small-scale farming (i.e. owners and tenants) were chosen. The long-term average annual soil loss caused by water erosion (G) was calculated using the erosion model USLE 2D and ArcGIS 10.1. The nonparametric Mann-Whitney test was used for the statistical evaluation of the data. The difference between the soil loss (G) on land blocks farmed by small producers (owners) and large producers (tenants) was significant ($p < 0.05$). Differences between the values of the cropping-management factor (C) were not statistically significant ($p = 0.054$). Based on the analysis of other variables in the USLE equation it can be stated that a continuous slope length, conditioned by the size of land blocks, played an important role in the amount of soil loss caused by water erosion. Above all, to protect the soil from erosion and maintain soil quality it is necessary to reduce the size of land blocks farmed by tenants and improve the crop rotation systems.

Keywords: water soil erosion, erosion control, intensive agriculture, land ownership, crop rotation, South Moravia

INTRODUCTION

Soil erosion is one of the main problems caused by using inappropriate methods of intensive farming. Currently, more than 50% of arable land is threatened by water erosion in the Czech Republic (Janeček *et al.*, 2012). The result of water erosion is not only a reduction of the topsoil layer, but also a deterioration of the physical and chemical properties of the soil leading to the reduced availability of nutrients for growing plants.

Land use and land cover are factors, which significantly affect surface runoff and also soil erosion (Kosmas *et al.*, 1997; Schiettecatte, 2008; Leh *et al.*, 2011). This paper deals with the issue of soil erosion in connection with large-scale farming as well as small-scale farming. It can be assumed that the method of farming is closely linked with the type of user. Owners will use different farming methods in comparison with tenants. A major role in the changes of land ownership was made by the collectivization of agriculture in the 1950's. Changes in the use of land in the Czech Republic in the years 1938–1998 was demonstrated by Sklenička (2002) in a study performed in North Bohemia.

This paper should help to clarify the issue of intensive large-scale farming on leased land, which was cultivated with traditional agricultural practices by its owners before collectivization. The implementation of anti-erosion crop rotations is difficult in practical terms and almost does not apply in large-scale farming as it is not in their economic interest. However, the importance of anti-erosion crop rotations is unquestionable in terms of both soil and biodiversity protection, as well as in terms of landscape-formation (Cudlinová *et al.*, 1999).

Kvítek *et al.* (1997) and Vašinová *et al.* (2012) agree that the most important factors affecting the amount of water flowing out of basin are:

- the percentage of arable land in the basin,
- the block size of the arable land and their locations in the field,
- the layout, size and diversity of perennial crops (meadow, forest) in the landscape,
- the depth of the soil profile and grain size.

Kvítek *et al.* (1997) also pointed to the problem of ignorance and disregard for basic approaches to water retention (e.g. ploughing sloping land or shallow soil, the poor design of grassing measures or the bare paths of concentrated runoff), errors in the use of agricultural technologies (creating pathways for concentrated runoff on slopes made by a tractor's tracks) and missing the regular maintenance of existing erosion control measures. Also Soukup and Hrádek (1999) reported in their thesis that there was a connection between crops cultivated, tilling methods used on the land and the retention capabilities of the basin. The effect of crop rotations and tilling methods in relation to soil erosion has also been examined (e.g. Kwaad *et al.*, 1998; Benediktas and Genovaite, 2003; Fiener and Auerswald, 2007; Watson and Evans, 2007; Prasuhn, 2012). Other similar studies have been performed e.g. Van Rompaey *et al.* (2007) who demonstrated the influence of changes in the spatial distribution of land cover and land block size on soil erosion. Erosion on large blocks of arable land were also discussed by Černý Pixová and Sklenička (2011) and soil conservation in connection with land ownership was examined by Lee (1980) in the USA.

MATERIAL AND METHODS

The aim of this paper was to compare two methods of farming in terms of their effects on water soil erosion. The examined methods were (1) large-scale farming, where more than 50% of the land blocks were leased, and (2) small-scale farming, where the land blocks were almost exclusively privately owned (more than 90%).

The main questions defined for the evaluation and comparison of these two farming methods were:

1) Does a significant difference between the values of the long-term average annual soil loss (G) exist?
2) Does a significant difference between the average values of the cropping-management factor (C) exist over five-year period?
3) Does a significant difference between the values of continuous slope length (l_d) exist?

Study Area

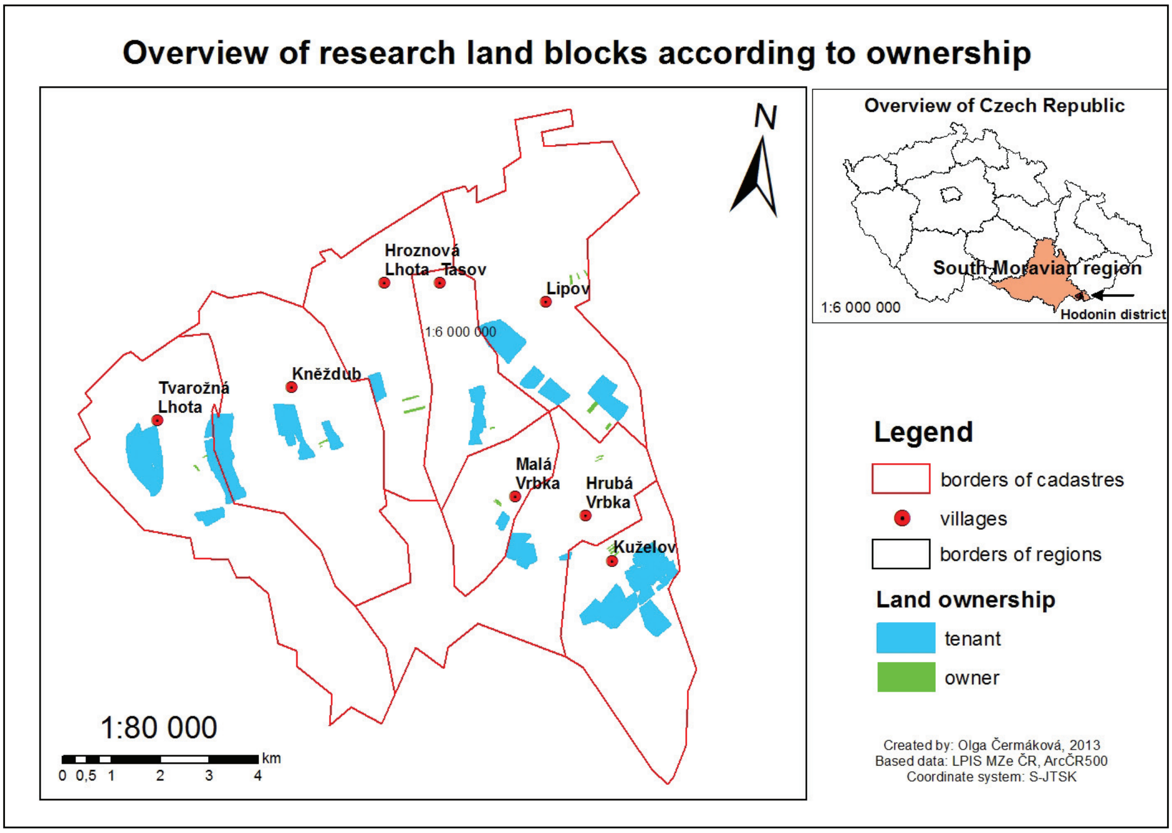
Based on a survey of cadastres potentially threatened by water erosion (VÚMOP, 2012) 8 cadastres in the district of Hodonín, South Moravian region, Czech Republic were selected. Specifically, these were the Lipov, Kněždub, Kuželov, Tvarožná Lhota, Malá Vrbka, Hrubá Vrbka, Hroznová Lhota and Tasov cadastres. In these cadastres at least twenty percent of the area was from the moderately to extremely threatened categories. This region was chosen because in addition to large-scale farming on rented land, a number of farmers, who practice small-scale farming on their own land still exist there.

The Selection of Research Land Blocks and Data Collection

Based on a field survey and the analysis of digital maps 48 land blocks on gentle slopes were selected. Half these land blocks represented large-scale farming and half small-scale farming, respectively owners and tenants (Fig. 1). For the purposes of this paper the term „land block" means a continuous area of agricultural land farmed by one user and almost exclusively with one crop. To obtain comparability the land blocks for each type of farming was selected so that they did not significantly differ in their average steepness (S) or in the value of soil erodibility factor (K). Therefore farm owners and tenants were not disadvantaged by the natural conditions, on which they have only a little or no influence.

The input data for the purpose of evaluating erosion was obtained by a field survey and digital maps. Values of the cropping-management factor (C) and the conservation practices factor (P) were determined according to field survey and information obtained from farm owners and tenants. Crop rotations (or sequences of crops) were detected for the five-year period (2008–2012). The values of C factor for orchards and vineyards without grassland were determined by comparing vegetation canopy and agricultural technologies used with C factor values listed in the Table of C factor values (Tab. I) in the Methodology (Janeček *et al.*, 2012). The average value of C factor determined for vineyards without grassland was 0.55 and 0.35 for orchards without grassland. The values of other factors of USLE equation were determined using digital maps and in accordance with the applicable Methodology (Janeček *et al.*, 2012):

- the soil erodibility factor (K) from the VÚMOP (2013) (scale 1:5 000),
- the boundaries and size of land blocks from the Land Parcels Information Systems – LPIS (Mze CR, 2013, scale 1:1 000),
- the steepness (S) was calculated from the digital terrain model in ArcGIS 10.1 by Slope function. The digital terrain model was created based on 3D contours from ZABAGED® (ČÚZK, 2013, scale 1:10 000) and based on the layers of water courses and bodies of water from the freely available database DIBAVOD (VÚV TGM, 2013, scale 1:10 000). It was created by using the Topo To Raster function.



1: *Map showing research land blocks by ownership*

I: *Overview of the results of the statistical tests*

	SMALL-SCALE FARMING (OWNERS)	LARGE-SCALE FARMING (TENANTS)	
Variable	**Average**	**Average**	**P**
G (t/ha/year)	4.34	13.07	0.000*
C factor	0.17	0.26	0.054
C factor (without grassland)	0.20	0.31	0.022*
l_d (m)	123.52	686.49	0.000*
land block size (ha)	0.32	21.52	0.000*
LS factor	2.62	4.61	0.000*
S (°)	5.96	5.96	0.910
	range from-to	**range from-to**	**P**
K factor	0.28–0.38	0.26–0.38	0.282

Note: * – significant difference between values obtained for small-scale farming (owners) and large-scale farming (tenants)

Data Analysis

The long-term average annual soil loss (G) was calculated using the USLE 2D erosion model (Desmet et Govers, 1996) and ArcGIS 10.1 (ESRI, 2010). USLE 2D is an empirical erosion model, which is based on the universal equation of the long-term average annual soil loss USLE (Wischmeier and Smith, 1978).

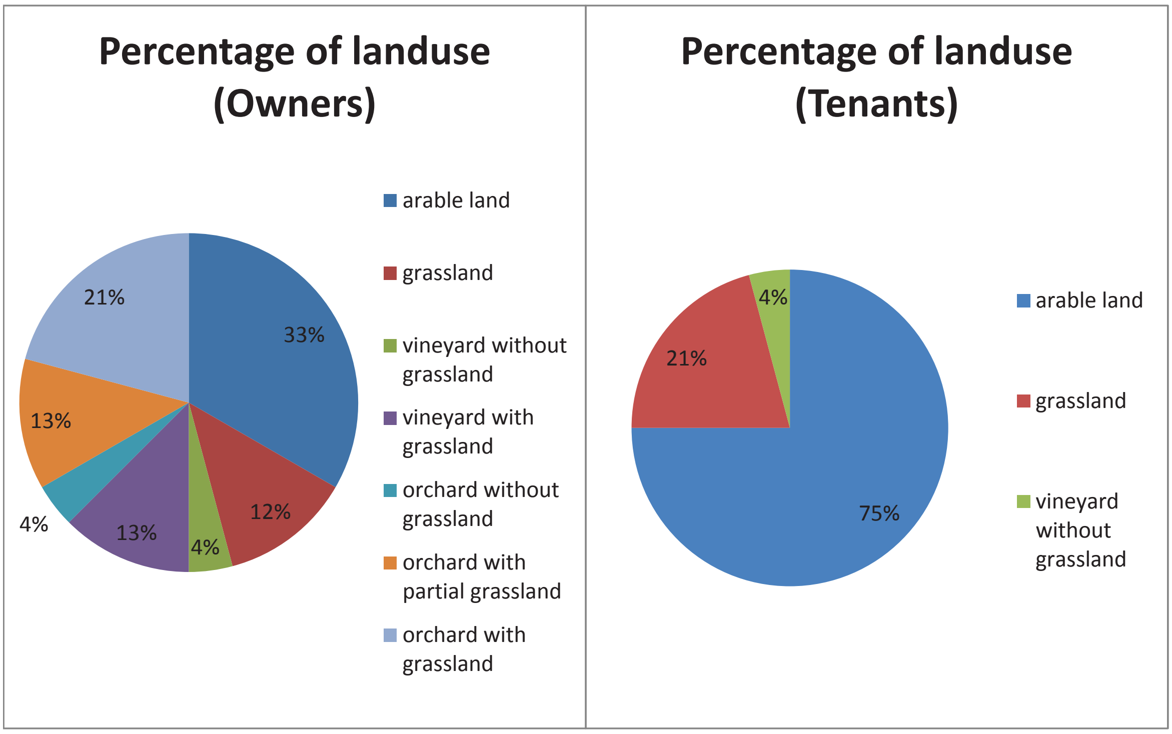
The main input data to USLE 2D is the digital terrain model (DTM) and „parcel“ grid, which represent boards of investigated land blocks determined by surface runoff interruption. The interruption may be caused by a road network, watercourses, forests, anti-erosion channels or other erosion control measures. Thus the layer of “parcels” is a grid, in which each raster element is classified as an integer value. A value of 0 means that the LS-factor is not calculated for this area and the surface runoff is interrupted, while values greater then 0 indicate agricultural land, where the LS-factor is calculated.

Vector input data was first converted in ArcGIS 10.1 to raster format. In addition, data was reclassified and adjusted using map algebra tools, so that in the final „parcel" grid agricultural land had a value of 1, and other land had a value of 0. USLE 2D software works only with data in Idrisi format (.rst), therefore the „parcel" grid and DMT was transfered via ASCII format to .rst format by LS-Converter 1.0. In the USLE 2D the topographic factor (LS factor) was calculated for each cell of the raster. Of the possible methods of LS factor calculation the variant Flow direction – Multiple flow and LS algorithm (McCool, 1989) was chosen, which uses the RUSLE method (Renard *et al.*, 1993). The final raster was further modified by the MEAN 3×3 filter to eliminate excessively high values of the LS factor. The value of the long-term average annual soil loss (G) according to the USLE equation (Wischmeier and Smith, 1978) was obtained using the Raster Calculator tool as a multiple of grids with values of factors LS, R, C, K, P. A constant value 40 $MJ.ha^{-1}.cm.h^{-1}$ for R factor was applied in accordance with the valid methodology (Janeček *et al.*, 2012). From these values the average value of G was calculated using the Zonal Statistics tool.

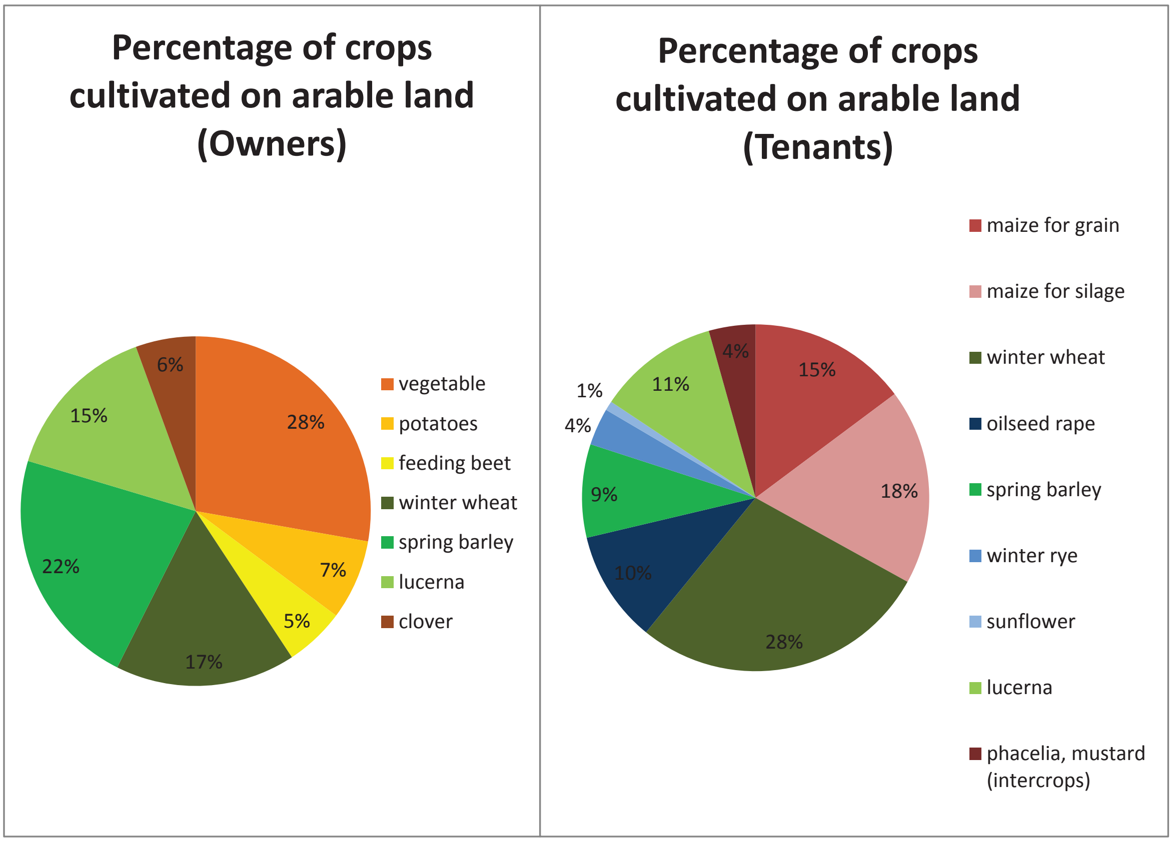
Statistical analysis of the data was performed in SPSS Statistics 21 (IBM, 2013). The normality test results showed that most of the observed indicators did not have a normal distribution, so a nonparametric Mann-Whitney test was used. This test was used to detect whether there were any significant differences between the variables such as the LS factor, the steepness (S), the size of land blocks, continuous slope length (l_d), C factor and the long-term average annual soil loss (G) of the two farming methods investigated. The difference between K factor values was tested with Fisher's exact test, because the data was categorical and the conditions for using Chi-square test were not meet. The reciprocal dependence between the studied factors were also determined using Spearman's correlation coefficient, separately for each farming method.

RESULTS

The non-parametric Mann-Whitney test showed significant difference between the long-term average soil loss (G), where the average was about 3 times higher in the case of large-scale farming (see Tab. I). The average value of G for owners was 4.34 t/ha/year and the average value of G for tenants was 13.07 t/ha/year. The difference between the cropping-management factor (C) of large-scale farming (tenants) and small-scale farming (owners) was not demonstrated ($p = 0.054$). However, when the value for permanent grassland was removed, the statistical analysis of the difference between the C factor was significant ($p = 0.022$). The difference in the continuous slope length length (l_d) was demonstrated and the average of l_d was about 5.5 times greater in the case of large-scale farming. According to the Spearman correlation coefficient it can be stated that continuous slope length played an important role in soil loss ($rs = 0.521$, $p < 0.01$). It was conditioned by the size of the land blocks ($rs = 0.733$, $p < 0.01$), where the average size was nearly 70 times greater in the case of large-scale farming (see Tab. I). The difference between the LS factor was also demonstrated and the results that are listed in Tab. I show that this difference was



2: *Comparison of land use by farming owners and tenants*



3: *Comparison of crops cultivated on arable land by farming owners and tenants.*

mainly due to the difference in slope length (L). A significant correlation was demonstrated between C factor and soil loss (G) in the case of small scale-farming (rs = 0.887, $p < 0.01$) and large-scale-farming (rs = 0.676, $p < 0.01$). The average steepness was 5.96° for both farming methods and the K factor did not differ significantly either (see Tab. I). This fact is consistent with the requirements for site selection (see Methodology).

The field survey found out some facts about land use and also the crops cultivated by land owners and tenants. Fig. 2 shows that a greater diversity of landuse was observed in the case of owners, while in the case of tenants cropland represented 75% of landuse. A greater diversity of cultivated crops on arable land was observed on rented land (see Fig. 3). However, the situation was different with regard to the percentage of crops, because with tenants corn for grain or silage and winter wheat represented 61%, while the crops that owners cultivated were more evenly represented. The focus on tillage practices in particular, showed some differences in the agricultural technology used. Owners generally used smaller machines in comparison with tenants. Owners often applied rotation of winter and vernal crops with ploughing in the autumn. No-tillage rotation of winter crops prevailed with tenants and the soil was only harrowed a few times. These findings are reflected in the change of the C factor (see Tab. I).

Erosion control measures applied by tenants were anti-erosion channels and the planting of inter-crops (*Phacelia sp.*, *Sinapis sp.*), but these were rarely observed. In the case of owners the erosion control measures were observed most frequently, for example erosion control grassing of orchards and vineyards (at least partial), anti-erosion channels and furrows and contour ploughing.

DISCUSSION

In view of the fact that the land blocks selected for purposes of this research had approximately the same steepness and similar soil properties characterized by K factor, the results showed, that the difference in soil loss was mainly due to the size of land blocks, i.e. the size of continuous slope length (l_d). The value of l_d was on average 70 times greater for the land blocks used by tenants (large-scale farming) compared with the land blocks farmed by owners (small-scale farming). Additionally, the longer side of the land blocks researched were generally oriented against the contour direction and the tillage was also carried out against the contour. This fact points to the inappropriate consolidation of land blocks in history and the subsequent lack of organizational and technical erosion control measures aimed at reducing the slope length and rational use of agricultural technology. The irrational size of land blocks of arable land was also pointed out by Černý, Pixová and Sklenička (2011).

The difference in the average value of C factor was not as substantial. Although, the average value of C factor was on average approximately 1.5 times greater in the case of tenants compared to owners. At this point it is necessary to take into account the different interests of small-scale producers and large-scale producers. Small-scale producers mainly concentrated on growing crops intended for use in animal husbandry and growing root crops, whereas large-scale producers subordinated their selection of crops more to market demand (e.g. maize grown for industrial purposes), the selling price and the subsidies available (e.g. growing erosion control intercrops and oilseed rape). As the preferences connected with selection of crops cannot be controlled easily, efforts to reduce the value of the C factor should be focussed on. This would mainly be the application of agro-technical measures involving for example the use of crop residues or the modification of sowing and harvesting times. For example Pokladníková and Dufková (2004) found, that for winter cereals harvest time is most important.

The field survey proved some irrational farming practices, which were detected especially in the case of tenants. Above all, poor or missing crop rotation systems, high frequencies of the same crops on the same field, overall low diversity of cultivated crops and also oversized landblocks could be highlighted. These facts are related to the need for higher incomes for farmers (especially large producers) and the current demands of the commodity market. This situation could be improved by systematic long-term planning, as supported by Dogliotti *et al.* (2014).

The USLE 2D erosion model which was used in this research is often used in the Czech Republic and has been applied for example to create a map of potential vulnerability of arable land by water erosion in the Czech Republic (VÚMOP, 2000), to make recommendations for management on arable land blocks (Žížala and Kristenová, 2012), for creating maps of the soil erosion threat and sediment transport in the Czech Republic (Krása *et al.*, 2001) and updates (Krása *et al.*, 2008). However, it should be noted that the quality of the final output from USLE 2D depends on the quality of the digital data inputs. The condition for obtaining the most accurate results is an especially good quality digital terrain model, but also sufficient detail and accuracy of the other input data (a map of BPEJ or K factor, the borders of land blocks and the value of the C factor). In this research a DMT based on a 3D contour of ZABAGED® with a scale of 1:10 000 and with a basic interval of 5, 2 or 1 meter, depending on the nature of terrain, was created. The size of the land blocks researched would have made it preferable to use a more accurate dataset, for example the stereoscopically evaluated digital terrain model from Geodis Brno company. However, the high accuracy of this model makes it very costly, and therefore it was not used in this research. The case of digital relief models 4G and 5G from ČÚZK was a similar situation. Both of these models were not yet available for the research area during the period of this research. Future research should therefore focus on the employment of the above mentioned data from ČÚZK in a similar research project.

CONCLUSION

This research proved some differences between the two compared methods of farming and land ownership. In large-scale farming (tenants) a significantly higher average value of the soil loss (G) was detected. The average value of G for owners was 4.34 t/ha/year and the average value of G for tenants was 13.07 t/ha/year. The differences between the values of C factor were not statistically significant although small producers showed, on average, a better value of C factor compared to tenants. Based on the analysis of other variables in the USLE equation it can be stated that a continuous slope length (l_d) conditioned by the size of land blocks played an important role in the amount of soil loss caused by water erosion. Value of l_d was on average 70 times greater for the land blocks used by tenants compared with the land blocks farmed by owners.

Focus on landuse and cultivated crops showed a greater diversity of landuse in the case of owners, while in the case of tenants cropland represented 75% of landuse. A greater diversity of cultivated crops on arable land was observed on rented land. However, the situation was different with regard to the percentage of crops planted, because with tenants corn for grain or silage and winter wheat represented 61%, while the crops that owners cultivated were more evenly represented. Thus, the field survey proved some irrational farming practices, which were detected especially in the case of tenants. Above all, poor or missing crop rotation systems, high frequencies of the same crops on the same field and oversized landblocks could be highlighted.

The facts presented lead to the recommendations, that it is necessary to reduce the size of land blocks farmed by tenants and to improve the crop rotation systems in order to protect the soil from erosion and maintain soil quality.

SUMMARY

This thesis was aimed at evaluating the impact of farming methods and land ownership on water soil eroion. The main goal was to compare two methods of farming: (1) large-scale farming, where more than 50% of the land was leased, and (2) small-scale farming, where the land was almost exclusively privately owned (more than 90%). The research area was 8 cadastres in the district of Hodonín, South Moravia, Czech Republic. In these cadastres 48 land blocks representing both large-scale and small-scale farming (i.e. owners and tenants) were chosen. They were chosen based on a field survey and an analysis of digital maps and had approximately the same steepness and similar soil properties characterized by K factor. Data about crop rotations, tilling methods and erosion control measures employed on land blocks was collected by the field survey. Other data was obtained from digital maps. The long-term average annual soil loss caused by water erosion (G) was calculated using the erosion model USLE 2D and ArcGIS 10.1. The digital terrain model, which was the main input to USLE 2D, was based on 3D contours of ZABAGED® (1:10 000). The statistical analysis was carried out in SPSS Statistcs 21. The nonparametric Mann-Whitney test was used for the statistical evaluation of the data. The difference between the soil loss (G) on land blocks managed by small producers (owners) and large producers (tenants) was significant ($p < 0.05$). The average value of G for owners was 4.34 t/ha/year and the average value of G for tenants was 13.07 t/ha/year. Differences between the values of the cropping-management factor (C) were not statistically significant ($p = 0.054$). Based on the analysis of other variables in the USLE equation it can be stated that a continuous slope length (l_d) conditioned by the size of land blocks played an important role in the amount of soil loss caused by water erosion. The value of l_d was on average 70 times greater for the land blocks used by tenants compared with the land blocks farmed by owners. Greater diversity of landuse was observed in the case of owners, while in the case of tenants cropland represented 75% of landuse. A greater diversity of cultivated crops on arable land was observed on the rented land. However, the situation was different with regard to the percentage of crops planted, because with tenants corn for grain or silage and winter wheat represented 61%, while the crops that owners cultivated were more evenly represented. Above all, to protect the soil from erosion and maintain soil quality it is necessary to reduce the size of land blocks farmed by tenants and improve the crop rotation systems.

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