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The influence of different types of grassland on soil quality in upland areas of Czech Republic

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Abstract

The diversity of grassland in upland areas of Czech Republic was studied on selected soil characteristics of these biotopes. In the first phase, 44 soil characteristics were studied and mutual correlations were found between many of them. In the following phase characteristics were chosen which correlated most with other soil characteristics and, at the same time, were easy to evaluate in practise. A great number of correlations were also evidenced between many soil characteristics and the content of humus and nitrogen, which are closely linked to organic matter in soil. In studying these characteristics on selected areas with different types of grassland and consequential cluster analysis and further evaluation, the grassland plots were divided into three groups, from newly established vegetation to species-rich communities. Non-parametric analysis was carried out on the results and a statistically significant difference was proved between the species rich and poor vegetation and carbon and nitrogen content of the soil. Slightly different humus quality (higher amount of HA) was also found under richer vegetation. These results show that at 0 – 20 cm layer, 58.9 tonnes of carbon ha^{-1} was measured under species-poor pastureland and 106.1 tonnes of carbon ha^{-1} under species-rich vegetation. The results showed that besides supporting species diversity, the described quality change can also be important for carbon sequestration. The difference of about 40 – 50 tonnes of carbon ha^{-1} and converting 10% of grassland in the Czech Republic to species-rich vegetation would mean sequestration of about 3.9 Mt carbon. If only agroenvironmentally subsidized areas are converted, carbon sequestration in such vegetation could amount to 1.7 Mt.

Key words

Biodiversity, Carbon sequestration, Grassland, Organic matter, Soil

Introduction

Soil plays an important role in carbon cycle on Earth and also ensures key functions related to productivity of the world's agroecosystems. Carbon is also a suitable agro-environmental indicator of soil quality. To use more specific data, the atmosphere contains approximately 760 Pg carbon while carbon content in soils is significantly higher – about 1567 to 2011 Pg (IPCC, 2000; Houghton, 2007). Of this amount, about 40% is contained in soils of agroecosystems where it can be controlled, to a certain extent, by farmers. The estimate is that about 8% of atmospheric carbon per year passes from atmosphere to soil and back again (IPCC, 2000). The global estimate of carbon content in arable soils is about 10% of total soil reserves (Paustian *et al.,* 2000) while grassland contains about 30% of this amount.

Soil organic matter is of great production and non-production importance as it affects number of soil characteristics. The change in organic matter content is determined, among other factors, by the change in land use towards agricultural utilization. The amount of carbon in the soil depends on input from plant and animal residue and on losses (emissions from decomposing material, erosion, etc). The possible increase in carbon content of soil is thus determined by these two components and can be achieved either by increasing the input and/or reducing the losses. Both these components are influenced by number of factors, including agricultural management. The potential carbon sequestration due to a change in land management is estimated at 250 – 500 kg carbon ha^{-1} yr^{-1} (Lal, 2003), with the greatest carbon storage rate occuring in conversion of arable land to grassland or forest (Guo and Gilford, 2002).

A significant amount of soil organic carbon is released when the natural ecosystem is disturbed by agricultural management (Post and Kwon, 2000). Tiessen and Stewart (1983) showed that during intensive agricultural activity the supply of carbon in soil dropped in numerous areas. Antle and McCarl (2002) described how the supply dropped by 20 – 50 % within 50 years when natural soil was cultivated. Morami *et al.* (2006) described the decrease in organic matter content after introduction of intensive soil tillage, which showed change in soil characteristics and increased CO_2 emissions and loss of organic carbon and nitrogen. Six *et al*. (1998) concluded that difference in aggregate turnover largely control the difference in fine particular organic matter in conventional tillage vs. no-tillage, and consequently soil organic matter was affected by both the amount of aggregation and aggregate turnover.

If the state of soil organic matter is considered under extensive systems, then carbon accumulation in soil can occur even in agriculture (e.g. West and Post, 2002), which is determined e.g. by change in soil fertility. Content of organic matter in soil often increases when a crop-based system is changed to permanent vegetation. Such vegetation can be considered, in terms of landscape heterogeneity and biodiversity, to be another indicator of quality of the environment. Increased content of organic matter in soil was monitored in the upper 10 cm layer of soil by e.g. Don *et al.* (2009). A simillar increase in the amount of organic matter was also confirmed by McLauchlan *et al.* (2006).

Other types of intervention in agroecosystems also affect the content of organic matter in soil. For example, Billings *et al.* (2006) described increased volume of soil carbon after a five year experiment with fertilizing. In Canadian conditions, Malhi *et al.* (2003) also described an increase in carbon content. Disturbed soil of grassy vegetation have potential for carbon sequestration and some research projects state that fertilization can affect this sequestration (Billings *et al.,* 2006). Fertilization can increase the amount of captured carbon by increasing the production of biomass, both surface and subsurface. This is also documented by research results from Switzerland, where Ammann *et al.* (2007) studied newly established plots of grassland with variable intensity of use. During three-year study, they found that in comparison to extensive management, intensive use and supplies of nitrogen lead to higher production of biomass and reduced the loss of SOC caused by mineralization. Changes in such plant biomass *via* activity of microbial communities can lead to long-term storage of carbon in the soil. However, increased primary production does not necessarily always lead to increased carbon sequestration, because of higher loss due to respiration (e.g. Verbung *et al.,* 2004). Increased carbon mineralization of recalcitrant carbon pools after fertilizing with nitrogen has been described by Dijkstra *et al.* (2005).

Besides production of biomass within an agroecosystem, plant diversity also affects the stability of ecosystem. This in turn may additionally determine carbon sequestration in soil. Few publications have so far dealt with the influence of biodiversity on carbon fluxes. Among the few studies published, Adair *et al.* (2009) stated that the total subsurface carbon allocation increased in response to increasing biodiversity. In this experiment renewed areas of grassland, with diversity of 1 – 16 species of plants, were studied. There was greater diversity in a study by Steinbeiss *et al.* (2008), where the studied areas comprised of 1 – 60 species of plants. In the experiment carbon storage significantly increased with sown species richness in all depth segments and carbon losses were even significantly lower with higher species richness. During 12 year experiment, Fornara and Tilman (2008) showed that high-diversity mixture of perrenial grassland plant species stored 500 and 600 % more carbon and nitrogen than, on average, monoculture plots of the same species. Carbon sequestration in soil is a complex problem when e.g. diversity of plants can relate to stimulation of subsurface microbial activity, but there is a lack of information on sequestration of carbon in soil (Fornara and Tilman, 2008).

From the scientific studies published to date, it is evident that little attention has been given to the relationship between biodiversity of grassland and soil characteristics. This study examined how different methods of grassland management and their varying biodiversity relate to chosen soil characteristics, and looks at the correlation between physical and chemical characteristics of the soil being studied. Attention was also given to the question of carbon sequestration in various grassland biotopes.

Materials and Methods

During first phase of study, while monitoring soil on Czech organic farms, soil characteristics were selected (from a wide spectrum) which showed greatest mutual correlation. They were further studied on farms in the Jeseniky Microregion (Fig. 1) with various types of grassland. In this area, 10 farms were chosen which are managed organically according to EU Council Regulation No. 834/2007. The chosen areas of farmland varied in livestock load and management, and therefore also in diversity of grassland. Since 2000 this has been evaluated 3x and soil samples for analysis were repeatedly taken from the chosen areas of land.

The physical and chemical characteristics of the soil were measured by the methods commonly used in pedological laboratories (Klute *et al.,* 1986; Page *et al.,* 1982). On the basis of correlation between individual characteristics and practical feasibility, the following basic variables were chosen and proposed for soil monitoring.

Soil texture was assessed by hydrometer method. Soil samples were collected in Kopecky cylinders to measure bulk density and porosity, and minimum air capacity was expressed by the proportion of non-capillary pores.

pH of soil was measured by KCl or $CaCl_2$ leach, conductivity was measured in field by Delta T Devices firm (WET Sensor, type WET-2). Exchangeable ions were estimated after leaching the soil sample in an acidic solution according to Mehlich III. Analysis relating to organic matter included measuring carbon after oxidation by chromic acid in the presence of surplus sulphuric acid (Nelson and Sommers, 1982). Quality of humus was expressed as ratio of humic acid to fulvic acid (HA:FA), using spectrophotometry at 465 and 665 nm. Organic nitrogen was measured by Kjeldahl method with breakdown via sulphuric acid and release of NH_4^+ ions. A respirometric test was carried out to outline the basic biological processes. CO_2 production was measured under laboratory conditions (Šantrůčková, 1993).

Botanical evaluation of studied localities was compiled from data gained during field floristic and phytogenic surveys. These were undertaken repeatedly during spring and summer months. The Jeseníky microregion, which was studied, lies within the temperate zone of Holarctic floristic kingdom, in Central European province (deciduous forest of the temperate zone of Europe). The whole area lies within Central European province of the Central European floristic area. Orographic and climatic conditions within this area have determined the existence of both temperate zone flora (Mesophyticum) and psychrophilous zone flora at higher altitude (Oreophyticum). The floristic survey within the studied area was processed comprehensively, using basic floristic methods. Only taxons of higher vascular plants were recorded and the nomenclature corresponds to the "Key to Czech Flora" (Kubát, 2002).

For purpose of studying vegetation, 2–3 homogenous micro-localities were randomly chosen (from possible locations registered by farmers according to individual forms of management) on each organic farm; the area of each plot was roughly between 16 and 25 m^2. In tabular processing of the images of vegetation, methods of Zurich– Montpellier School were used (Moravec *et al.,* 1994). Degree of cover and abundance were recorded according to 7 grade Braun-Blanquet scale. The names of syntaxons used were consolidated according to the summary of plant communities within the Czech Republic (Moravec *et al.,* 1994; Chytrý *et al.,* 2007). From the year 2000, evaluation was carried out 3 times, always during the same vegetation period (spring). All plots were maintained as grassland and only varied in the form of management, *i.e.,* the type of renewal (renewal of grass communities, unrenewed original vegetation).

The results of soil analysis were worked out at the

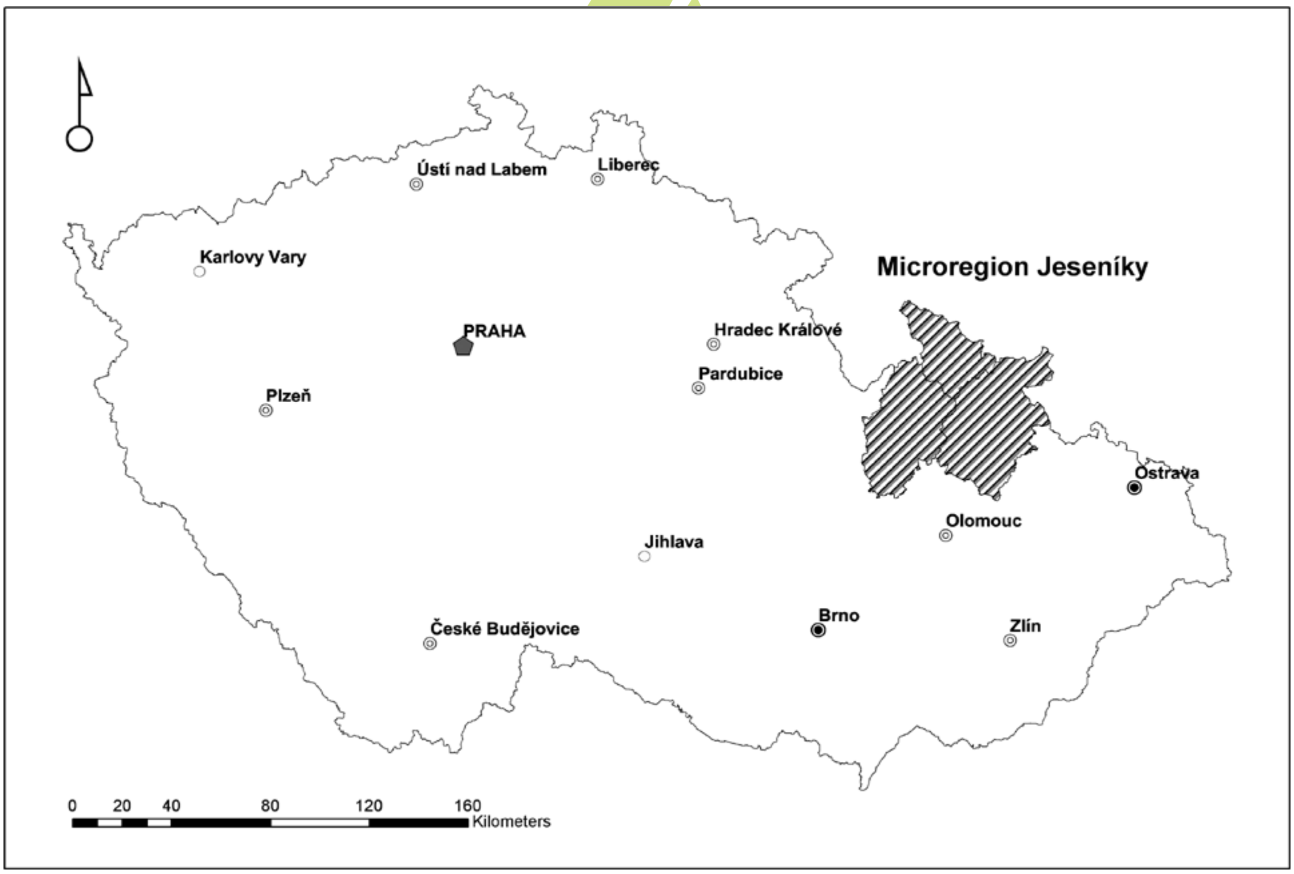


Fig. 1 : Map of study area - Jeseníky microregion, Czech Republic

beginning of project using correlation. Kruskal-Wallis analysis was done to identify statistically significant differences in individual groups of grass vegetation on the basis of soil characteristics. In this article, differences are only stated for carbon and nitrogen Cluster analysis was used to express the similarities between individual farms according to soil characteristics. A "Statistical" programme (StatSoft) was used.

Results and Discussion

On the basis of detailed botanical analysis, the first part of research divided the grassland plots into the following categories which differ in method of management and diversity of communities.

Temporary grassland–newly established grassland : Species richness of the herb level was between 12–20 vascular plant species within the area. The vegetation was not fully closed; and the degree of total cover was between 60 –90%. The herb level was dominated by *Trifolium pratense* and *T. repens*. Grasses were significantly abundant (*Trisetum flavescens*, *Dactylis glomerata*, *Lolium perenne* and *Phleum pratense*) with the addition of broad-leafed nitrophilous herbs such as *Anthriscus sylvestris, Chaerophyllum aromaticum, Cirsium arvense, Taraxacum sect. Ruderalia* and annual weeds, like *Tripleurospermum inodorum, Veronica arvensis, Capsella bursa pastoris* and *Thlaspi arvense*. Original pastureland species started appearing: *Achillea millefolium* agg., *Alchemilla vulgaris* s. lat., *Leontodon autumnalis*. The moss level was not developed.

Temporary grassland - older re-cultivation : Species richness of the herb level was between 21 – 27 vascular plant species within the area. In few parts of pasture area, the vegetation was not fully closed; degree of total cover of the herb level was found between 70 – 100%. Species with wide ecological valence prevailed in the community – *Ranunculus repens*, *R. acer*, *Equisetum arvense*, *Trifolium repens*, *Pastinaca sativa* s. lat., *Lotus corniculatus, Cerastium holosteoides* subsp. *triviale*, *Daucus carota subsp. carota, Galium mollugo* agg., *Glechoma hederacea, Leontodon autumnalis, Achillea millefolium* agg., *Euphorbia cyparissias, Veronica chamaedrys* agg. and *rhizome-spreading grasses Alopecurus pratensis, Agrostis capillaris, Holcus lanatus* and *Lolium perenne*. Large colonies of numerous ruderal species were obvious in the phytocenoses (e.g. *Potentilla anserina, Rumex obtusifolius, Tanacetum vulgare* and *Urtica dioica*).

Seminatural grassland – species-rich communities : This group included original pasture areas which were not re-cultivated for last 40 years and were grazed extensively (very low density of animals, no fertilizing). Species richness of the herb level was between 28–40 vascular plant species within the area. The vegetation was completely closed (total degree of cover of the herb level here is 100%) and two levels were vertically distinguishable. The highest level mostly consisted of grasses (*Agrostis capillaris*, *Anthoxanthum odoratum*, *Dactylis glomerata*, *Festuca pratensis* s. lat., *Phleum pretense*) as well as dicotyledonous species tolerant to regular grazing and trampling

Table 1: Correlations between soil characteristics of grassland ($p < 0.05$ and 0.01, resp.)

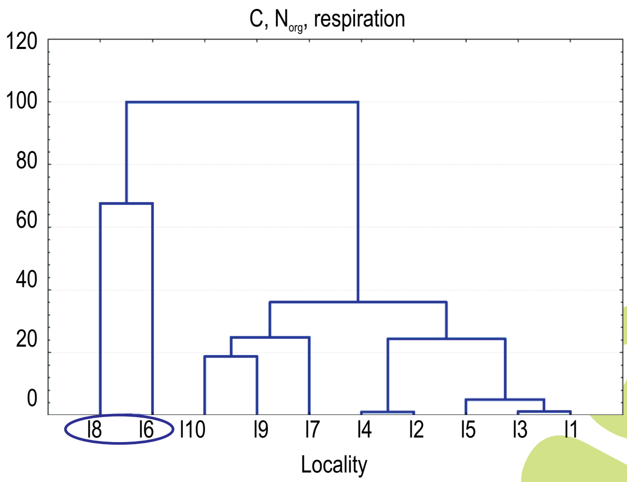
Porosity (%)	Conductivity ($mS.m^{-1}$)	pH/$CaCl_2$	P ($mg\ kg^{-1}$)	K ($mg\ kg^{-1}$)	Ca ($mg\ kg^{-1}$)	Mg ($mg\ kg^{-1}$)	$C_{org.}$ ($mg\ kg^{-1}$)	$N_{org.}$ ($mg\ kg^{-1}$)	HA:FA (Q 4/6)	Respiration ($mg\ CO_2\ 100\ g^{-1}$)	
-0.36	-	-	-	-	-	-	-0.48	-0.53	-	-0.38	Bulk density
-0.99	-	0.54	-	-	-	-	-	-0.60	-	-	($mg\ m^{-3}$)
	0.39	-	-	-	-	-	-	0.46	-	0.32	Porosity
	-	-	-	-	-	-	-	0.64	-	-	(%)
		0.36	0.40	0.34	0.39	0.45	-	0.31	0.22	-	Conductivity
		0.75	-	0.68	0.68	0.83	-0.76	-0.79	-	-	($mS\ m^{-1}$)
			0.42	0.34	0.79	0.41	-0.28	-0.18	0.32	-	pH/$CaCl_2$
			-	-	0.94	-	-0.68	-0.54	-	-	
				0.50	0.41	0.30	-	-	0.33	-	P ($mg\ kg^{-1}$)
				-	-	-	-	-	-	-	
					0.34	0.30	-	-	0.33	-	K ($mg\ kg^{-1}$)
					-	0.83	-	-0.58	-	-	
						0.54	-0.20	-	0.36	-	Ca ($mg\ kg^{-1}$)
						0.71	-0.72	-0.63	-	-	
							-	-	-	-	Mg ($mg\ kg^{-1}$)
							-	-0.71	-	0.31	
								0.53	-	0.31	$C_{org.}$ (%)
								0.77	-0.77	-	
									-	0.34	$N_{org.}$ ($mg\ kg^{-1}$)
									-0.61	-	
										-	HA : FA
										-	(Q 4/6)

Key : 0.53 coefficient of correlation (Czech organic farms)
0.77 coefficient of correlation (farms in the Jeseníky microregion)
(coefficients of correlation are in the table positive or negative)
- no significant correlation

Table 2 : Comparison of organic carbon and nitrogen content in relation to diversity of grassland (Kruskal-Wallis ANOVA (and Post - hoc comparison, p <0.05)

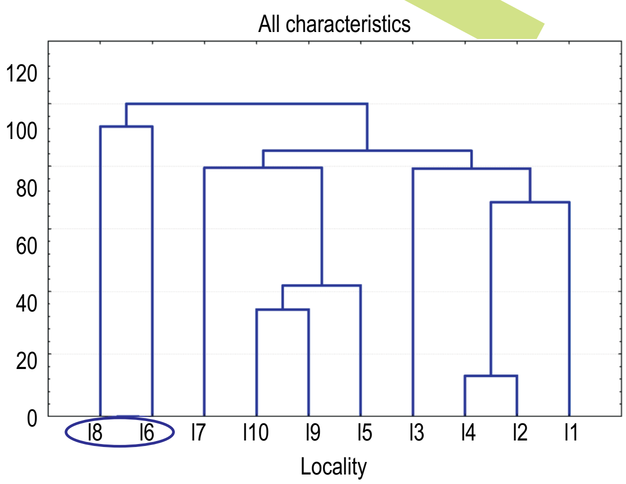
	$C_{org.}$ (%)	$N_{org.}$ (mg kg^{-1})
Newly established	+	+
grassland	2.02	2069.90
Older grassland	-	-
re-cultivation	2.76	3167.13
Species rich communities	+	+
of grassland	3.93	5704.15

Key : + there is a difference between groups; -no statistical difference was found between groups; number average value for $C_{org.}$ and $N_{org.}$



Key : farms with species rich communities of grassland

Fig. 2 : Hierarchical tree of relationship between localities in evaluation of C, $N_{org.}$ and respiration



Key : farms with species rich communities of grassland

Fig. 3 : Hierarchical tree of relationship between locations in evaluation of all studied soil characteristics

(*Achillea millefolium* agg., *Centaurea jacea*, *Campanula patula*, *Galium mollugo* agg., *G. verum* agg., *Heracleum sphondylium* s. lat., *Hypericum maculatum*, *Leucanthemum vulgare* agg., *Leontodon autumnalis*, *L. hispidu* and *Pimpinella saxifraga*). The ground level consisted of *Ajuga reptans*, *Hieracium pilosella*, *Luzula campestris* agg., *Alchemilla vulgaris* s. lat., *Taraxacum sect. Ruderalia*, *Bellis perennis*, *Euphrasia rostkoviana*, *Glechoma hederacea*, *Plantago lanceolata*, *P. major*, *Prunella vulgaris*, *Veronica chamaedrys* agg., *Trifolium repens*. The vegetation also included groups of plants which were thorny, poisonous or disliked by cattle and visibly tower over the surrounding low vegetation (*Artemisia vulgaris*, *Carduus* spp. div., *Cirsium* spp. div., *Colchicum* spp. div., *Rumex* spp. div.). The moss level was often found to be absent or quite poor.

During the research period, important correlations were registered between number of soil characteristics and organic carbon and nitrogen content (Table 1). Non-parametric analysis of these results statistically confirmed significant difference between species-poor and species-rich plant communities in terms of carbon and nitrogen content in the soil. During evaluation, it was found that the difference between intensive and extensive species-rich communities varied between 40 - 50 tonnes carbon ha^{-1}. This was evident from the data obtained, which show that 58.9 tonne carbon ha^{-1} was found 0–20 cm layer in re-cultivated, species-poorer pasture, while in species rich communities this amount was significantly higher – 106.1 tonnes carbon ha^{-1}.

A slightly better quality of humus, expresed by HA : FA ratio under species-richer vegetation was not significant in the present study. A higher stability of organic substances contained in soil can relate to this. Other differences were also registered in other soil parameters in individual types of communities. Statistically significant differences found in parameters relating to soil organic matter via Kruskal Wallis test (Table 2). Species-rich communities were also earmarked from the overall set by cluster analysis (Fig. 2 and 3), both in terms of soil organic matter (organic carbon and nitrogen), and on the basis of processing all studied soil characteristics.

In the present study, correlation was found between number of soil characteristics and humus and total nitrogen content. Significant difference between species-poor and species-rich plant communities was described in terms of these characteristics. This is in accordance with the reports of Conant *et al.* (2001), who conclude that grassland can act as a significant carbon sink with the implementation of soil-protecting management. Management practices affect the loss or carbon sequestration in soils. The experimental results revealed that physical and chemical characteristics, including soil carbon and nitrogen were maximum in moderately grazed meadow and minimum in intensively grazed meadow (Singh and Rai, 2004). Maia *et al.* (2009) described how, in Brazilian conditions, degraded grassland management and nominal management on Oxisols increased stock, while nominal management on other soil types and improved management on Oxisols increased stocks of carbon. Steinbeiss *et al.* (2008) studied relationships between plant diversity and carbon storage. Carbon storage significantly increased with species richness achieved by additional sowing and carbon loss were significantly smaller with higher species richness. The increasing species diversity increased root biomass production and this diversity was very important for change in soil carbon.

Similarly, Gerzabek *et al.* (2002) found difference in the carbon content in the soil of intensively utilized grassland and extensive communities (alpine meadows). In the first case, carbon content at 0-20cm layer was 60.5 tonnes ha^{-1} and in the latter 91.8 tonnes ha^{-1} (Gerzabek *et al.,* 2002). This data corresponds to the present findings where at 0 – 20 cm layer 58.9 tonnes carbon ha^{-1} was measured in species-poor pasture vegetation (with respect to bulk weight of soil), while in species-rich communities it was 106.1 tonnes carbon ha^{-1}.

Such increase was probably due to the biomass of roots transformed to soil carbon by microorganisms. Carbon input depends on particular plant species and on competition between different plants, ranging, according to specialist publications, from 10 to 280 g carbon m^{-2} yr^{-1} (Rees *et al.,* 2005). Steinbeiss *et al.* (2008) also concluded a similarly wide range and described that for carbon storage, biodiversity expressed as species richness was more important than any difference in the biomass input. Some studies also emphasized on high biomass of the subsurface plant parts in species-richer grassland in comparison to intensively fertilized re-cultivated grassland (Fiala, 1993).

Carbon sequestration in soils has been discussed in recent years in relation to many factors (e.g. climate change, type of agricultural management, soil type, initial condition). The amount of carbon which can be sequestrated in soils differ according to land use and type of management. In arable land with zero-tillage system, it was about 1.42 tonnes CO_2 ha^{-1} yr^{-1}, in reduced tillage system the result was below this value. In permanent vegetation (grasses, crops), the value was 2.27 tonnes. In recent years, organic farming has been developing globally and the amount of sequestrated carbon under such a system vary from 0 to 1.98 tonnes. Grassing arable land is very important for sequestration, amounting to 7.03 tonnes or 5 tonnes. On the other hand, ploughing up grassland resulted in reduction of carbon in soil by 3.66 tonnes CO_2 ha^{-1} yr^{-1} (Smith *et al.,* 1996, 2000; Vleeshouwers and Verhagen, 2002; Freibauer, 2003; Gumbert, 2002). On the basis of this, scenarios for potential carbon sequestration in European soils have been drawn up (Gumbert, 2002). For a conversion from arable land to permanent grassland this potential was estimated to be 140 Mt CO_2 yr^{-1} (Vleeshouwers and Verhagen, 2002). However, these changes can be initiated, according to the present findings and specialist publications (Gerzabek *et al.,* 2002; Bardgett *et al.,* 2009), not only by grassing but also via qualitative changes in grass vegetation, *i.e.* strengthening their species diversity: considering the difference between intensive and extensive species-rich communities which is about 40 – 50 t carbon ha^{-1} as it was found during our research and conversion of 10% of Czech grassland acreage to species-richer communities, sequestration would amount to about 3.9 Mt C. If such a change is implemented only in areas with agroenvironmental measures (20% of grassland) then carbon sequestration in these communities could reach about 1.7 Mt.

Besides environmental effects such natural carbon binding can even have an economic dimension, as the cost of sequestration is currently being discussed, according to some studies it may range between 10 and 25 USD per tonne (Pretty *et al.,* 2002). Research into grassland diversity and soil characteristics of these biotopes show the importance of species-rich communities for several characteristics, including those relating to soil organic matter. These communities become an important store of carbon and organic nitrogen, which are also in correlation with other soil characteristics. The results of the research may help to optimise sensitive landscape management and in the proposal of subsidy policy systems within agro-environmental measures.

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