Soil Organic Carbon Dynamics and its Influence on the Soil Erodibility Factor

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Abstract: The effect of erosion and erosion control measures on changes in the amount of organic matter in soil was studied. We investigated the influence of organic matter inputs into the soil on surface runoff, soil erosion and soil erodibility (K-factor), including the monitoring of carbon dynamics, as a result of torrential rains. The research was conducted on experimental plots in Třebsín site. Erosion leads to soil carbon loss and subsequently to increasing concentrations of carbon in sediments (enrichment ratio). We can conclude from the results that the input of organic matter into the soil (especially farmyard manure) significantly contributes to a decrease in surface runoff and soil loss and also to a reduction of carbon leaching into sediments; so it contributes to carbon sequestration into the soil.

Keywords: agrotechnical erosion control measures; soil erodibility factor; soil erosion; soil organic carbon

The global problem of accelerated soil erosion is a major environmental threat to sustainability and productive capacity of agricultural soils (Pimentel *et al.* 1995). The reduced productivity of eroded lands further decreases their functionality (Tongway & Ludwig 2003) and degrades ecosystem services (Lal 2010). Croplands are the most vulnerable to erosion because of the scanty vegetation cover and seasonal disturbance of the surface soil. The vulnerability of croplands to erosion is determined by management practices and by a range of physical conditions, including climate (Das *et al.* 2004), lithology (Figueiredo *et al.* 1999), topography (Kimaro *et al.* 2008) and soil texture (Seeger 2007). The main risky periods for runoff and soil erosion occur when the vegetation cover is minimal and rainfall intensities are relatively high, which is the case of summer crops such as sugar beet and maize (known as well as broad-row crops) during the spring season (Leys *et al.* 2007).

Among various forms of erosion, interrill erosion seems to be the most dangerous in conditions of this country. Horton already observed that phenomenon in 1933 and he described it as erosion occurring in interrill areas which are the areas between small rivulets called the rills (rill erosion) caused by concentrated runoff on the soil surface. Apart from the loss of fertile soil and muddy floods, runoff from arable land can cause the pollution of water bodies by sediments and transported agrochemicals and nutrients (Verstraeten & Poesen 1999; Steegen *et al.* 2001; Holland 2004). Even if the soil is not washed away and remains on the same area (parcel) after the erosion process, it modifies its own natural biological, physical or chemical properties.

The increasing concentration of atmospheric carbon dioxide (CO_2) and other greenhouse gasses in the 20th century (IPCC 2001) showed an increasing interest in resources which cause a reduction of these gasses (Lal 2006). The global carbon cycle plays an important role in global climate. The Kyoto protocol from the year 1997 emphasizes that soil is the main carbon reservoir, which must be protected and carbon sequestration should be supported. Carbon sequestration in agricultural soils can contribute to climate change mitigation through some management practises (e.g. protective cultivation technology).

Soils store approximately 1500 gigatons of carbon. Thus soils contain three times more carbon than the air (Lal 2003).

Soil organic carbon has a significant effect on chemical and physical characteristics of soil and it is one of the essential components of soil quality assessment (Gregorich *et al.* 1994; Lal 2004). Lal (2004) reported a high rate of carbon loss from soils on eroded sites.

Soil erosion should be considered as a multilevel process which includes: (1) separation of soil particles; (2) transport and redistribution of eroded sediment in landscape; (3) sedimentation or loss of particles into water systems.

All erosion stages cause an adverse impact on carbon loss (Lal 2006). The fact that carbon is concentrated in the surface layer (0–20 cm) has numerous consequences, because it can be easily released, transported and sequestrated into sediments. As a consequence, higher carbon content (higher carbon enrichment ratio) was observed in sediments.

An overview of the impacts of soil erosion on carbon dynamics in each stage: (A) a decrease in soil mineralization during soil carbon depletion, that is why soil productivity and biomass content are decreased; (B) water disruption of soil particles (soil aggregate disintegration) and subsequent transport also accelerate mineralization; (C) carbon concentrated in colluvial and alluvial sediments can contrarily decrease mineralization (Lal 2003).

The increase in carbon dioxide as a result of erosion is based on the fact that a larger part of released carbon from eroded soils is easily mineralized. From long-term experiments the annual net flux of carbon to the atmosphere from water erosion was calculated to be 0.37 Pg CO_2 (Jacinthe & Lal 2001).

Experiments based on surface runoff show that 29–45% of exported carbon by surface runoff was potentially mineralized. Similarly, it was proved on all samples from simulated runoff from small catchments that surface runoff intensity significantly affects the impact of erosion on the carbon cycle (Jacinthe *et al.* 2002).

Roose & Bartches (2006) compared data from numerous experiments concerning the effects of land use on soil carbon losses by erosion in surface runoff from different climatic, inclination, soil and management conditions. The effect of carbon enrichment ratio in sediments was also discussed. Surface runoff was observed from 54 lands under different vegetation cover of soil and different management practices. It was found that the organic carbon loss by water erosion was 1–50 kg C/ha/year in soils protected by plant remains, 50–500 kg C/ha/year in harvested fields, burned soils or grazed pastures, and more than 1000 kg/ha/year in bare soils.

In another study in northern Algeria, the impact of land use and different management practices on runoff, erosion and carbon dynamics was observed. The carbon loss by erosion was 0.1–42 kg C/ha/year on plots with vegetation cover, 19–136 kg C/ha/year in bare soils, which was related to soil type, inclination, land use and cultivation. The annual loss of eroded soil was relatively closely correlated with annual erosion on runoff plots and with carbon content in the topsoil. The study also showed that sediments contained a higher amount of carbon than the topsoil and that this enrichment ratio increased according to the soil cover type; that means lower cover = higher enrichment ratio (Morsli *et al.* 2006).

According to Robert (2006), the increase in soil carbon sequestration can be done by: (A) conversion of arable soil to forest or pasture/meadow – the carbon fluxes increase by 0.5 t C/ha/year on average; (B) change in agricultural management by protective cultivation – e.g. no-tillage seeding, leaving 30% of mulch on the soil surface.

MATERIAL AND METHODS

Site description. The experimental site Třebsín is situated near Jílové near Prague at an average altitude of 340 m in Sázava and Vltava watersheds. The erosion research has been conducted on this site since 1986. It is a unique area in the Czech Republic which is used for direct measurement of actual erosion in agriculturally managed soils.

There are 9 experimental plots 35 m in length and 7 m in width. One plot 2 m in width and 25 m in length is maintained as fallow land (without any vegetation).

The surface runoff from each experimental plot is diverted by channels into a collection tank of the volume of 1 m^3 and additional tank for collecting another 1/5 of total runoff.

A telemetric station equipped with ombrographs is installed on the research site. The study site has mildly warm, mildly moist climate with mild winter. The mean annual temperature is 7.4°C and mean annual precipitation is 517 mm. Geomorphologically, this locality is a part of the Benešov hilly area and the terrain is characterised in some places by very broken topography with very sloping lands. Geological bedrock consists of schist of the older Palaeozoic era. Very deep medium-fine soils without gravel originated on these substrates, however, the soil was significantly washed away by water erosion on sloping lands. The soil is classified as silt, with quite low soil organic matter content. There is a hard soil treatment, with no good moisture regime. The soil structure of topsoil corresponds mainly to crumb structure, while in some plots it is cloddy structure. The study site is situated on the slope of north exposition (Figure 1). The average inclination of plots is 8°.

The soil type was identified as Haplic Cambisol (FAO 2006).

Description of experimental research. The influence of fertilization on organic matter input to soils and carbon dynamics was examined in relation to surface runoff, soil loss by erosion and soil erodibility (K-factor) as a result of the occurrence of torrential rains. Changes in soil organic matter (SOM) were evaluated, including a survey of initial accumulation, infiltration and initial soil water content.

The soil erodibility factor is one of the six factors in the Universal Loss Equation (USLE) (Wischmeier & Smith 1978), which depends on soil structure, texture, permeability and soil organic matter content. That is why soil samples were taken regularly several times per year for determination of soil texture (and/or particle size distribution curve) and soil organic matter content. On the basis of soil sample analysis and soil erosion loss, the carbon transport was studied.

The basic analysis was performed on samples of fine particles (< 2 mm) (ISO 11464:2011). TOC (total organically bound carbon) was determined as C_{ox} (total oxidizable carbon) (ISO 14235:1998), soil organic matter was expressed as content of $C_{ox} \times 1.724$ (Nelson & Sommers 1982), C_{pyro} (pyrophosphate-extractable carbon – active forms of Al, Fe – organic ligand, Van Reeuwijk 1992); C_{pm} (permanganate-extractable carbon – labile carbon forms, Blair *et al*. 1997); C_{hws} (hot water-extractable carbon – activated carbon forms, Körchens *et al*. 1990).

The research was conducted on this site from 2008 to 2011. During the experimental time maize (*Zea mays* L.) was cultivated all plots except the fallow

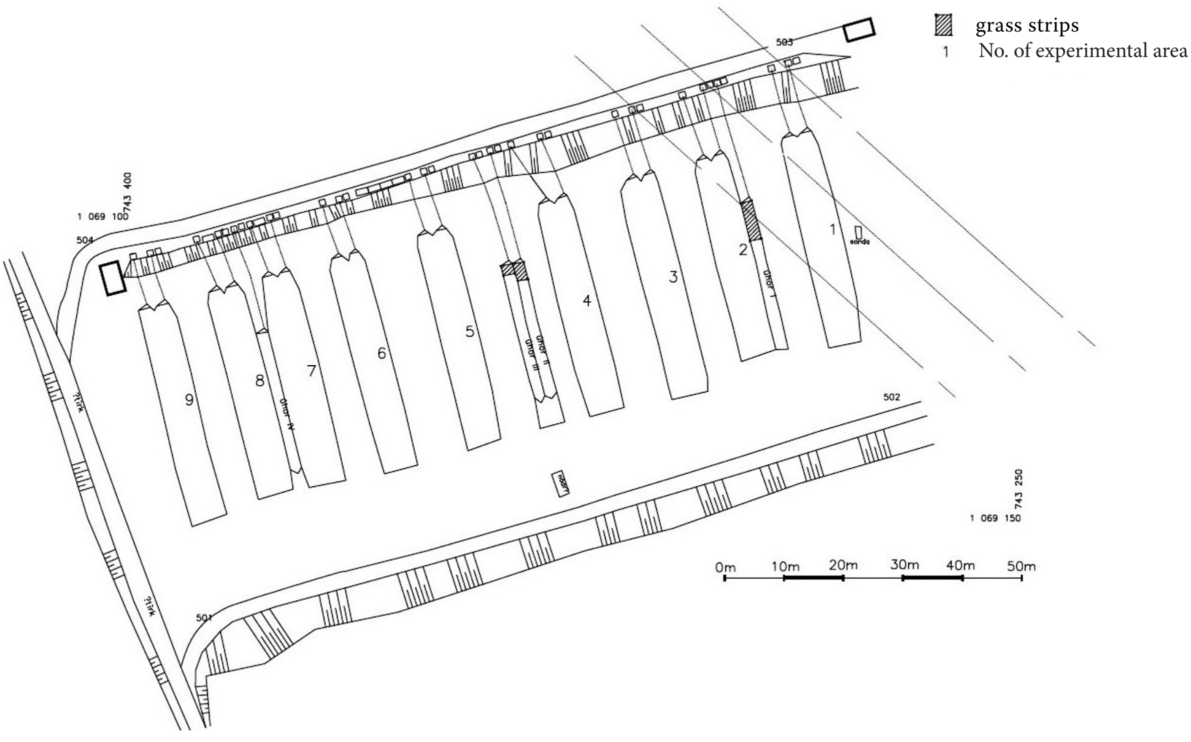

Figure 1. Topographic plan of Třebsín study site (author L. Chamout)

land. There were nine plots in three variants (repeated 3 times). The carbon dynamics was observed since 2009. The control variant was fallow land.

(1) Variant V1 (farmyard manure – FM) – maize sown into the cultivated soil after farmyard manure ploughing down in autumn at an amount of 300q/ha each experimental year. Before ploughing, farmyard manure was equally spread out by a manure spreader and shallow ploughing done was by a rototiller.

(2) Variant V2 (green manure – GM – *Sinapsis alba*) – maize sown into the soil after application of green manure by ploughing down of *Sinapsis alba* in mid-August. *Sinapsis alba* was sown at a seeding amount of ca. 12 kg/ha.

(3) Variant V3 (no manuring – NM) – maize sown into the cultivated soil without organic fertilizers. Only stubble breaking was performed in autumn and after germination of weeds a rototiller was used. In spring the common seed-bed preparation was done with sowing into the cultivated soil.

(4) Variant V4 (fallow land – FL).

Soil samples were taken four times per year from all 9 plots and from the fallow land, at a depth of 0–10 cm, from 3 places on each plot (top, medium and lower part of catena). In total, 160 soil samples from 480 places (1 sample taken from 3 places on each plot) were analysed.

Water and sediment samples were taken after the event of natural rainfall, so the number of soil samples depended on the amount of rainfall during the year. Totally, 377 samples were taken in the years 2008–2011.

RESULTS

One soil sample set was taken before the start of our experiment (before manuring) in October 2007. The other 15 soil sample sets were taken since 2008. During the four years of the experiment we found a positive effect of manuring, which was expressed by an increase in soil organic matter content and by a decrease in K-factor values on plots applied farmyard manure. This change is shown in Table 1.

At the beginning of our experiment, the soil organic matter content was approximately the same at all variants, it was lower only in fallow land. The application of farmyard manure for four years in variant 1 increased the organic matter content by 2.3%, while in variant V2 (green manure) the soil organic matter content slightly decreased probably due to fast mineralization of organic matter during winter and spring seasons (see Table 1). Other researchers stated that green manure (also *Sinapsis alba*) mineralizes by 80% during 1 year. Based on the results of soil organic matter content and K-factor on plots with *Sinapsis alba* (V2) we concluded that this variant had approximately similar results like plots without the organic matter input (V3). Comparing the results in the spring season we suggested that a small amount of *Sinapsis alba* was mineralised already during winter and spring, while farmyard manure remained on plots for a longer time. The plots with farmyard manure showed in the long run higher soil organic matter contents compared to other variants. The K-factor values on these plots showed much lower soil organic matter contents compared to the other variants (V2, V3). A positive impact of manuring on an increase in organic matter content was definitely demonstrated. This variant also showed the highest fluctuation during the whole year, as shown in Figure 2.

While comparing the effects of each variant (different ways of manuring) on the development, stabilization and deposition of different organically bound carbon forms in soils and their effect on

Table 1. The soil organic matter content and K-factor at the beginning and at the end of the experiment in Třebsín variant

	Starting testing value (October 2007)		Final testing value (September 2011)	
	SOM (%)	K-factor	SOM (%)	K-factor
V1 (farmyard manure)	2.24	0.44	4.54	0.33
V2 (green manure)	2.14	0.42	1.99	0.43
V3 (not fertilized)	2.40	0.44	1.85	0.44
V4 (fallow land)	1.12	0.38	1.20	0.41

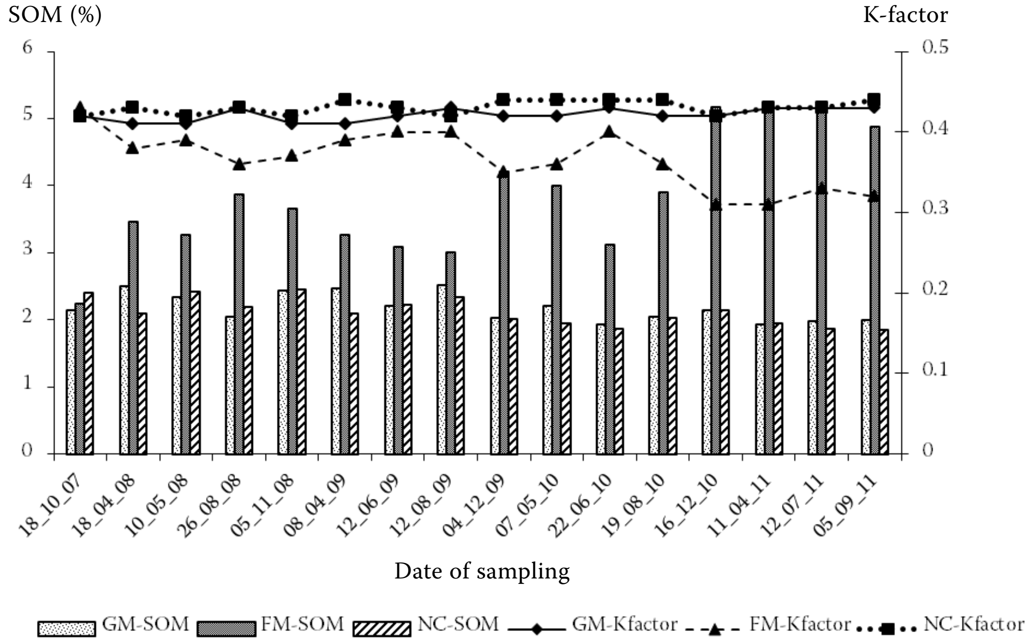

Figure 2. The soil organic matter content and K-factor changes on plots on Třebsín research site in the years 2007–2011

the erodibility factor during the four-year period, a total increase in SOM content was observed for variant V1. The effect of other variants was not proved. The K-factor for all variants highly correlated with the SOM content for all periods. The highest correlation coefficient was computed for variant V1, 98%, the other coefficients were 77% for V3 and 65% for V2. The SOM content is an important determinative item for the K-factor calculation.

During the evaluation of total organic matter a significant increase of organic carbon was detected only for variant V1 (the trend of a gradual increase in total content during the four-year period), for variant V2 the trend was linear (stabilization of SOM) and for V3 the SOM content slightly decreased.

In spite of SOM fluctuations, each fluctuation during the vegetation period is caused by organic matter input (and its transformation and deposition), by total soil loss (leaching of organic carbon in sediments) and by other processes of soil carbon sequestration. It is necessary to consider all these factors.

The first factor is the impact of carbon input which depends on cultivation and management practices and compliance of the identical sowing plan on the experimental site. This factor can be considered as "constant" (in accordance with different ways of manuring).

The second factor which influences mainly the process of SOM deposition is the total content of different forms of organically bound carbon. Four methods were used for this purpose: C_{ox}, C_{pm}, C_{pyro}, C_{hws}. The quantity and quality of organic matter were evaluated by three methods – C_{pm}, C_{pyro} and C_{hws}.

The C_{ox} method (total content of oxidizable carbon) was used as a comparative method. The quality of soil organic matter was evaluated by the method $C_{pm.}$ By this method it is possible to identify different carbon forms or more precisely to evaluate the stability of main humic substances (HS). To monitor the process of sequestration and formation of carbon storage it is necessary to determine the C_{pyro} content (the active organically bound forms of carbon in a complex with Fe and Al). The method C_{hws} is used for determining the extremely labile carbon forms (low-molecular forms of saccharides and lipids – the available nutrients to plant roots).

During the three-year research 11 soil sample sets (4-2009, 4-2010 and 3-2011) from 3 places on all tested plots were taken. Table 2 shows proportional values of each carbon fraction. Each variant is evaluated separately. The median value shows the real value of medium content of a given carbon form for each year. The min and max values of carbon fractions determine the total variance of assessing values during the vegetation period.

While comparing each form and contents of organically bound carbon, the effect of the farmyard manure input (V1) was proved on the potential stabilization (stability of HS) and carbon sequestration in the soil profile. The values of C_{pm} were relatively stable (stabilization of organic matter). The content of stable carbon forms was high in spite of the increasing SOM content and an increase in surface runoff during the year. However, the content of labile soil carbon C_{hws} slightly increased. The C_{pyro} values indicate the content of tightly bound organic matter. The C_{pyro} content (for V1) had a slightly increasing tendency (about 24%). The narrowing of the min/max range is also important (it determines the balance of aggregate forces).

The effect of each form of soil organic matter on the formation of stable SOM in variant V2 was rather reversed than for variant V1. The values for all carbon forms were generally lower than for V1. The organic carbon loss was certainly due to the total SOM inputs and soil washing away, on a sustainable level. The content of each form did not decrease very much, but the organic carbon storages were gradually slightly decreasing.

When compared to variant V3, the contents of each carbon form were lower than for V1 and even for V2. Each trend was not diverse while comparing to variant V2, but there was an obvious trend of a decrease in C_{pyro} content.

The content of different forms of soil organic matter for fallow land (V4) is used for a comparison of the contents of each carbon form. The C_{ox}, C_{pm}, C_{pyro} and C_{hws} contents for V4 were always lower by 50–75% than for the soil with maize crop.

A comparison of the variants by the Box Plot method showed the highest variance on plots

Table 2. The content of organic carbon fractions in soil samples in the years 2009–2011

	2009			2010			2011		
	median	min	max	median	min	max	median	min	max
V1 (farmyard manure)									
C_{ox} (g/kg)	18.4	12.9	30.7	24.2	13.8	34.4	30.6	22.7	34.2
C_{pyro} (g/kg)	3.7	2.3	7.2	3.5	2.3	7.4	4.6	3.6	5.6
C_{hws} (mg/kg)	458	350	1140	643	372	789	655	420	726
C_{pm} (g/kg)	4	3.3	6.5	3.9	2.5	7.2	x	x	x
V2 (green manure)									
C_{ox} (g/kg)	13.8	5.8	5.3	12.5	10.2	13.4	11	10.1	13
C_{pyro} (g/kg)	3.5	1.4	4.5	2.5	1.3	3.3	2.3	2	2.5
C_{hws} (mg/kg)	411	217	520	326	232	587	258	156	355
C_{pm} (g/kg)	3.1	2	3.8	1.9	1.2	2.3	x	x	x
V3 (not composting)									
C_{ox} (g/kg)	13	9.2	14.5	12	7.5	13.8	11.2	8.1	13.6
C_{pyro} (g/kg)	2.8	2	6	2.1	1.2	5	1.7	1.6	1.9
C_{hws} (mg/kg)	318	241	484	305	192	423	247	144	318
C_{pm} (g/kg)	2.9	2	3.5	2	1.3	2.6	x	x	x
V4 (fallow land)									
C_{ox} (g/kg)	7.9	7.3	7.9	7.9	7.5	8.8	7.8	7.5	8
C_{pyro} (g/kg)	1.5	1.1	2.3	1.6	1.3	1.9	1.5	1.2	1.8
C_{hws} (mg/kg)	168	150	342	138	121	222	154	118	215
C_{pm} (g/kg)	1.6	1.3	1.7	1.2	1.1	1.5	x	x	x

x – C_{pm} value was not evaluated in that year

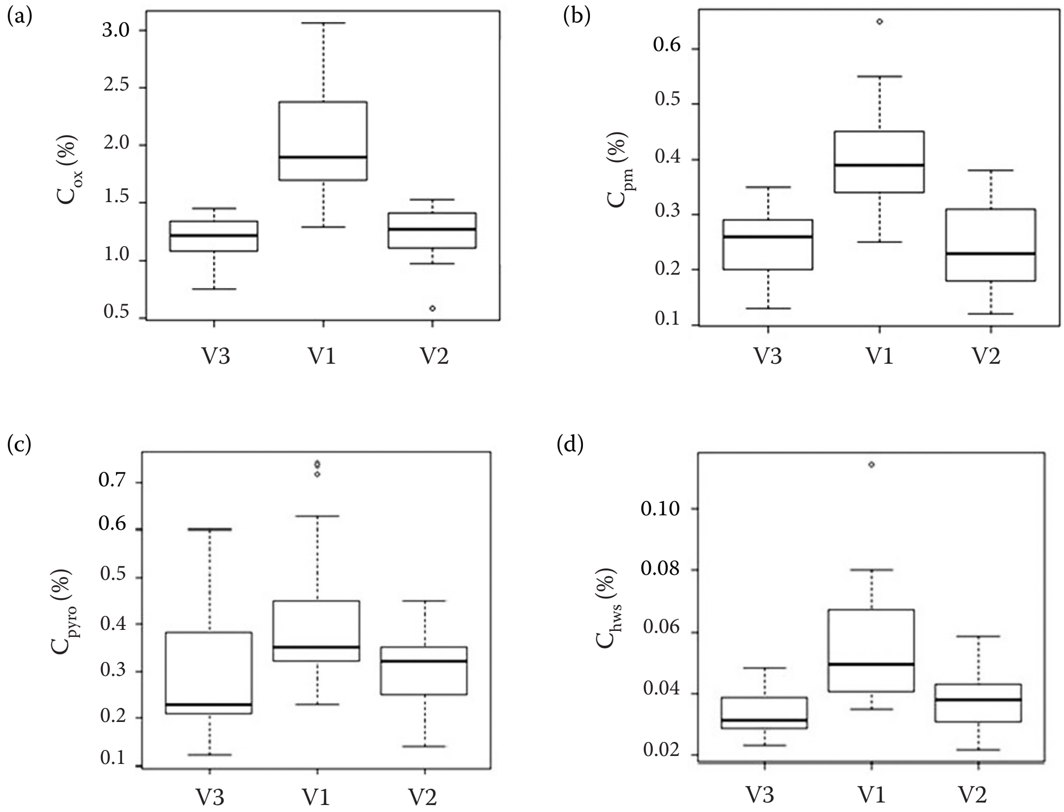

Figure 3. Comparison of the four forms of carbon in three varieties of maize; (a) C_{ox} method, (b) C_{pm} method, (c) C_{pyro} method, (d) C_{hws} method

with maize applied farmyard manure (V1) and the lowest on plots without the organic matter input (V3). Overall evaluation of statistical changes (significance level) is documented in Figure 3.

Figure 3 shows a comparison of each method for determination of partial organic matter characteristics and their provability. In the comparison of increased SOM content for V1, V2 and V3, a statistically significant change was proved while measuring C_{ox} and C_{pm}. From the comparison of the effect of manuring by methods C_{pyro} and C_{hws} an obvious deviation of values for V1, V2 and V3 was found, but this change was not statistically significant.

The third factor, which was evaluated for the assessment of different methods of management and which depends on total SOM input and deposition, was the water erosion – and/or SOM content in sediments after rainfalls. The values of torrential rainfall frequency and total soil loss are shown in Table 3.

During the four-year research, 47 torrential rainfalls were observed. 23 of them caused runoff and soil loss on the plots. An average torrential rainfall total was 22.6 mm; the maximal rainfall total was 61 mm. Table 3 shows the sum of surface runoff and soil loss in each year for the observed variants.

According to Tables 3 and 4, the best variant for the best soil-conservation measure is the cultivation of maize applied farmyard manure (V1). The surface runoff in this variant was lower by 51% than in the variant without the organic matter input (V3) and also the soil losses were lower even by 87.5% (4-year observation). Compared to variant V4, a positive effect of farmyard manure was even more noticeable – the soil loss was only 4% compared to fallow land. The effect of green manure incorporated into the soil (V2) compared to conventional management was much lower – surface runoff was smaller only by 5% and soil loss by 25% compared to V3. We supposed that it was caused by the worse growth of *Sinapsis alba* in the autumn 2009–2010 and thus it gained a lower amount of soil organic matter (during sowing and its growth the soil was extremely dry and with no rainfalls). In general it is obvious that the worst variant is to leave the soil as a fallow land (see

Table 3. Comparison of technologies with respect to surface runoff and soil loss

Variant	Year	Surface runoff		Loss of soil	
		l/ha	%	kg/ha	%
V1 (farmyard manure)	2008	13 266	3.50	98	2.00
	2009	40 332	10.60	533	0.90
	2010	60 747	12.70	277	1.30
	2011	217 813	23.30	11 162	4.40
V2 (green manure)	2008	33 599	8.90	600	12.20
	2009	62 264	16.30	933	1.60
	2010	166 679	34.80	1 739	8.20
	2011	460 787	49.30	70 989	27.70
V3 (not fertilized)	2008	42 760	11.30	1 424	29.00
	2009	65 932	17.30	1 260	2.20
	2010	110 893	23.20	932	4.40
	2011	474 440	50.80	96 550	37.60
V4 (fallow land)	2008	377 000	100.00	4 905	100.00
	2009	382 000	100.00	58 251	100.00
	2010	478 400	100.00	21 299	100.00
	2011	934 200	100.00	256 493	100.00

Table 4), mainly in the period after harvest (July, August), when the soil is bare and without any plant remains in many cases.

Similarly like for soils, the quality and quantity of eroded carbon was also determined in sediments by the above-mentioned methods.

In the evaluation of total SOM loss due to total surface runoff, it was necessary to realize and compare the content of each carbon form in the soil profile and to compare it with the total content in sediments. Total average soil organic carbon contents in sediments are shown in Table 5. For

Table 4. Comparison of technologies according to surface runoff and soil loss (average values of 4 years)

Variant	Suspended solids		Surface runoff		Loss of soil	
	mg/l	%	l/ha	%	kg/ha	%
V1 (farmyard manure)	19 235	16.5	15 719	19.4	544	3.7
V2 (green manure)	48 792	41.9	30 211	37.3	3 235	21.8
V3 (not fertilized)	62 271	53.4	31 946	39.4	4 355	29.4
V4 (fallow land)	116 543	100.0	81 035	100.0	14 824	100.0

Table 5. Average values of the carbon fraction in sediments determined by different methods

Variant	C_{ox} (%)	C_{pyro} (%)	C_{hws} (mg/kg)	C_{pm} (%)
V1 (farmyard manure)	3.43 (1.70)	0.54 (0.39)	887 (223)	0.44 (0.08)
V2 (green manure)	2.45 (0.89)	0.48 (0.21)	792 (276)	0.36 (0.05)
V3 (not fertilized)	2.24 (0.66)	0.49 (0.26)	723 (210)	0.35 (0.06)
V4 (fallow land)	1.42 (0.51)	0.60 (0.48)	389 (132)	0.23 (0.08)

Standard deviation is in parentheses

Table 6. Enrichment ratios of C sediments/C soil

Variant	C_{ox}	C_{pyro}	C_{hws}	C_{pm}
V1 (farmyard manure)	1.52	1.29	1.53	1.00
V2 (green manure)	1.88	1.67	2.24	1.50
V3 (not composting)	1.82	1.88	2.25	1.46
V4 (fallow land)	1.95	1.63	2.03	1.64

a comparison of the effectiveness of each variant (input/washing), an enrichment ratio is expressed in Table 6.

From the aspect of quantification of organic matter loss from the soil and subsequent sequestration in sediments and comparison of each variant with respect to carbon loss, the enrichment ratio is a very important determinant. Its value shows the ratio of each carbon form in sediments and soils (example: C_{ox} sediments/C_{ox} soil).

Trends in Table 6 definitely prove previous considerations about the evaluation of each management form in relation to the total carbon sequestration. The lowest values of this ratio were always found out for variant V1. The ratio for V2 and V3 was characterised by quite an insignificant deviation. The enrichment ratio was higher for variant V4; it means there is a precondition of higher soil vulnerability (easy release of organic matter, low aggregation bonds).

Based on our results we assumed that the cultivation of maize applied farmyard manure (V1) is preferably reflected in the carbon enrichment ratio. The value of enrichment ratio was the lowest of all variants (1.52); the highest values were determined for variant V2 (1.88) and for the variant without organic matter input (1.82).

DISCUSSION

Several authors have shown the importance of the soil organic matter content in soil vulnerability to erosion (Barthes *et al.* 1999; Auerswald *et al.* 2003; Tejada & Gonzalez 2007, 2008), underlining how an increase in soil organic matter content entails a decrease in soil loss. However, the influence of organic matter on soil properties and soil loss depends upon the type, amount, size and dominant components of the added organic materials (Tejada & Gonzalez 2006, 2007).

We used two different types of organic fertilizer in the form of farmyard manure and green manure (*Sinapsis alba*) on the experimental site and we studied their influence on surface runoff, soil loss by water erosion and the effect on the soil erodibility. By investigating the soil organic carbon (SOC) dynamics and changes of K-factor, surface runoff and soil losses we found out that the farmyard manure positively influenced all the observed properties and values but we cannot confirm the positive influence of green manure because its application onto the soil surface slightly decreased the SOM amount and increased the K-factor, which could be caused by bad weather conditions or poor seed quality.

This finding correlates with the research of Matsumoto *et al.* (2008), who also tried to investigate the behaviour of the carbon balance in maize fields under cattle manure in Northeast Thailand. The result of their study was to increase soil organic carbon which is related to soil fertility, the application of organic matter was recommended and there is a demand from farmers in this area for organic matter, such as cattle manure to apply to farmland. The application of cattle manure improves crop productivity (Henpithaksa 1993; Vityakon & Seripong 1988) by nutrient supply from the mineralization of cattle manure and results in overall improvement of soil fertility. However, the production of cattle manure is limited in Northeast Thailand.

Also the research of Kimura *et al.* (2011) concluded that the addition of organic matter to farmed soils is more important for aggregate stability than the type of farming system. This has important consequences for soil erodibility and sustainable soil quality.

We also have to cope with this problem in this country because the animal production continuously decreases and thus it does not produce such a necessary fertilizer as the cattle manure is, which we proved also in our study. There is also a lack of statistical information concerning the amount of applied manure to farmland, because most manure is not commercially traded.

Saha *et al.* (2010) described why soil physical attributes are paid attention in the soil-quality concept. It is because there is a close relationship with soil organic carbon and organic matter. Thus, any soil-management system that improves soil organic matter has a direct effect on soil physical properties and microbial biomass. Under such a situation, the mixed application of both organic and inorganic nutrients might be the right proposition for these soils, primarily for the improvement of soil physical health. The incorporation of organic matter in the form of either crop residues, organic manure or amendment has a significant effect on bulk density (BD) of soil (Celik *et al.* 2004), soil aggregation (Lal & Mathur 1989), soil structure (Chaudhary & Ghildya 1969), soil moisture-retention capacity (Hudson 1994), infiltration rate (Tiwari *et al.* 1998) and increased resistance to water erosion, which we proved in our study by decreasing the K-factors values thanks to the application of farmyard manure on the experimental sites.

Soil erosion by water is a selective process that generally removes soil components having the smallest size and the lowest density (Lal 1995). Consequently, sediments are usually enriched with fine silt and clay-sized particles containing the most stable soil organic carbon forms in soil because of the physical protection afforded inside soil aggregates (Golchin *et al.* 1998; Kay 1998). Moreover, a significant part of carbon removed from soils by erosive processes has been found to be dissolved in runoff water (dissolved soil organic carbon).

That is why we examined also the quantity and the quality of different forms of C (C_{ox}, C_{pyro}, C_{hws} and C_{pm}) in sediments captured in various bulk tanks (Table 5) and we compared them with the content of different forms of carbon in soils under maize (*Zea mays* L.) differently farmed (farmyard manure, green manure, no manuring and the control variant of fallow plot). This comparison is expressed by the enrichment ratio (input of C/runoff of C) (Table 6). And again, the variant under farmyard manure shows the lowest values, which means that the soil with this farming management is the most protected against water erosion, which is proved by strong aggregation bonds and more difficult release of soil organic matter. The worst was found to be the variant of fallow land where the values of the enrichment ratio were the highest.

Similar research was also done by Stavi & Lal (2011), whose specific objective of their study was to compare the actual loss of resources, including water, total sediments and soil organic carbon from soils obtained from eroded (ER) and uneroded (UN) sites. They believed that such an investigation may have practical implications in terms of land management for soil erosion control. The experiment was conducted on the farm 100 ha wide under various agricultural crops, but mainly maize. The surface soil for this study was obtained from a 13-ha maize field, which had been under continuous no-till farming and crop residue management for about 25 years. In general, the maize was planted in mid-April and harvested in mid-October. The soil was frequently fertilized in winter with untreated cattle manure. Field records indicated the occurrence of sites which had experienced seasonal and light to moderate levels of rill and interrill erosion. The surface soil of uneroded sites was well structured and dominated by mid-size aggregates, in contrast to the soil of the eroded sites, which had a noticeably looser structure, and with the dominance of very small aggregates. They found out that the mean overall concentration of SOC was significantly higher in UN than in ER. However, trends of SOC loss were similar to those of sediment yield being generally higher from ER than that from UN. The very high SOC concentration under both erosion phases is attributed to the frequent application of manure during the dormant season.

CONCLUSION

We can assume from the results that the organic matter input (mainly through farmyard manure) into the soil significantly contributes to a decrease in surface runoff and soil loss and also to a reduction of carbon leaching into sediments; so it contributes to soil sequestration.

On the basis of four-year observations of natural rains it is possible to state that the variant fertilized with farmyard manure was characterized not only by the effect on higher yields, but also by a decrease in soil loss by erosion and by the amount of surface runoff compared to cultivation without the organic matter input. Worse results were obtained in the variant with green manure (*Sinapsis alba*), which was also caused by an insufficient amount of green matter in 2009 and 2010.

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