EMPIRICAL APPROACH FOR ASSESSMENT OF SOIL ORGANIC CARBON LOSSES BY WATER EROSION ON CALCIC CHERNOZEM

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ABSTRACT

Water erosion and loss of soil organic matter cause significant damages on the national economy of the Republic of Bulgaria. For development of sustainable agricultural systems, it is necessary to predict the development of these two degradation processes in order to effectively control them. Many models and methods have been created for this aim. Two of ways for assessment of soil organic carbon losses by water erosion are the parametric and the empiric approaches. The parameter sediment enrichment ratio (ER) was determined for two crops, grown by four tillage systems (in six years experiment. Except the parametric method, an empirical equation was developed for assessment of organic carbon losses by the amount of soil eroded.

INTRODUCTION

Soil erosion is the most widespread form of soil degradation. Land area globally affected by water erosion is 1094 million ha (Mha), of which 751 Mha is severely affected (R. Lal, 2003). The negative consequences of it are loss of soil, loss of organic matter, compaction, loss of macro and micronutrients and reduction of soil fertility and productivity of the entire ecosystem. Also the related biogeochemical cycles of carbon (C) and nitrogen (N) are strongly influenced by water erosion, as their flows, storage, distribution and residence time in the soil are affected (Berhe et al., 2007).

Human impact on soil resources is increasing due to intensive food production and reaches critical points. Nowadays, over 35% of the earth's surface, which is not frozen, is used by humans. Soils in which the natural vegetation has been replaced with crops cultivation or for other purposes are subjected to a sharp increase of the action of erosion processes, significant loss of organic matter and nutrients, loss of biodiversity (FAO, 2015). The first meter of soil contains about 1,500 PgC carbon, which is more than the total contained in the atmosphere (approximately 800 PgC) and terrestrial vegetation (500 PgC) (FAO, 2015). Soil Organic Carbon (SOC) is a key element of the global carbon cycle, with this cycle covering the atmosphere, vegetation, soil, water basins. The SOC maintains all the basic functions of the soil, such as stabilizing the soil structure, retaining and releasing nutrients and affecting water infiltration and soil moisture retention. On sloping terrain, the effects of water erosion lead to depletion of soil organic matter. Losses of organic carbon by water erosion could be several times greater than those by mineralization. Since the conversion of natural ecosystems into agricultural ones, according to Gregorich and Anderson (1985), there has been a significant decline in soil carbon stocks. Therefore, SOC reserves in eroded soils are much lower than in non-eroded soils (Rhoton and Tyler, 1990). Anderson et al. (1986) report depletion of soil carbon reserves of up to 70% in severely eroded and up to 40% in slightly eroded soils in Canada. De Jong and Kachanoski (1988) found that about 50% of soil carbon loss in arable land is due to soil erosion.

Water erosion causes severe decrease of soil carbon stocks compared to non-eroded or slightly eroded soils and in addition, the soil organic matter is replaced into the landscape or in low-lying areas, and the destruction of the soil aggregates makes the soil organic matter encapsulated therein more susceptible to mineralization by microbial processes. The amount of SOC that is laterally distributed by soil erosion globally, predominantly through water erosion, is estimated to be between 0.3 and 5 Gt C y^{-1} (Berhe et al., 2007). The total amount of carbon lost by soil erosion, estimated by Polyakov, V., R.Lal 2004, at approximately 4.0-6.0 Pg/y if it is assumed that 10% of soil is displaced with organic matter content are by about 2-3% as a result of water erosion.

The need of development of sustainable agricultural systems requires the protection of soils of the effects of degradation processes and the preservation of soil functions. Various erosion control measures, methods and technologies are created and implemented (Dimitrov, 2004).

Soil degradation processes need early and timely monitoring (Rajan, 2010) in order to take proper measures to conserve soil resources. In order to avoid soil degradation as a result of the action of water erosion and the related with it another degradation process, loss of organic matter, it is necessary to take into account the negative changes in the soil quality indicators and to apply measures to overcome it.

A number of approaches and models (CENTURY, EPIC, SWAT-C, etc.) are applied to predict the loss of organic matter by water erosion (Starr, Lal, 2000, Wang et al.,2012, Xuesong Zhang, 2018, Parton et al, 1996). Starr G. and Lal R.(2000) consider several ways to calculate organic carbon losses. One of them is called parametric and it can use the USLE, RUSLE or other model to calculate soil loss (eroded soil), as well as directly measure the amount of eroded soil.

Another possible way to estimate organic matter losses by the amount of eroded soil is empirical, using regression models between organic matter loss and different soil and erosion parameters. On the basis of repeated measurements of erosion indicators - the volume of surface water runoff and the amount of eroded soil, as well as the concentration of organic matter in them, the losses of organic carbon by water erosion are estimated directly.

In this work on the basis of the results of six years of field experiments, the sediment enrichment ratio (ER) was determined for two crops and four tillage systems and an empirical equation was revealed for assessment of organic carbon losses by the amount of soil eroded, and another equation for assessment of organic carbon losses by the amount of soil eroded, sediment enrichment ratio and soil organic carbon content. They have been summarized and developed on the large number of experimental results, obtained on calcium chernozem.

MATERIAL AND METHOD

Site description and experimental design

The surveys were conducted on the land of the village of Trustenik, Ruse district, during the period 2012-2017 yr., on a slope of 5^0 (8.7%), in two stages. Two conventional and two soil protection technologies have been tested, including erosion control methods of surface and vertical (internal soil) mulching. In the first stage, which took place during the period 2012-2015yr., compost was used as mulching material, both for surface and for vertical mulching. In the second stage, conducted in the period 2015-2017yr., manure was used for the same purpose. The survey was conducted in four variants and four replicates.

These four different variants are respectively; conventional tillage along the slope, conventional tillage across the slope, conventional tillage across the slope with surface mulching and soil protection advanced technology for minimum and unconventional soil tillage for growing maize and wheat, applied across the slope. Advanced soil protection technology for growing wheat includes operations vertical mulching with compost or manure, direct sowing and plant-protection weed control applied transversely of the slope. Advanced soil protection technology for growing maize for grain, includes basic soil tillage without plowing - loosening and soil protection operations vertical mulching with compost or manure, cutting with making ducts at the same time as sowing and digging, and harvesting applied transversely to the slope.The amount of surface water runoff and eroded soil, as well as the amount of organic carbon in them, were taken into account for each erosion rainfall during the entire survey period 2012-2017yr. Organic carbon losses have been analyzed for all individual outflows that have been statistically processed. During the six-year study period, 25 erosive rainfalls during maize vegetation and 21 in wheat vegetation were recorded. Data processing was performed with Statistica 13.1. ***a*** - crop cultivation technologies (***a1, a2, a3, a4***, which combine four cultivation variants in both crops respectively) are considered as manageable factors; ***b*** - type of crop grown (***b1***-wheat, ***b2***-maize for grain).

Data analyses

During the six-year study period, 25 erosive rainfalls during maize vegetation and 21 in wheat vegetation were recorded. Data processing was performed with Statistica 13.1 and a - crop cultivation technologies (a_1, a_2, a_3, a_4, which combine the four cultivation variants in both crops respectively); b - type of crop grown (b_1-wheat, b_2-maize for grain) are considered as manageable factors.

Enrichment ratio of SOC is the ratio between concentrations of organic carbon in sediment to those in the soil ($ER=C_{\text{in sediment}}/C_{\text{in soil}}$) (Star&Lal, 2000). This method uses the coefficient ER (sediment enrichment ratio), and the loss of organic matter can be expressed by the equation:

$$CL(kg/ha)=SL(kg/ha)xERxSOC \quad (1)$$

ER - sediment enrichment ratio;
SOC – soil organic carbon;
CL - loss of organic carbon;
SL – soil loss (amount of eroded soil)

RESULTS AND DISCUSSIONS

Sediment enrichment ratio

The highest is the sediment enrichment ratio in variants with surface application of organic materials - compost or manure, for both maize and wheat (Table 1).

The enrichment of the surface soil layer with organic carbon, increases the sediment enrichment ratio. In the experiment with maize for grain, the ER in surface mulching (**a_3**) is 1.11 and in the wheat experiment - 1.08. In variant **a_4**, with the application of technologies for minimum and unconventional tillage this coefficient is 1.01 (for maize) and for wheat is 0.97. The amount of organic matter in the eroded soil is lower in wheat, averaging about 0.95-0.97 (Table 1), while in maize plots, in all variants, the ER is above 1.00. The differences between the ERs in the two crops are not statistically significant.

The influence of applied tillage systems is statistically significant on the sediment enrichment ratio but impact of crop type on the ER is not significant.

Empirical equations

In order to use the data obtained from models (USLE, RUSLE, etc.) or from direct measurements of soil loss and to calculate the loss of organic matter, a regression analysis of the influence of this factor on the loss of organic carbon was performed.

For equation, that combines more results, for different inclinations of the slope, tillage systems, crops, to data of results of six years experiment, were added results of previous experiments. This analysis includes results of studies carried out at earlier stages, with six different maize cultivation tillage systems (minimum, zero, conventional along the slope, conventional across the slope, cutting and furrowing) conducted in 2006-2007yr. (Tzvetkova et. al, 2007), as well as the results obtained on fallow in 2011 with different slopes (2.3^0 - 8^0), simulated rainfalls in various intensity and sequence (Lozanova, Rousseva, 2011), as well as the results of the conducted research for the period 2012-2017y. with the four tillage systems in corn and wheat cultivation a relation is obtained to calculate the loss of soil organic carbon by the loss of soil with the equation (Figure 1);

CL (kg/ha) = 1.1519 + 0.0143 x SL (kg/ha); R^2 = 0.9166 (2)
CL – loss of organic carbon (kg/ha),
SL – soil loss/eroded soil (kg/ha)

This equation is simple, easy way for assessment of organic matter loss by water erosion on calcium chernozem, but it doesn't include the sediment enrichment ratio and organic matter content.

To determine the relation of the loss of soil organic matter due to water erosion processes by the amount of eroded soil, soil organic carbon and the sediment enrichment ratio of the humus, regression analysis was performed, the results of which are presented in Table 2. As the statistical analysis show, carbon loss depends on a very high degree of these factors. All the parameters studied in this case have a significant influence on the loss of organic matter of the soil, with the strongest dependence on soil loss.Based on this analysis, a regression equation is done for the loss of organic matter by the factors listed in the table. This equation expresses the loss of organic carbon by the amount of soil eroded, the sediment enrichment ratio and the amount of organic carbon in the soil.

CL = -22.2713 + 8.9926xSOC + 9.3489xER + 0.0150xSL; R^2=0,9385 (3)

SOC - organic carbon in soil (%);
ER - sediment enrichment ratio;
SL - soil loss/eroded soil (kg/ha);
CL - loss of organic carbon (kg/ha).

losses of organic matter by water erosion assessment in soil calcic chernozem by parametrical and empirical model

The results could be obtained by calculation of soil organic carbon losses by water erosion to the values actually measured for organic matter loss are shown on fig.5. The equations that applied are; equation (1), replacing the ER with the average value obtained in the experiments performed - 1.04 and the average value obtained for organic carbon content (%) - 1.46%; equation (2) and equation (3).

The equations applied are:

CL(kg/ha) = SLxERxC;

where calculated average **ER = 1.04;** ***average*** **C% =1.46;**

CL (kg/ha) =1.04 x1.46 x SL(kg/ha) x 0.01

CL (kg/ha) = 1.1519+0.0143 x SL (kg/ha); R^2 = 0.9166 (2)

CL(kg/ha)=-22.2713 + 8.9926xSOC + +9.3489xER +0.0150xSL; R^2=0,9385 (3)

Figure 2 depicts the experimentally obtained results for organic carbon (CL) losses and calculated according to equations (1), (2) and (3). All three equations approximate the actual values of organic matter loss and the amount of eroded soil obtained in the field experiments. The values of R^2 for equation (3) are higher than for equation (2), that means it is more adequate.

CONCLUSIONS

Because field measurement of erosion impact on SOM remains a difficult task, modelling of this process is a viable option. To estimate the loss of soil organic matter, the parametric method can be applied using the sediment enrichment ratio. The sediment enrichment ratio (ER) on calcium chernozem in different tillage systems was between 0.95 and 1.04 for wheat and for maize. ER is the highest when applied organic materials on the soil surface - 1.11 for maize and 1.08 for wheat. The sediment enrichment ratio depends on a number of factors, that need more research.

The empirical equations are much easier to apply, because the only variable is the amount of soil eroded (equation 2), but they don't include soil organic carbon content and other parameters.

An empirical equation was developed for assessment of organic carbon losses by the amount of soil eroded, sediment enrichment ratio, soil organic carbon content (equation 3), this equation being summarized and developed on large number of results obtained on calcic chernozem.

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Table 1

Sediment enrichment ratio (ER) for different soil tillage systems (a1-a4) and cultivated crop (b1, b2)

Tillage system	Crop	Middle	Median	Minimum	Maximum	Standard deviation	Coefficient of Variation
a_1	b_1 wheat	0,95	0,96	0,65	1,27	0,15	15,89
a_2		0,95	0,93	0,69	1,26	0,15	15,82
a_3		1,08	1,05	0,80	1,81	0,26	21,31
a_4		0,97	0,94	0,49	1,41	0,27	27,48
a_1	b_2 maize	1,04	1,00	0,70	1,30	0,14	13,37
a_2		1,03	0,99	0,70	1,41	0,15	14,17
a_3		1,11	1,07	0,84	1,53	0,16	14,73
a_4		1,01	1,00	0,80	1,42	0,12	11,44

a_1 - conventional tillage along the slope, a_2 - conventional tillage across the slope, a_3 - conventional tillage across the slope with surface mulching and a_4 – advanced soil protection technology for minimum soil tillage, b_1-wheat, b_2-maize for grain

ANOVA effect on ER, Tillage system p=0.00049, Crop NS

Table 2

Regression analysis of carbon loss (CL) by water erosion

N=205	Regression summary for dependent variable: CL; R^2= 0,9385; F(3,201)=1039,2 **p<0,0000**					
	b*	Standard error of b*	b	Standard error of b	t(201)	p-value
Intercept			-22,2713	2,6111	-8,53	0,0000
SOC (soil organic carbon)	0,1145	0,0186	8,9926	1,4639	6,14	0,0000
ER (sediment enrichment ratio)	0,1314	0,0174	9,3489	1,2356	7,57	0,0000
SL (soil loss)	1,0014	0,0187	0,0150	0,0003	53,69	0,0000

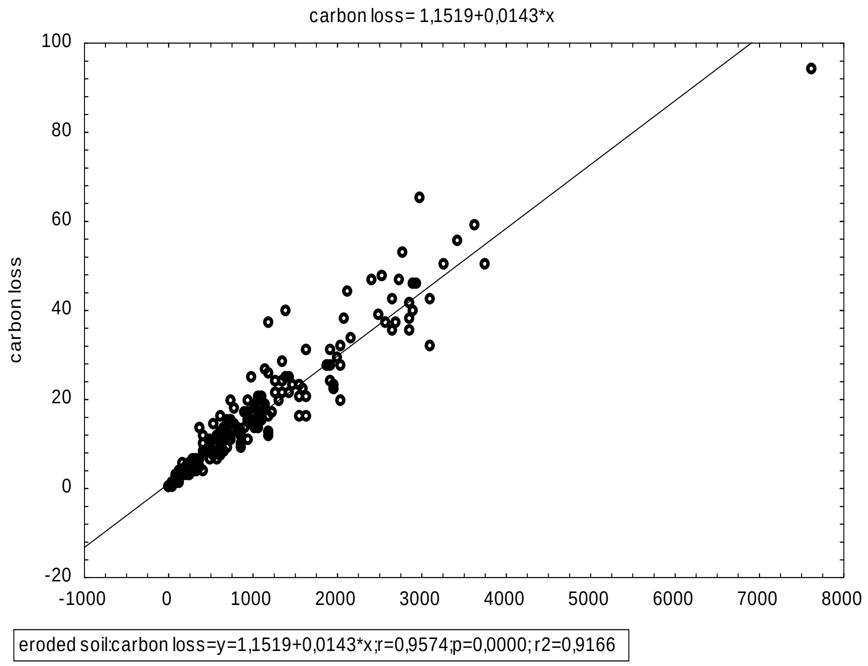

Figure 1. Relation of loss of soil organic carbon (kg/ha) on the amount of soil eroded (kg/ha) in the analysis of 236 results

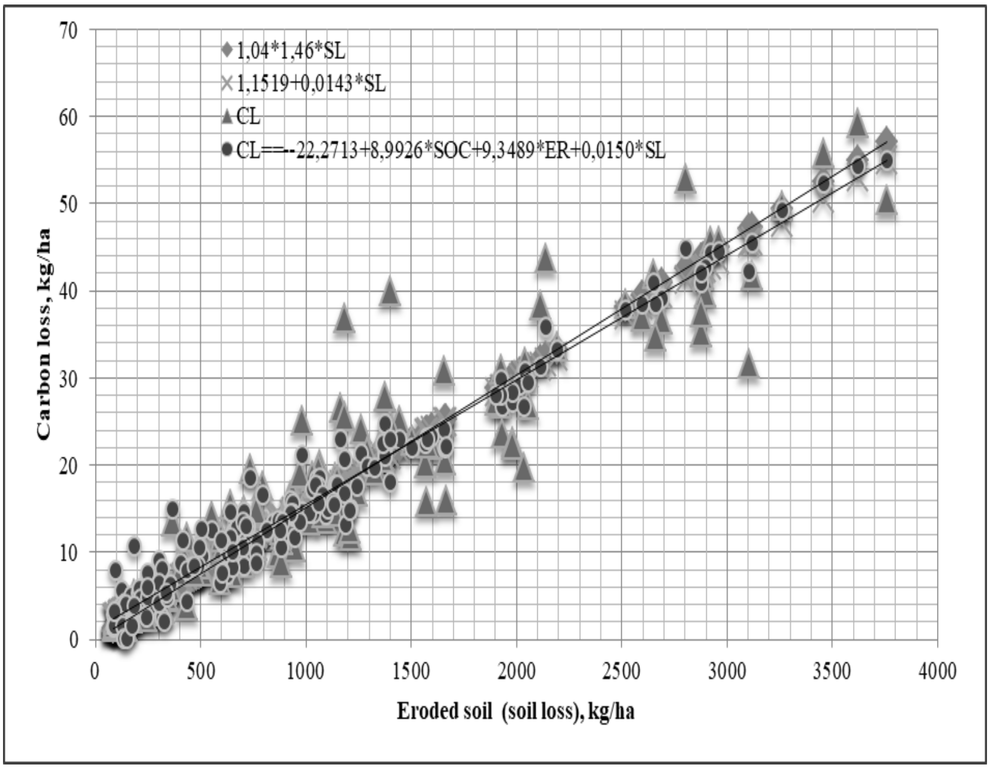

Figure 2. Experimentally obtained data for the loss of organic carbon CL (kg / ha) and calculated by equations relative to eroded soil (kg/ha) in soil calcic chernozem.