SOIL SCIENCE ANNUAL
2021, 72(1), 134621

https://doi.org/10.37501/soilsa/134621

Soil erodibility factor (K) in soils under varying stages of truncation

Hanna Radziuk*, Marcin Świtoniak

Nicolaus Copernicus University, Faculty of Earth Science and Spatial Management, Department of Soil Science and Landscape Management, Lwowska 1 Str., 87-100 Torun, Poland

* H. Radziuk, anka.radziuk@gmail.com, ORCID iD: http://orcid.org/0000-0001-5279-2175

Received: 10.05.2020
Accepted: 18.03.2021
Associated editor: A. Łachacz

Keywords

Hummocky landscape
Soil truncation
Soil erodibility factor K
Soil texture
Soil organic carbon
Clay-illuvial soils

Abstract

Soil erosion is the most widespread problem in soil management. It leads to changes in the properties of soil horizons, which in turn can also affect the pace of slope processes. This may be significant problem in young morainic areas where truncation of clay-illuvial soils (Luvisols, Retisols) transforms both the organic carbon content and texture of arable horizons. Changes in soil susceptibility to erosion can be measured using the soil erodibility factor (K) widely used in erosional models. The aim of the submitted study is a calculation of the erodibility factor (K) for soils represented different stages of truncation in a hummocky landscape of Northern Poland. Erodibility factor was calculated using the formula of the Erosion Productivity Impact Calculator (EPIC) model. For assessment of the factor, soil profiles were divided into four groups, varying degrees of soil truncation: completely eroded, strongly eroded, slightly eroded and non-eroded arable soils, non-eroded forest soils. In the course of the performed study, it was noted that the soil erodibility K factor values were between 0.0172-0.0352 $t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$ and depended on the stage of soil truncation. Properties of surface horizons of completely eroded soils accelerate erosion about 6% compared to strongly eroded and 12% to slightly eroded soils and even 48% as against non-eroded forest Luvisols/Retisols. The main factors affecting erodibility growth in truncated profiles was a revealed decrease in both – ccarbon content and sand fraction in humus horizons. Susceptibility to erosion was also increased by exposure of Bt or C(k) horizons richer in clay fraction.

1. Introduction

Soil erosion is a widespread degradation process that mainly leads to problems in agricultural areas. In some vulnerable landscapes, such as the hummocky morainic landscape in the northern or central part of Europe, erosion can change primeval soil cover significantly. The region specifies with complicated hilly relief and the existence of numerous closed depression with an accumulation of colluvial sediments (Sommer et al., 2008). High potential erosion risk of the territory connects with the intensity of land use from medieval times and systematic deforestation accompanied by frequent rainfall events (Doetterl et al., 2016). Specific features of soil formation and their use led to significant heterogeneity of soil cover on a local scale in hummocky uplands (Bednarek and Szrejder, 2004; Marcinek and Komisarek, 2004; Podlasiński, 2013; Świtoniak, 2015; Świtoniak et al., 2016). Soil erosion and intensive use of arable lands transformed soil cover and soil profile morphology (Jankauskas et al., 2004; Sommer et al., 2008; Świtoniak, 2014; Deumlich et al., 2018). The main directions of soil transformation is connected with removal of topsoil horizons by tillage and water erosion and colluvium formation in local depressions. In many places, where the eluvial material was erosionally removed, Bt, and C(k) horizons were exhumed (Sinkiewicz, 1998), which changed the texture of surface horizons (Kobierski, 2013; Świtoniak, 2014). Soil organic carbon content decreased in such "scalped" soils, comparing to non-eroded ones, and calcium carbonate (from Ck horizon) enriched arable layers due to soil truncation (Świtoniak, 2014). Abovementioned alterations changing the properties of the surface horizons and their susceptibility to water erosion, that are well quantified in spatial algorithms and data used for erosion modelling.

One of the most well-known models for assessing soil loss is USLE (Universal Soil Loss Equation) elaborated by Wischmeier and Smith (Wischmeier and Smith, 1978), that later was evaluated in RUSLE – Revised Universal Soil Loss Equation (Renard et al., 1997, 2017; Panagos et al., 2015). These models use calculated soil erodibility factor K as a quantitative measure of a soil's inherent susceptibility/resistance to erosion and the soil's influence on runoff amount and rate (Renard et al., 1997). Based on soil texture and soil organic carbon content the K-USLE factor (K_{USLE}) can be calculated which is an important measure of soil erodibility that was adopted in many erosion models (Vaezi et al., 2008; Auerswald et al., 2014; Zhang et al., 2019). Despite strongly conditioned K_{USLE} value on the climate and cropping system, currently, it is one of the most successful and practical tools to determine potential erodibility, drawing directly on basic soil properties (Borselli et al., 2012; Kinnell, 2016; Zhang et al., 2019). According to the authors of the method, estimation of K factor showed the most accurate results with the calculation of observation data for the particular unit plot (Wischmeier and Smith, 1978). The principals of erodibility factor K calculation were developed in other models such as EPIC – Erosion Productivity Impact Calculator (Williams et al., 1983), GAMES – Guelph Model for Evaluating the Effects of Agricultural Management Systems on Soil Erosion and Sedimentation (Rudra et al., 1986), EUROSEM – European Soil Erosion Model (Morgan et al., 1998), and others.

The current approach mainly focuses on large-scale K factor estimation (Panagos et al., 2015; Wang et al., 2016; Zhang et al., 2019) that has some difficulties in linking its meaning to specific soil conditions. Wawer with co-authors (Wawer et al., 2005) had made the estimation of K factor for Polish soils in different texture groups without association with landscapes. The review of the literature on the calculated K factor for the specific soils in a hummocky landscape discovered the knowledge gap in this position.

The aim of the presented study is a calculation of erodibility factor (K) for soils representing different stages of truncation in a hummocky landscape of Northern Poland. The obtained results will allow for an initial estimation whether the properties of highly eroded soils affect (or not?) the rate of this phenomenon.

2. Study objects and methods

This research draws its data from two main sources: own study and previous research on soil erosion carried out in Department of Soil Science and Landscape Management, NCU Toruń (Świtoniak, 2007; Świtoniak et al. 2013, 2014a, 2014b, 2018; Matecka and Świtoniak, 2020). All investigated soils were located within a hummocky moraine landscape and were developed from glacial tills of last Vistulian glaciation. According to the data of Torun meteorological station, the annual mean temperature in 1971–2018 was 8.2°C and the annual mean precipitation was 548 mm (Governmental Statistical Office of Poland, 2019).

For assessment of soil erodibility factor, 44 soil profiles were chosen, that were divided into four groups with 11 pedons in every group, varying by primary properties. The particular stages of truncation were detailed described by Świtoniak in previous paper (2014):

- *Soils A* – completely eroded soils on the tops of hummocks – Eutric Regosol (Protocalcic) (IUSS Working Group WRB, 2015) with calcareous or non-calcareous parent materials (C, Ck) in arable horizons. The sequence of soil horizons mainly is ACkp-Ck.
- *Soils B* – strongly eroded Luvisols with the horizon Bt in the arable layer. The group contributed by Haplic Luvisol (Protocalcic) with horizons sequence ABtp-Bt-Ck. Surface horizons (ABtp) include illuvial material from *argic* horizons (Świtoniak et al., 2016).
- *Soils C* – slightly eroded or not eroded pedons in the low part of a slope. Some pedons have an admixture of colluvial material in the arable horizon. This group is the most diverse, including Albic Luvisols with horizons sequence Ap-E-Bt-Ckg, Albic Abruptic Luvisols (Ap-E-2Bt-2Ckg), Albic Retisols (Ap-E-E/B-Btg-Ckg); Abruptic Luvisols (A(B)p-A(B)p2-E-2Btg-2Cg) and Mollic Gleysol (Luvic) (Ap-A-Eg-2Btkl).

All these soils are arable and use in a convenient tillage system. Eleven of soil profiles constituted own study, that was conducted in 2018 in the experimental plot Orzechowo (Rynsk County, 53°12'50.53'' N 18°48'05.08'' E). Others investigated soils were located in different places of Chełmno and Brodnica Lake Districts, Świecie Plateau, and Kraina Morainic Plateau (fig. 1).

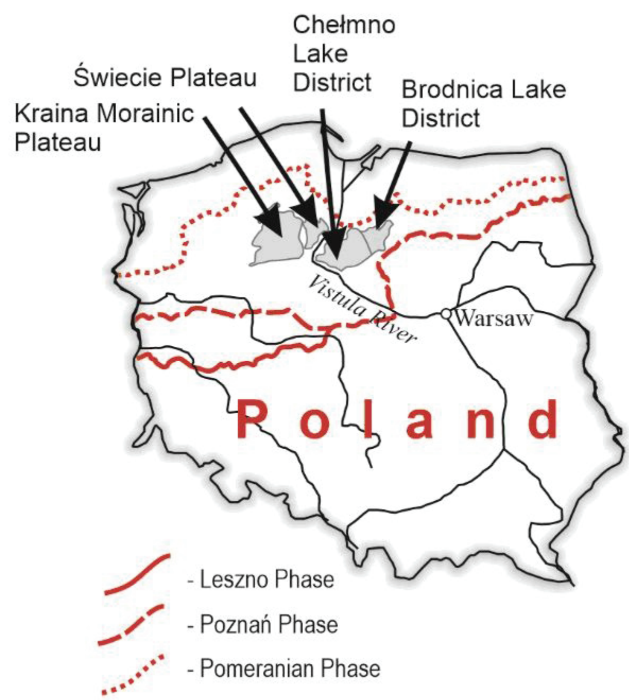

Fig. 1. Location of studied soils within physico-geographical mesoregions

The last soil group represents non-eroded, "control" or "reper" pedons. These soils are covered by forests and show no erosion alterations regardless of the location on the different slope positions.

- *Soils R* – non-eroded forest soils never used in agriculture. They mainly represent by Albic Abruptic Luvisol (Neocambic) with soil horizons O-A-Bw-Eg-2Btg-2C. To estimate soil properties in each point samples with disturbed soil structure were taken from the plow Ap (0–30 cm) or non-plow A horizon.

Standard soil analyses were performed according to the methods as follows: soil organic carbon (SOC) content – by Tiurin method (PN-ISO 14235:2003); grain size distribution – by sieves and sedimentary aerometric method of Casagrande as modified by Prószyński (PN-ISO 11277:2005); pH of soil-to-solution ratio of 1:2.5 using 1 M KCl and H_2O as the suspension medium (PN-ISO 10390:1997) (Systematyka gleb Polski, 2019). Determining characteristics were required for a general description of soils and calculation of soil erodibility factor (K). In the study, we used the method of K factor calculation proposed by Williams in EPIC model (Williams, 1984; Arnold et al., 2012). In contrast to the first approach by Wischmeier and Smith (Wischmeier and Smith, 1978), EPIC model used even fewer soil characteristics based on soil textural classes and content of soil organic carbon. The equation of Williams (1–5) (Arnold et al., 2012) calculates the K factor ($t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$) as:

$$K = f_{sand} \times f_{sl\text{-}cl} \times f_{hisand} \times f_{orgc} \times 0.1317 \qquad (1)$$

$$f_{sand} = (0.2 + 0.3 \times \exp[-0.256 \times m_s \times (1\text{-}m_{silt}/100)] \qquad (2)$$

$$f_{sl\text{-}cl} = (m_{silt}/(m_c+m_{silt}))^{0.3} \qquad (3)$$

$$f_{hisand} = 1\text{-}(0.7 \times (1\text{-}m_s/100)/((1\text{-}m_s/100) + \exp[-5.51 + 22.9 \times (1\text{-}m_s/100)]) \qquad (4)$$

$$f_{orgc} = 1\text{-}(0.25 \times orgC/(orgC + \exp[3.72\text{-}2.95 \times orgC]\ ) \qquad (5)$$

where m_s is the percent sand content (0.05–2.00 mm diameter particles), m_{silt} is the percent silt content (0.002–0.05 mm diameter particles), m_c is the percent clay content (< 0.002 mm diameter particles), and *orgC* is the percent organic carbon content of the layer, %.

The statistical analysis was made in the program PAST. The set of data illustrates the normal distribution (Shapiro-Wilk's test, $p > 0.05$), the one way ANOVA was used for soils comparison.

3. Results

Data on soil texture are key in the calculation of K factor. Surface horizons of the studied soils were characterized by some changes in grain size distribution depending on the stage of pedon truncation.

Completely (*A*) and strongly (*B*) eroded soils have the quite homogenous texture of surface horizons. They represent the loamy sand textural class mostly. Only in three cases, the material was classified as sandy clay loam and in two surface horizons – as loam. These eroded pedons stood out by the highest mean clay content – 16.5 (*A soils*) and 16% (*B soils*) and the lowest share of a sand fraction (57.6 and 60.6%) respectively. Compared to the other groups (*soils C* and *R*), they also had a slightly higher content of silt fractions.

Slightly changed by erosion, *soils C* have eluvial horizons and were characterized by definitely lower clay content (7.1%) and an increase in sand content (70.6%) in A horizons compared to the described above eroded soils.

The largest share of a sand fraction with the lowest clay content was noted in the forest, non-eroded *soils R*. Concurrently, the silt content was the lowest in these soil's surface mineral horizons. In almost all cases, these horizons have loamy (fine) sand texture.

Another very important parameter is soil organic carbon content. The investigated soil samples had very different values (Tab. 1). The values of this parameter increased from completely eroded soils to non-eroded forest soils (*soils R*) and that indirectly confirms the effect of soil erosion on sediment and carbon redistribution in hummocky landscape (Deumlich et al., 2018). *Soils A* (top of hills) had the lowest content of organic carbon. The mean value for these soils is only 0.62%, ranges from 0.38 to 0.84%. *Soils B* have a higher mean value of SOC content – 0.71% with a minimum of 0.35% and a maximum of 0.99%. Forest soils have the highest values among all investigated pedons with mean SOC content 1.56% and ranges from 1.25 to 2.44%.

The K factor equation implies the calculation of three components based on particle size distribution (2–4). The results of analyses the parameter f_{sand} founded on the content of sand and silt have slight variability, fluctuated between 0.250 and 0.322 (Tab. 2). The most changeable parameter, depending on soil texture, is f_{hisand} that uses data of sand content for derivation (the coefficient of variance equals 7.65 while it is 6.67 and 5.61 for f_{sand} and $f_{sl\text{-}cl}$ respectively). In our case, variability of the parameter f_{hisand} changes from 0.706 to 0.998. It was revealed that *soils R* have a minimal range of calculated components f_{sand} and f_{hisand}. Extremes for all components of K_{USLE} are minimal in forest soils. The highest content of mentioned components was found in *Soils A* and *B* with very small differentiation between them both mean value and extremums without statistically significant differentiation ($p > 0.05$).

An opposite trend was observed in the case of $f_{sl\text{-}cl}$ component. The highest values were recorded for non-eroded soils while the lowest was obtained for completely eroded soils. The variation of SOC content in soils affected the calculation of parameter f_{corg} (Tab. 2). It equals for examined soils from 0.753 for non-eroded forest soil with a high content of SOC to 0.994 in uphill completely eroded soils with minimal content of SOC. As could be seen from derivation, the parameter f_{corg} increases with the loss of soil organic carbon.

The individual parameters (f_{sand}, f_{hisand}, $f_{sl\text{-}cl}$, f_{corg}) for soils in studied groups do not show significant differences. Hence, the final calculated K factor varies from 0.0171 to 0.0352 $t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$ (Tab. 3). Additionally, the Tukey post hoc test does not reveal differences between *soils A* and *B* in

Table 1
Soil texture and soil organic carbon content for investigated soil's surface mineral horizons

Soil group	Profile No	Soil classification (WRB 2015)	Sand 2.0 – 0.05 %	Silt 0.05 – 0.002 %	Clay < 0.002 %	Textural class	SOC, %	Source
A	A2	Eutric Regosol	55	30	15	SL	0.70	own study
A	A1	Eutric Regosol (Protocalcic)	56	25	19	SL	0.70	own study
A	A4	Eutric Regosol (Protocalcic)	59	24	17	SL	0.59	own study
A	1	Eutric Regosol (Protocalcic)	61	29	10	SL	0.64	Świtoniak et al. 2014b
A	3	Eutric Regosol (Protocalcic)	60	25	15	SL	0.38	Matecka, Świtoniak 2020
A	4	Eutric Regosol (Protocalcic)	60	26	14	SL	0.83	Matecka, Świtoniak 2020
A	6	Eutric Regosol (Protocalcic)	56	24	20	SCL	0.46	Matecka, Świtoniak 2020
A	8	Eutric Regosol (Protocalcic)	52	29	19	L	0.84	Matecka, Świtoniak 2020
A	9	Eutric Regosol (Protocalcic)	58	23	19	SL	0.62	Matecka, Świtoniak 2020
A	11	Eutric Regosol (Protocalcic)	58	26	16	SL	0.59	Matecka, Świtoniak 2020
A	12	Eutric Regosol (Protocalcic)	59	23	18	SL	0.50	Matecka, Świtoniak 2020
Mean value A			**57.6**	**25.8**	**16.5**		**0.62**	
B	B1	Haplic Luvisol (Protocalcic)	59	26	15	SL	0.61	own study
B	B2	Haplic Luvisol (Protocalcic)	50	30	20	L	0.78	own study
B	B3	Haplic Luvisol (Protocalcic)	59	23	18	SL	0.87	own study
B	B4a	Haplic Luvisol (Protocalcic)	57	24	19	SL	0.82	own study
B	B4b	Haplic Luvisol	57	23	20	SCL	0.99	own study
B	E2	Haplic Luvisol (Protocalcic)	59	28	13	SL	0.86	Świtoniak 2007
B	1	Haplic Luvisol (Protocalcic)	68	18	14	SL	0.86	Świtoniak et al. 2015
B	3	Haplic Luvisol (Protocalcic)	71	19	10	SL	0.54	Świtoniak et al. 2015
B	2	Haplic Luvisol (Protocalcic)	56	23	21	SCL	0.39	Świtoniak et al. 2013
B	2	Haplic Luvisol (Protocalcic)	73	16	11	SL	0.35	Świtoniak et al. 2014b
B	1	Haplic Luvisol (Protocalcic)	58	27	15	SL	0.74	Świtoniak et al. 2018
Mean value B			**60.6**	**23.4**	**16.0**		**0.71**	
C	C1	Albic Luvisol	70	23	7	SL	0.81	own study
C	C2	Albic Luvisol	63	25	12	SL	0.85	own study
C	C3	Mollic Gleysol (Luvic)	69	21	10	SL	1.10	own study
C	C7	Abruptic Luvisol	69	21	10	SL	1.07	Świtoniak 2007
C	D2	Albic Abruptic Luvisol	70	28	2	SL	0.65	Świtoniak 2007
C	D3	Albic Abruptic Luvisol	77	20	3	LS	0.72	Świtoniak 2007
C	D8	Abruptic Luvisol (Protocalcic)	78	18	4	LS	0.78	Świtoniak 2007
C	E1	Albic Retisol	68	27	5	SL	0.80	Świtoniak 2007
C	E4	Albic Retisol	69	26	5	SL	0.80	Świtoniak 2007
C	2	Albic Abruptic Luvisol	77	18	5	LS	0.47	Świtoniak et al. 2015
C	3	Abruptic Luvisol	67	18	15	SL	0.71	Świtoniak et al. 2013
Mean value C			**70.6**	**22.3**	**7.1**		**0.80**	
R	1	Albic Neocambic Retisol (Abruptic)	74	21	5	SL	1.82	Świtoniak et al. 2014
R	2	Albic Abruptic Luvisol	77	20	3	LS	1.38	Świtoniak et al. 2014
R	3	Albic Abruptic Luvisol (Neocambic)	77	20	3	LS	1.25	Świtoniak et al. 2014
R	A4	Albic Abruptic Luvisol (Neocambic)	80	18	2	LS	1.42	Świtoniak 2007
R	A6	Albic Abruptic Luvisol (Neocambic)	75	22	3	LS	1.63	Świtoniak 2007
R	A7	Albic Abruptic Luvisol	76	20	4	LS	1.47	Świtoniak 2007
R	A8	Abruptic Luvisol (Neocambic)	76	22	2	LS	1.44	Świtoniak 2007
R	A11	Abruptic Luvisol (Neocambic)	79	19	2	LS	1.55	Świtoniak 2007
R	B2	Abruptic Luvisol (Neocambic)	77	20	3	LS	1.25	Świtoniak 2007
R	B3	Albic Abruptic Luvisol	76	21	3	LS	2.44	Świtoniak 2007
R	B6	Abruptic Retisol (Neocambic)	82	14	4	LS	1.60	Świtoniak 2007
Mean value R			**77.2**	**19.7**	**3.1**		**1.57**	

Table 2
Summary statistics for components of K factor calculation

	Soil A*	**Soil B**	**Soil C**	**Soil R**	**Soil A**	**Soil B**	**Soil C**	**Soil R**
	f_{sand}				f_{orgc}			
Min	0.294	0.262	0.258	0.250	0.951	0.923	0.898	0.750
Max	0.317	0.322	0.289	0.270	0.993	0.994	0.989	0.860
Mean	**0.301**	**0.292**	**0.274**	**0.262**	**0.976**	**0.963**	**0.953**	**0.812**
Stand. error	0.002	0.005	0.003	0.002	0.004	0.007	0.008	0.010
Stand. dev.	0.007	0.018	0.010	0.006	0.014	0.022	0.028	0.034
Coeff. var	2.453	6.009	3.771	2.036	1.406	2.330	2.906	4.195
	$f_{sl\text{-}cl}$				f_{hisand}			
Min	0.834	0.823	0.834	0.930	0.991	0.915	0.817	0.710
Max	0.915	0.892	0.980	0.970	0.999	0.999	0.987	0.900
Mean	**0.862**	**0.855**	**0.921**	**0.957**	**0.995**	**0.980**	**0.927**	**0.831**
Stand. error	0.007	0.007	0.013	0.004	0.001	0.009	0.019	0.017
Stand. dev.	0.025	0.023	0.042	0.013	0.002	0.028	0.061	0.056
Coeff. var	2.871	2.639	4.550	1.489	0.227	2.882	6.625	6.813

*Soil A – completely eroded Eutric Regosol (Protocalcaric); Soil B – strongly eroded Haplic Luvisol; Soil C – slightly eroded Albic Luvisol, Mollic Gleysol; Soil R – non-eroded forest soils

Table 3
K factor summary statistics

Statistics	Soil A*	Soil B	Soil C	Soil R
N	11	11	11	11
Min	0.0317	0.0269	0.0251	0.0171
Max	0.0352	0.0350	0.0338	0.0242
Mean	0.0331	0.0311	0.0294	0.0223
Stand. error	0.0011	0.0026	0.0029	0.0021
Variance	0.00001	0.00001	0.00001	0.00001
Stand. dev.	0.0011	0.0026	0.0029	0.0021
Median	0.0326	0.0314	0.0283	0.0231
Coef. variation	3.53	8.35	9.97	9.51

*Soil A – completely eroded Eutric Regosol (Protocalcaric); Soil B – strongly eroded Haplic Luvisol; Soil C – slightly eroded Albic Luvisol, Mollic Gleysol; Soil R – non-eroded forest soils

values K ($p > 0.05$). However, the statistical analyses of ANOVA demonstrates contrast between non-eroded soils (*soils R*) and each other groups of soils (*Soils A, B*, and *C*) that are more potentially vulnerable to water erosion.

4. Discussion

Based on summary statistics for factor K (Tab. 3), it is possible to estimate soil erodibility for soils in the morainic hummocky landscape. Obtained data give the possibility to make a general finding that the most eroded soils (*A*) are highly more vulnerable to superficial water soil erosion. Properties of surface horizons of completely eroded Eutric Regosols (Protocalcaric) can accelerate erosion by about 12% compared to slightly eroded arable soils (*C*) and even 48% as against non-eroded Luvisols/Retisols (*R*). Soil truncation may, therefore, lead to an increase of erosional processes pace.

The susceptibility to water erosion obtained for the discussed eroded soils with sandy loams on the surface (*groups A* and *B*) is similar at other studies in Poland. The previous data (Wawer et al., 2005) for the sandy loam textural class estimated K factor (EPIC model) at the level of 0.028-0.032 $t\cdot ha\cdot h\cdot ha^{-1}\cdot MJ^{-1}\cdot mm^{-1}$. Our calculated data complement the previous estimations. The possible difference from the previous estimation could be explained more accurately using soil organic carbon data, which is hard for assessment on a large scale. It should be noted that similar values of K factor were obtained for soils in Northern Poland (Panagos et al., 2015).

All characteristics have a very similar effect on K-factor calculated for studied soils. The increasing amount of sand and SOC have a positive impact and affect K value reduction while K factor grows up with higher clay and silt content.

One of the most important factors influencing the increase of resistance to erosion among studied soils is a sand fraction. Sandy soils with good infiltration capacity and relatively good permeability of the soil profile are relatively resistant for slopewash (Stewart et al., 1975; Vopravil et al., 2007; Dymond, 2010). Completely and strongly eroded soils have the smallest amount of sand fraction (57.6 and 60.6%) because parent materials (glacial till) or illuvial horizons Bt have been exposed on the surface. In the "control" non-eroded pedons the amount of sand is highest (> 70%) in topsoil because they still have eluvial well-developed horizons.

The influence of silt fraction on susceptibility to erosion is generally well known. Soils show higher erodibility if the silt content is high, regardless of both other factions share (Stewart et al., 1975; Ghosal et al., 2020). According to Stewart et al. (Stewart et al., 1975) sandy loams are over 2 times more susceptible to water erosion than loamy sands. In the case of studied soils, the share of silt fraction is highest in completely eroded soils (*A*) and decreases gradually in successive soil groups. Differences between individual soil groups are significant. Completely eroded soils have 25.8% of silt while non-eroded pedons contain almost 20% of this fraction in topsoil.

In K factor estimation some authors pointed on the significant role of clay particles in soil loss (Hillel et al., 1998; Vaezi et al., 2008). As notes, clay is a basic aggregate's building agent that is why its content is so important for structural analysis soil (Kay and Angers, 2001; Blanco-Canqui and Lal, 2010). The amount of clay has a positive effect on forces that hold soil particles in aggregate. At the same time, clay particles do not consolidate into aggregates, and disperse in water could increase soil loss with a worsening situation under tillage (Watts and Dexter, 1997; Getahun et al. 2016; Lipiec et al., 2018). The analyses showed that completely (*soils A*) and severely eroded (*soils B*) pedons are characterized with higher clay content (14–20%) while slightly eroded or not eroded pedons (*soils C* and *R*) are mainly described by the significant involvement of sand particles with clay content from 2 to 15% in different profiles. Nevertheless, assessment of the impact of this fraction on the erosive susceptibility of investigated soils is difficult. The only one component of K where this fraction was taken into account is $f_{sl\text{-}cl}$. According to this coefficient values, increasing of clay fraction reduces the risk of erosion. A positive correlation of clay content with K factor value is probably only an indirect result of a parallel decrease in sand content. Most studies indicate that clay-rich soils have high erosion resistance (Steward et al. 1975; David, 1988; Dymond, 2010). It is possible that in studied eroded soils (*A* and *B*) the clay content is too low to create erosional-resistant soil aggregates but high enough to reduce the permeability of soil material and increase the risk of surface runoff.

Soil organic carbon content is an important determinative item for the K-factor calculation (Steward et al., 1975; Kadlec et al., 2012; Wang et al., 2016). The organic carbon impacts the possibility of soil particle to granulation and agglomeration. The other effect of soil organic carbon is increasing of aggregate stability and, indirectly, soil resistance to erosion (Horn et al., 1994; Hillel et al., 1998; Kay and Angers, 2001). Therefore, to decrease soil loss it is necessary to work in the direction of compensation of soil organic matter widespread in erosive landscapes. In the case of tested soils, the component f_{orgc} associated with the soil organic carbon was most correlated with the general differentiation of K factor value. An almost two-fold decrease in mean carbon content in humus horizon of arable soils (*A*, *B*, and *C*) compared to forest soils (*R*) probably had a significant impact on reducing aggregate stability and increasing susceptibility to erosion (Table 2). The differences in soil organic carbon content in arable horizons were much smaller in absolute values. Nevertheless, subsequent stages of truncation (*soils C*, *B*, and *A*) are marked by a gradual decrease in carbon content which reflects f_{orgc} value progression (Tables 1 and 2).

5. Conclusions

The conducted studies indicate evident changes in soil erodibility K factor calculated with Wiliams equation (1984) depending on the degree of soil truncation. According to obtained results subsequent stages of soil transformation – cfrom natural to completely eroded – cincreasingly susceptible to erosion. The greatest increase in K factor values was noted between natural forest morainic soils and those that show slight erosional alterations but are already in agricultural use. The main factor affecting this rapid erodibility growth was a revealed decrease in both – ccarbon content and sand fraction in humus horizons. In the studied agricultural areas, the slope processes are stimulating not only by exposing the soil to external erosive factors (precipitations) but also by changing the properties of the soil material itself. Further stages of soil truncation are marked by gradual but much slower growth of soil erodibility. It would seem that the exposure richer in clay fraction Bt or C(k) horizons, will cause a reduction of erosional risk. Nevertheless, the clay content in these soils is too small to create wash-resistant aggregates but high enough to reduce soil permeability in favor of increased potential surface runoff. At the same time, these soils are characterized by a further decrease in soil organic carbon content which also can reduce their resistance to water erosion. A comparison of the erodibility of strongly and completely eroded soils revealed that the small differences in K mean values are not statistically significant.

The obtained estimated values of soil erodibility are based on texture and soil organic carbon content only as in the soil susceptibility to water erosion K by Wiliams (1984) The soil susceptibility to erosion also depends on other factors influencing durability and water resistance of the soil aggregates e.g. – calcium carbonate content. Therefore, further research should take into account parameters related to these features.

Acknowledgment

The attendance at the Nicolaus Copernicus University in Toruń was supported by Scholarship of Visegrad Fund (nr. 51910163).

References

Arnold, J.G., Kiniry, J.R., Srinivasan, R., Williams, J.R., Haney, E.B., Neitsch, S.L., 2012. SWAT Input Data: .Sol Chapter 22. SWAT Input/Output File Documentation, Version 2012, 301-3016. http://swat.tamu.edu/media/69365/ch22_input_sol.pdf

Auerswald, K., Fiener, P., Martin, W., Elhaus, D., 2014. Use and misuse of the K factor equation in soil erosion modeling: An alternative equation for determining USLE nomograph soil erodibility values. Catena 118, 220–225. https://doi.org/10.1016/j.catena.2014.01.008

Bednarek, R., Szrejder, B., 2004. Soil cover structure of the representative catchment of Struga Toruńska river. In: Kejna, M., Uscka, J. (Eds.), Integrated Monitoring of the Natural Environment. Functioning and Monitoring of Geoecosystems in the Grooving Human Activity Conditions. State Inspectorate for Environmental Protection, NCU, Toruń, 243–250 (in Polish).

Blanco-Canqui, H., Lal, R., 2010. Principles of soil conservation and management. https://doi.org/10.1007/978-1-4020-8709-7

Borselli, L., Torri, D., Poesen, J., Iaquinta, P., 2012. A robust algorithm for estimating soil erodibility in different climates. Catena 97, 85–94. https://doi.org/10.1016/j.catena.2012.05.012

David, W.P., 1988. Soil and Water Conservation Planning: Policy Issues and Recommendations, Philippine Journal of Development JPD. XV, 1-c, Philippine Institute for Development Studies.

Deumlich, D., Ellerbrock, R.H., Frielinghaus, M., 2018. Estimating carbon stocks in young moraine soils affected by erosion. Catena 162, 51–60. https://doi.org/10.1016/j.catena.2017.11.016

Doetterl, S., Berhe, A.A., Nadeu, E., Wang, Z., Sommer, M., Fiener, P., 2016. Erosion, deposition and soil carbon: A review of process-level controls, experimental tools and models to address C cycling in dynamic landscapes. Earth-Science Reviews 154, 102–122. https://doi.org/10.1016/j.earscirev.2015.12.005

Dymond, J.R., 2010. Soil erosion in New Zealand is a net sink of CO2. Earth Surface Processes and Landforms, 35, 1763–1772. https://doi.org/10.1002/esp.2014

Getahun, G.T., Munkholm, L.J., Schjønning, P., 2016. The influence of clay-to-carbon ratio on soil physical properties in a humid sandy loam soil with contrasting tillage and residue management. Geoderma 264, 94–102. https://doi.org/10.1016/j.geoderma.2015.10.002

Ghosal, K., Bhattacharya, D., 2020. A Review of RUSLE Model. Journal of the Indian Society of Remote Sensing 48(4), 689–707. https://doi.org/10.1007/s12524-019-01097-0

Governmental Statistical Office of Poland (2019) Environment. Available at: https://stat.gov.pl/en/topics/environment-energy/environment/environment-2019,1,11.html.

Hillel, D., Warrick, A.W., Baker, R.S., Rosenzweig, C., 1998. Environmental Soil Physics: Fundamentals, Applications, and Environmental Considerations. Academic Press. San Diego California, Toronto, 771 p.

Horn, R., Taubner, H., Wuttke, M., Baumgartl, T., 1994. Soil physical properties related to soil structure. Soil and Tillage Research 30(2–4), 187–216. https://doi.org/10.1016/0167-1987(94)90005-1

IUSS Working Group WRB, 2015. World Reference Base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps. Update 2015. World Soil Resources Report, 106. FAO, Rome.

Jankauskas, B., Jankauskiene, G., Fullen, M.A., 2004. Erosion-preventive crop rotations and water erosion rates on undulating slopes in Lithuania. Canadian Journal of Soil Science 84(2), 177–186. https://doi.org/10.4141/S03-029

Kadlec, V., Holubík, O., Procházková, E., Urbanová, J., Tipp, M., 2012. Soil organic carbon dynamics and its influence on the soil erodibility factor. Soil and Water Resources 7, 97-108.

Kay, B.D., Angers, D.A., 2001. Soil structure. Soil Physics Companion, (April), 249–295. https://doi.org/10.1080/03670074.1944.11664380

Kinnell, P.I.A., 2016. Comparison between the USLE, the USLE-M and replicate plots to model rainfall erosion on bare fallow areas. Catena 145, 39–46. https://doi.org/10.1016/j.catena.2016.05.017

Kobierski, M., 2013. Morphology, properties and mineralogical composition of eroded Luvisols in selected morainic areas of the Kujavian and Pomeranian Province. University of Technology and Life Sciences. Bydgoszcz.

Lipiec, J., Czyż, E.A., Dexter, A.R., Siczek, A., 2018. Effects of soil deformation on clay dispersion in loess soil. Soil and Tillage Research 184, 203–206. https://doi.org/10.1016/j.still.2018.08.005

Marcinek, J., Komisarek, J., 2004. Anthropogenic transformations of soils of Poznań Lakeland as a results of intensive agricultural farming. Academy of Agriculture. Poznań (in Polish with English summary).

Matecka, P., Świtoniak, M., 2020. Delineation, characteristic and classification of soils containing carbonates in plow horizons within young moraine areas. Soil Science Annual 71(1) 23–36. https://doi.org/10.37501/soilsa/121489

Morgan, R.P.C., Quinton, J.N., Smith, R.E., Govers, G., Poesen, J.W.A., Auerswald, K., Chisci, G., Torri, D., Styczen, M.E., 1998. The European Soil Erosion Model (EUROSEM): A dynamic approach for predicting sediment transport from fields and small catchments. Earth Surface Processes and Landforms 23, 527–544.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, C., 2015. The new assessment of soil loss by water erosion in Europe. Environmental Science and Policy 54, 438–447. https://doi.org/10.1016/j.envsci.2015.08.012

Podlasiński, M., 2013. Denudation of anthropogenic impact on the diversity of soil cover and its spatial structure in the agricultural landscape of moraine. Szczecin. (in Polish with English summary).

Renard, K.G., Foster, G., Weesies, G., McCool, D., Yoder, D., 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE) (Agricultural Handbook 703). US Department of Agriculture, Washington, DC. https://doi.org/DC0-16-048938-5, 65–100

Renard, K.G., Laflen, J.M., Foster, G.R., McCool, D.K., 2017. The revised universal soil loss equation. Soil Erosion Research Methods 352 p. https://doi.org/10.1201/9780203739358

Rudra, R., Dickinson, W., Clark, D., Wall, G., 1986. GAMES – cA Screening Model of Soil Erosion and Fluvial Sedimentation on Agricultural Watershed. Canadian Water Resources Journal, 11, 58–71.

Sinkiewicz, M., 1998. The development of anthropogenic denudation in central part of northern Poland. Nicolaus Copernicus University, Toruń (in Polish with English summary).

Sommer, M., Gerke, H.H., Deumlich, D., 2008. Modelling soil landscape genesis – A “time split” approach for hummocky agricultural landscapes. Geoderma 145(3–4), 480–493. https://doi.org/10.1016/j.geoderma.2008.01.012

Stewart, B.A., Woolhiser, D.A., Wischmeier, W.H., Caro, J.H., Freere, M.H., 1975. Control of water pollution from cropland: A manual for guideline development. Washington (DC), USA. 7–26.

Świtoniak M., 2007. Genesis, systematics and use value of texture-contrasted soils in a young glacial landscape on the example of the Chełmno and Brodnica Lake District. PhD’s thesis manuscript – su-

pervisor prof. dr hab. Renata Bednarek. Faculty of Biology and Earth Sciences, Nicolaus Copernicus University in Toruń.
Świtoniak, M., Markiewicz, M., Bednarek, R., Paluszewski, B., 2013. Application of aerial photographs for the assessment of anthropogenic denudation impact on soil cover of the Brodnica Landscape Park plateau areas. Ecological Questions 17, 101–111.
Świtoniak, M., 2014. Use of soil profile truncation to estimate influence of accelerated erosion on soil cover transformation in young morainic landscapes, North-Eastern Poland. Catena 116, 173–184. https://doi.org/10.1016/j.catena.2013.12.015
Świtoniak, M., Charzyński, P., Mendyk, Ł., 2014a. Forested areas within hummocky moraine plateaus of Poland (Brodnica Lake District). [In:] Soil sequences atlas. [eds.] Świtoniak M., Charzyński P., Wydawnictwo Naukowe UMK, Toruń, 61 –76.
Świtoniak, M., Charzyński, P., Mendyk, Ł., 2014b. Agricultural areas within hummocky moraine plateaus of Poland (Brodnica Lake District). [In:] Soil sequences atlas. [eds.] Świtoniak M., Charzyński P., Wydawnictwo Naukowe UMK, Toruń, 77–91.
Świtoniak, M., Dąbrowski, M., Łyszkiewicz, A., 2015. The Influence of Human-induced Erosion on the Soil Organic Carbon Stock in Vineyards of Fordon Valley. Polish Journal of Soil Science 48(2), 197–211.
Świtoniak, M., 2015. Issues relating to classification of colluvial soils in young morainic areas (Chelmno and Brodnica Lake District, northern Poland). Soil Science Annual 66(2), 57–66. https://doi.org/10.1515/ssa-2015-0020
Świtoniak, M., Mroczek, P., Bednarek, R., 2016. Luvisols or Cambisols? Micromorphological study of soil truncation in young morainic landscapes – Case study: Brodnica and Chełmno Lake Districts (North Poland). Catena. https://doi.org/10.1016/j.catena.2014.09.005
Świtoniak, M., Hulisz, P., Jaworski, T., Pietrzak, D., Pindral, S., 2018. Soils of slope niches in the Toruń-Eberswalde ice-marginal valley. [In:] Soil sequences atlas II. [eds.] Świtoniak M., Charzyński P.. Machina Druku, Toruń, 157–175.
Systematyka gleb Polski. 2019. Polskie Towarzystwo Gleboznawcze, Komisja Genezy Klasyfikacji i Kartografii Gleb. Wydawnictwo Uniwersytetu Przyrodniczego we Wrocławiu, Polskie Towarzystwo Gleboznawcze, Wrocław – Warszawa, 290 s.
Vaezi, A.R., Sadeghi, S.H.R., Bahrami, H.A., Mahdian, M.H., 2008. Modeling the USLE K-factor for calcareous soils in northwestern Iran. Geomorphology 97(3–4), 414–423. https://doi.org/10.1016/j.geomorph.2007.08.017
Vopravil, J., Janeček, M., Tippl, M., 2007. Revised Soil Erodibility K-factor for soils in the Czech Republic. Soil and Water Research 2, 1–9.
Watts, C.W., Dexter, A.R., 1997. The influence of organic matter in reducing the destabilization of soil by simulated tillage. Soil and Tillage Research 42(4), 253–275. https://doi.org/10.1016/S0167-1987(97)00009-3
Wang, B., Zheng, F., Guan, Y., 2016. Improved USLE-K factor prediction: A case study on water erosion areas in China. International Soil and Water Conservation Research 4(3), 168–176. https://doi.org/10.1016/j.iswcr.2016.08.003
Wawer, R., Nowocień, E., Podolski, B., 2005. Real and calculated KUSLE erodibility factor for selected Polish soils. Polish Journal of Environmental Studies 14(5), 655–658.
Williams, J., 1984. A modeling approach to determining the relationship between erosion and soil productivity. In: Transactions of the ASAE, 27, 1 (Jan.-Feb. 1984).
Williams, J.R., Renard, K.G., Dyke, P.T., 1983. Epic – a New Method for Assessing Erosions Effect on Soil Productivity. Journal of Soil and Water Conservation 38, 381-383.
Wischmeier, W., Smith, D., 1978. Predicting rainfall erosion losses: a guide to conservation planning, U.S. Department of Agriculture Handbook, 537. https://doi.org/10.1029/TR039i002p00285
Zhang, K., Yu, Y., Dong, J., Yang, Q., Xu, X., 2019. Adapting & testing use of USLE K factor for agricultural soils in China. Agriculture, Ecosystems and Environment 269, 148–155. https://doi.org/10.1016/j.agee.2018.09.033

Zróżnicowanie wartości wskaźnika podatności gleb na erozję wodną (K) w glebach o różnym stopniu zerodowania

Słowa kluczowe

Słowa kluczowe:
Krajobraz pagórkowaty
Ogłowienie gleb
Wskaźnik podatności gleb na erozję
Uziarnienie
Węgiel organiczny
Gleby płowe

Streszczenie

Erozja jest jednym z najpowszechniejszych problemów związanych z użytkowaniem gleb. Między innymi prowadzi ona do zmian właściwości poziomów powierzchniowych i co się z tym wiąże – tempa procesów stokowych. Zjawisko to może być szczególnie istotne w obszarach młodoglacjalnych wysoczyzn morenowych gdzie ogłowienie gleb płowych wpływa nie tylko na spadek zawartości próchnicy w poziomach ornych ale także zmienia ich uziarnienie. Wpływ tych przeobrażeń na zmiany tempa procesów stokowych może być mierzona za pomocą szeroko stosowanego w modelach erozyjnych wskaźnika podatności gleb na erozję wodną (K). Celem prezentowanych badań było określenie w jakim stopniu ogławianie gleb płowych prowadzi do zmian ich podatności na erozję wodną. Wskaźnik K (zaadoptowany z modelu EPIC) obliczono dla czterech grup gleb: całkowicie, silnie i umiarkowanie zerodowanych oraz w pełni ukształtowanych nie przekształconych erozyjnie. Uzyskane wyniki ukazały znaczne zróżnicowanie wielkości wskaźnika K od 0.0171-0.0352 t·ha·h/ha·MJ·mm zależne wyraźnie od stopnia zerodowania gleby. Gleby całkowicie zerodowane mają średnio o 6% większą podatność na erozję w porównaniu z glebami silnie zerodowanymi oraz o 12% z glebami słabo zerodowanymi i aż o 48% w porównaniu do gleb płowych nie przekształconych erozyjnie. Głównymi czynnikami wpływającymi na wzrost podatności na erozję były stopniowo zmniejszające się wraz ze stopniem zerodowania zawartości próchnicy i frakcji piasku w poziomach ornych. Równocześnie, lecz w nieco mniejszym stopniu, było to spowodowane wzrostem zawartości frakcji iłu w odsłoniętych na powierzchni poziomach Bt i Ck.