Electronic Journal of Polish Agricultural Universities is the very first Polish scientific journal published exclusively on the Internet, founded on January 1, 1998 by the following agricultural universities and higher schools of agriculture: University of Technology and Agriculture of Bydgoszcz, Agricultural University of Cracow, Agricultural University of Lublin, Agricultural University of Poznan, Higher School of Agriculture and Teacher Training Siedlce, Agricultural University of Szczecin, and Agricultural University of Wroclaw.

ELECTRONIC JOURNAL OF POLISH AGRICULTURAL UNIVERSITIES

2002
Volume 5
Issue 2
Series ENVIRONMENTAL DEVELOPMENT

KLIMA K. 2002. ASSESSMENT OF ANTI-EROSION EFFICIENCY FOR THREE CROP ROTATIONS APPLIED TO MOUNTAIN SOIL **Electronic Journal of Polish Agricultural Universities**, Environmental Development, Volume 5, Issue 2.
Available Online http://www.ejpau.media.pl

ASSESSMENT OF ANTI-EROSION EFFICIENCY FOR THREE CROP ROTATIONS APPLIED TO MOUNTAIN SOIL

Kazimierz Klima
Department of Soil and Plant Cultivation, Agricultural University of Cracow, Poland

ABSTRACT

One factor field experiment was performed from 1992 to 1996 in Czyrna near Krynica (Low Beskid). Influence of the number of days without a plant cover upon intensity of soil losses was studied for 3 four-field crop rotations at a mountain side of average 13.5% slope. The content of plants displaying high soil-protective capacities contributed increasingly into successive crop rotations. The research has led to conclusion that soil loss intensity (y) is directly proportional to the number of days (x) at which the soil remained uncovered, counted from harvesting a preceding plant to sowing a proceeding plant that has been assessed. The relationship can be described by the following a regression equation: $y = 0.168x + 9.828$ [$kg \cdot ha^{-1} \cdot year^{-1}$]; n = 136, á = 0.01; r = 0.723.

Key words: anti-erosion crop rotations, soil losses, mountain slope, sheet erosion, sheet flow, erodible, erodibility

INTRODUCTION

Selection of anti-erosion crop rotations constitutes an important element of complex land development of eroded lands [21, 25]. So far in Poland no experiments aimed at assessing anti-erosive efficiency of crop rotations determined by the intensity of sheet erosion have been performed. Necessity of such research has been recently indicated by many authors, such as Niewiadomski [18] or Prochal i Mierzwa [21]. The role of crop rotations in limiting intense water erosion has been also highlighted in papers of international coverage. Schwertmann and

PRINT

Vogl [25] assessed the erosive damage caused by changes in crop rotation management that were introduced from 1880 till 1960, to be raised by an average 60% in Bavaria, and by 30% overall Germany. In crop rotation, unlike ordinary rotation, weather variability affects anti-erosion capacities of particular plants in a similar degree, since all plants are sown in regular yearly intervals. Hence, all the plants are influenced by the same weather conditions throughout the entire period of investigation, which marks the results with distinguished quality and high value.

The aim of the presented research was to determine the influence of number of days, counted from harvesting a preceding plant till sowing the plant that proceeds (proceeding), in 3 crop rotations diversified by the content of highly soil-protective plants, on the intensity of soil losses resulting from surface runoff.

METHODOLOGY

A one factor field study covering 5 water years, namely 1991/1992 – 1995/1996 was the subject of the present investigation. The research has been performed in the Mountain Experimental Station of the Chair for Land and Plant Cultivation, Agricultural University in Cracow, located in Czyrna near Krynica, in the south Poland (545 m above sea level). It is in the south-west part of Low Beskid (Photo 1).

Photo 1. General view of the experimental plot

At the mountain side with an average slope of 13.5% three crop rotations characterised by an increasing content of highly soil protective-plants were applied, namely:

- crop rotation A:
    1. fodder beet
    2. oat
    3. horse bean
    4. winter triticale,
- crop rotation B:
    1. fodder beet
    2. oat with red clover as a companion crop
    3. red clover
    4. winter triticale,
- crop rotation C:
    1. fodder beet
    2. oat with red clover and timothy as companion cropss
    3. red clover and timothy
    4. red clover and timothy.

Each rotation crop was repeated 12 times a year. The cultivated practice was applied in parallel to contour lines of the slope. All the plants sown as rotations crops were cultivated each year on the plots of 60 m^2 of area (5 by 12 m). On each plot a separated 10 m^2 (5 by 2 m) measuring band allowed to determine the amount of surface soil washed away with water. Słupik's bag catchers [26] were applied to measure soil losses induced by surface runoff. 2 m wide bag catchers, installed at the lowest parts of the plots, were emptied after every rainfall or thaw season that caused the sheet flow. Inspired and convinced by De Ploey's results [3] according to which a 5 m fragment of a slope is long enough to observe the occurrence of rill erosion, we decided to use plots of that geometry. The process of rill erosion was qualified by Józefaciuks [14] both as a sheet erosion and lineal erosion. Additional arguments for choosing a 5 m long measurement stripe were supplied by the results obtained by Froehlich [5] at Homrzyska in Beskid Sądecki. The author shown that a rainfall of 26 mm with a maximum intensity of 1.3 mm·per minute caused soil particles to reach the following maximum ranges:

- at the potato plot of 25% slope	1 m
- at the turfed cropland of 21% slope	2 m
- at the rye stand of 25% slope	6.8 m

Similar results suggesting rather short transport distances for soil particles were reported by Rejman i Usowicz [23], who obtained a value of 4.5 m as mean effective distance for transporting soil particles in loess-originating loosened soil.

Data presented in Fig.6 give the intensity of soil losses expressed in dry mass of the soil carried away with surface runoff throughout a water year, recalculated per hectare. The values represent mean values obtained by dividing by 4 (number of plants in a crop rotation) the total amount of washed down soil material (expressed in $kg \cdot ha^{-1} \cdot year^{-1}$) determined for all 4 measurement stripes at which the elements of a specific crop rotations were cultivated.

The number of days without coverage of cultivated plants was counted from harvesting a preceding plant to sowing a plant that followed and which was the assessed one.

RESEARCH CONDITIONS

The soil of the experimental plot was determined as a brown soil, with size grading typical for a skeletal soil. It was classified as V capability class of 12 oat-potato mountain complex. Sheet erodibility index, i.e. dust fraction to colloidal clay ratio varied from 1.9 to 2.1. The index was on average 3.5 times smaller than most erodible loesses [19].

The degree of susceptibility to being erodible, i.e. erodibility, for the part of the mountain where the experiment was performed was determined, with help of the Ministry for Agriculture and Forestry Manual no 3 [8] which recognizes soil conditions, slope and the amount of rainfall, was determined as equal to 2, which corresponds to moderate erosion in a 5 degree-scale of water erodibility. According to Józefaciuks' comments [12] to the Manual in question, moderately erodible lands do not display distinct erosive forms, and the basic soil conservation practice shall consist of soil-protective crop rotations and slope-transverse tillage.

The climatic conditions in winter time for the water years 1991/1992 –1995/1996 did not cause excessive thaw-induced erosion, since snowmelt processes were rather of solar than advective character. The average amount of rainfall in summer water half-years was nearly 2 times bigger than in the winter half-years and amounted to 542.8 mm and 265.5 mm, respectively. Annual rainfall for the water years 1991/1992 –1995/1996 ranged from 713.7 mm in 1993/1994 to 888.1 mm in 1991/1992, which corresponds to the average value of 808.3 mm (see Figs. 1-5). In terms of Kaczorowska [15] the water year 1993/1994 can be classified as a dry one, year 1991/1992 as a wet one, while the rest was just average. Hence, the research was conducted in various rainfall conditions, because apart from average years, a dry and a wet year occurred as well.

Fig. 1. Hydrologic year 1992
XI 1991–IV 1992 – 264.7 mm, V 1992–X 1992 – 623.4 mm, XI 1991–X 1992 – 888.1 mm

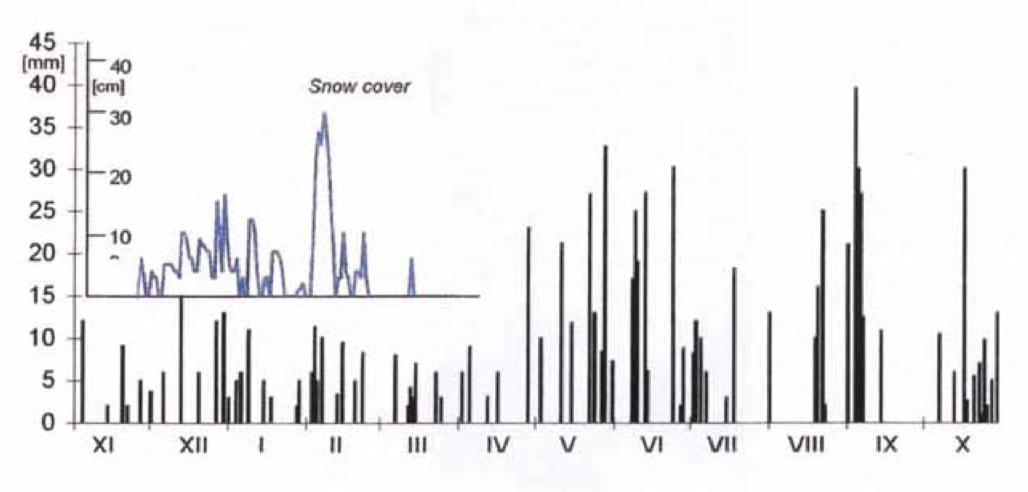


Fig. 2. Hydrologic year 1993
XI 1992–IV 1993 – 275.1 mm, V 1993–X 1993 – 533.2 mm, XI 1992–X 1993 – 808.3 mm

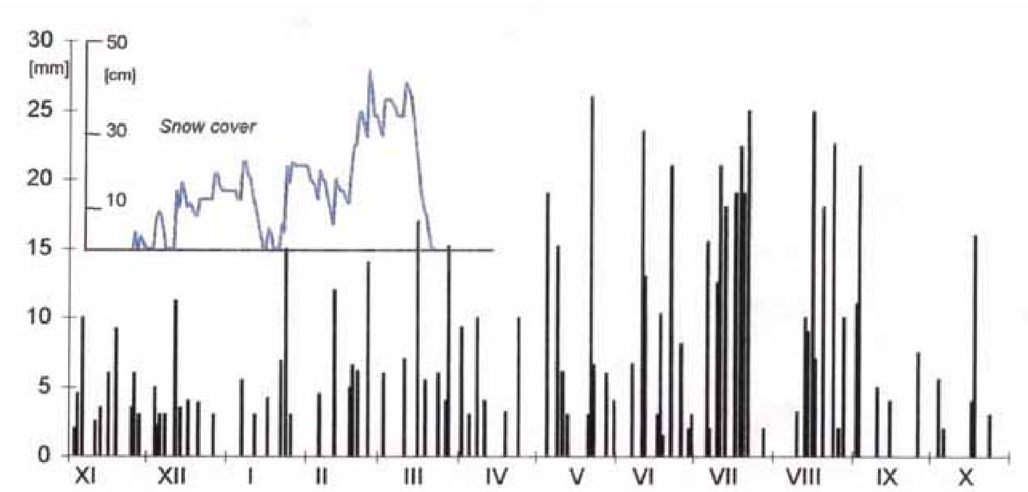
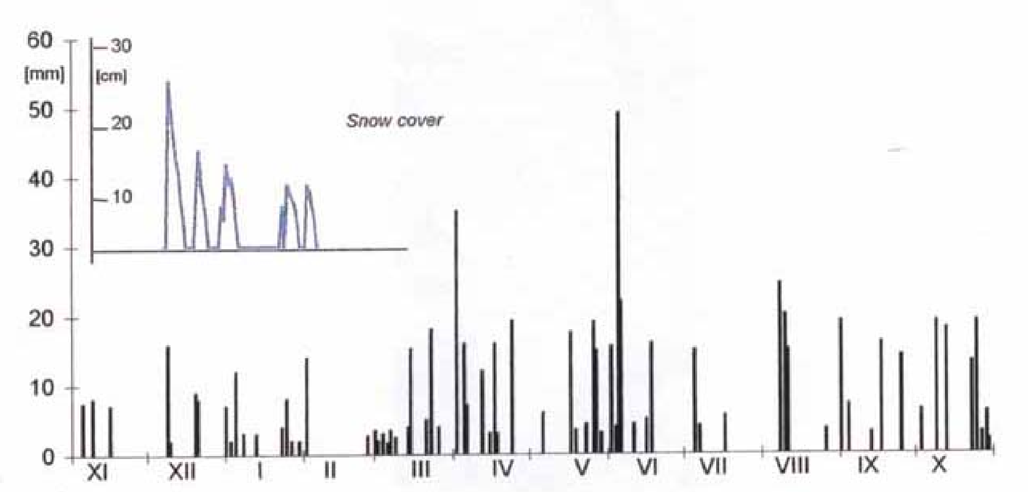


Fig. 3. Hydrologic year 1994
XI 1993–IV 1994 – 296.7 mm, V 1994–X 1994 – 417.0 mm, XI 1993–X 1994 – 713.7 mm



PRINT

Fig. 4. Hydrologic year 1994
XI 1993–IV 1994 – 296.7 mm, V 1994–X 1994 – 417.0 mm, XI 1993–X 1994 – 713.7 mm

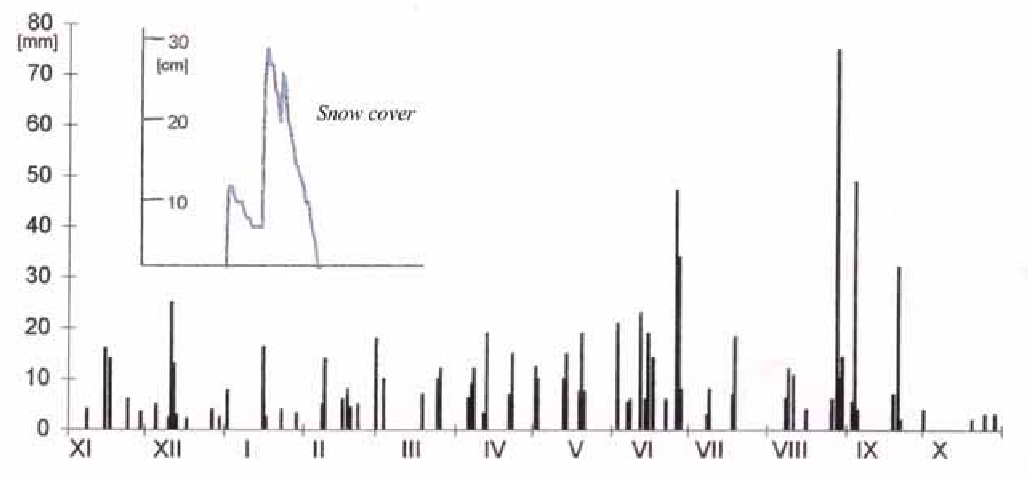
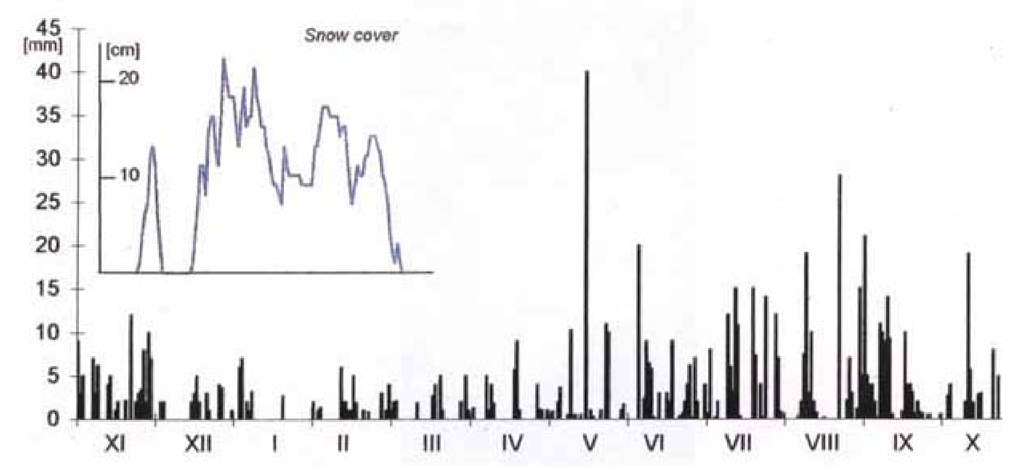


Fig. 5. Hydrologic year 1996
XI 1995–IV 1996 – 185.5 mm, V 1996–X 1996 – 582.7 mm, XI 1995–X 1996 – 768.2 mm



The water erosion was usually more intense in spring seasons, mainly when rainfall exceeded 20 mm. Rainfalls below 20 mm rarely caused erosion since nearly all the rainwater was absorbed by the soil profile. Throughout the investigated period the sheet flow was observed in 8 thaw periods and after 30 rainfalls (see Table 1). According to Gill's [6] classification, 10 low intensity rainfalls occurred, 19 short storms and downpours took place, while only one occurrence of a heavy rainfall turning periodically into torrential was observed.

PRINT

Table 1. Thaw seasons, heavy rains and deluges causing intensive surface runoff between 1st November 1991 and 30th October 1996

Thaw seasons and dates of rainfall	Water storage in snow [mm]	Duration of rainfall [min]	Total rainfall [mm]	Maximum intensity [mm · min-1]	Classification of rainfall according to:	
					Gil [1994]*	Chomicz [1951]**
23-26 Feb. 1992	26					
29 Apr.		50	23	0.5	3	A3
22 May		25	27	1.3	4	A4
28 May		38	41	1.5	4	B1
13 June		34	27.2	0.9	3	A4
24 June		26	30.2	1.6	4	B1
22 Aug.		32	25	1.1	3	A4
4-6 Sept.		2130	96.5	0.05	2	
17 Oct.		58	30	0.6	3	A3
12—15 Jan.1993	34					
16-21 March	67					
22 May		48	26	0.6	3	A3
11 June		36	23.5	0.8	3	A3/A4
22 June		49	21	0.5	3	A3
17-22 July		240	85.4	0.4	1	
16 Aug.		635	24.9	0.04	1	
24 Aug.		48	22.6	1.2	3	A4
2-3 Sept.		1 780	32	0.02	1	
17-18 Oct.		700	20	0.03	1	
05-06 Jan.1994	21					
27-30 Jan.	24					
02 Apr.		25	35	1.5	4	B1
26-27 May		1 850	34	0.01	1	
04-06 June		361	90.5	0.4	2	
08 Aug.		45	24.4	0.6	3	A3
24-26 Jan.1995	31					
12 June		38	23	0.7	3	A3
26 June		31	47.2	1.7	4	B2
27 June		33	34	1.4	4	B1
26-30 Aug.		2 100	105.6	0.03-1.5	6	
04 Sept.		81	49	0.7	4	A4
21 Sept.		120	32	0.03	1	
2-4 Dec. 1995	22					
6-9 March 1996	29					
20 May		38	41	1.6	4	B2
12-16 June		1300	24	0.02	1	
15-20 July		1963	47.2	0.09	2	
28 Aug.		59	28	0.7	3	A3

**** applies to heavy and torrential rains**
*** classified according to Gil [1994]**

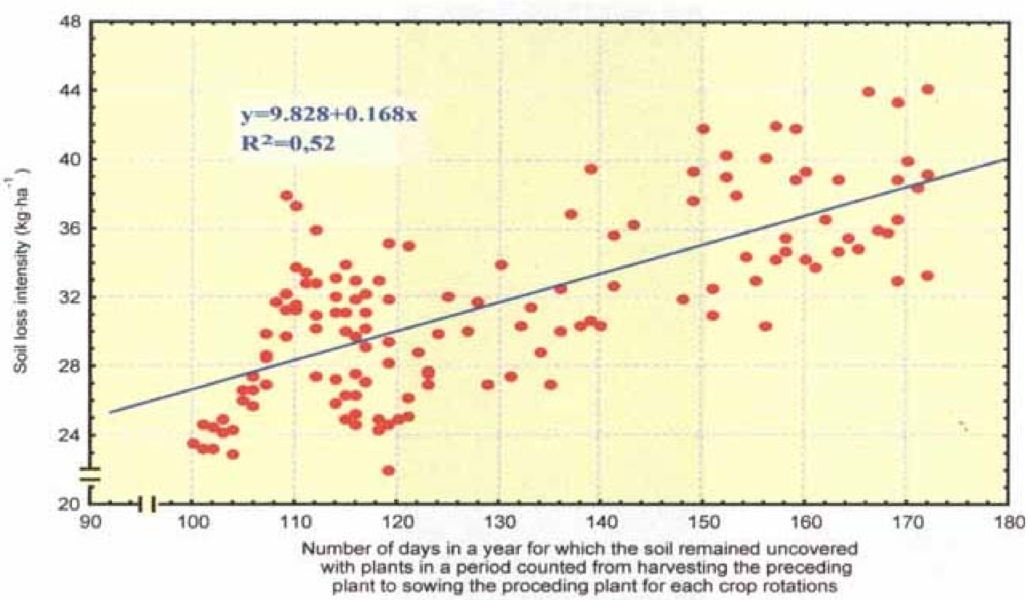
	Total Rainfall	Maximum intensity
1. Shower of low intensity	in 90	0.01–0.04
2. Rainfall of low intensity	90–300	0.08–0.16
3. Shower	in 30	0.5–1.0
4. Short downpour	30–50	1.4–2.2
5. Torrential rain	60–90	0.8–1.0
6. Extensive rain (0.01 – 0.16 mm·min-1) periodically turning into downpour (1.4–2.2 mm·min-1)	90-300	

PRINT

RESULTS AND DISCUSSION

Among the studied crop rotations the highest anti-erosive efficiency, which corresponds to the smallest amount of soil losses of 29.3 kg · ha^{-1} · $year^{-1}$, was found for crop rotation C, for which admixture of red clover and timothy was applied twice. For crop rotation B (red clover and winter triticale) 32.9 kg·ha^{-1} · $year^{-1}$ of soil loss was registered. For crop rotations A with horse bean and winter triticale, the average soil loss amounted to 37.6 kg · ha^{-1} · $year^{-1}$. The mass of the washed down soil (y) was directly proportional to the number of days in a year (x) counted from harvesting a preceding plant to sowing a proceeding plant ('harvest-*pre*-to-sowing-*pro*) that was assessed in each particular crop rotation. Throughout such periods the land was not covered with plants. Such a relation can be expressed by a regression equation $y = 0.168x + 9.828$ (Fig. 6). Determination coefficient was equal to 0.523 (n=136), and the correlation coefficient 0.723. The regression was found significant at the level of á = 0.01. Therefore, according to Guilforda [7] correlation can be regarded strong, and dependence significant.

Fig 6. Dependence between the number of days in a year for which the solil remained uncovered with plants and the intensity of sheet fliw-induced soil losses; for each crop rotation days counted fopr the period from harvesting the preceding plant to sowing the proceding plant



The obtained results confirmed the findings of other authors who noticed that anti-erosion efficiency of crop rotations decreases with prolonged periods without plant cover [9,10] and with raising the contribution of plants which require wide inter-drill distances [1]. Nevertheless, none of them have applied the regression equation, or at least no such approach has been presented the available literature on the subject, so it seems that the presented equation is one of the firsts analysis of dependence in terms of a mathematical equation.

The regression approach was applicable due to employing a model - never tested in Poland - of a crop rotation experiment in which the soil losses were measured directly and all the crop rotations were repeated 12 times a year.

The presented regression equation can be applied to verify - in Polish environmental conditions - the index of crop-rotation induced soil conservation determined by Konstantinov, as quoted by A. and C. Józefaciuks [14].
The presented regression equation can be also helpful in determining the value of C coefficient from the universal soil loss equation (USLE) [31], i.e. cropping and management factor (cultivated plants, soil protective crop rotations) under Polish environmental conditions. The equation based on a digital method of parameterisation is strongly recommended by FAO for general use [16,30].

The determined dependence between the length of the period without plant cover in each crop rotation and the intensity of surface runoff-induced soil losses, can be a valuable result for facility and farming investigations as well as planning studies conducted for complex management of eroded lands [13, 27, 28]. It should allow to plan the optimal number of crop rotation fields sown with highly efficient soil-protective plants. The obtained results clearly point to reducing the number of days without plant cover as an erosion-limiting factor at croplands.

The observation gains significance with regard to soil conservation practice when any factor accelerating erosion, such as increased slope or soil erodibility, grows. Practically, it may denote that in terms of crop rotations increasing slope or higher erodibility shall be compensated by an increased number of plots sown with winter crops or with mixtures of grass and papilionaceous plants. Such practice will the number of days without plant cover.

In the conducted research varied number of days without plant cover for particular crop rotation resulted from agricultural techniques typical for plants constituting the elements of a crop rotation.

The biggest number of days without plant cover (an average of 162 days) was found for crop rotation A, with horse bean. The soil was devoid of plant cover in the following periods: from harvesting fodder beet till oat was sown (between 190 and 211 days, average of 198 days); from harvesting oat till horse bean sowing (from 232 to 241, average of 238 days); from harvesting horse bean till sowing winter triticale, average of 9 days; from harvesting winter triticale until fodder beet was sown (from 191 to 212, average of 203 days). For crop rotation B (with red clover) the avearage number of days without plant cover amounted to 128, whereas for crop rotation C with admixture of red clover and timothy whose cultivation was repeated twice, the average number of days reached mere 109. For the crop rotations B and C, the observed reduced number of days resulted from the neglected tillage after harvesting oat with red clover as a supplementary crop (crop rotation B), after harvesting oat with timothy as a supplementary crop, and after the first year of cultivating the mixture of red clover with timothy in crop rotation C.

For crop rotation A the amount of surface runoff-induced soil losses reached the highest value and was equal on average to 37.6 kg $\cdot$ ha^{-1} $\cdot$ year^{-1} . It was an imminent result of long periods without plant cover of average of 162 days. Therefore bare soil was exposed to impact of falling raindrops that directly induced splash erosion [20,22]. The process facilitates crushing of soil aggregates, detachment of soil particles and their subsequent fluvial transport down the slope. Ellison [4] claims that the speed of surface runoff waters down the slope though enough to remove transportable soil particles, cannot cause their detachment.

The plants used in the studied crop rotations manifested various anti-erosive capacities. Average amount of soil losses in kg $\cdot$ ha^{-1} $\cdot$ year^{-1} at the sites cultivated with specific crops yielded the following values: 87.3, 24.2, 22.1, 19.6, 3.6, and 2.6 kg $\cdot$ ha^{-1} $\cdot$ year^{-1} for fodder beet, oat, horse bean, winter triticale, red clover and mixture of red clover with timothy, respectively.

Relatively small amounts of collected eroded soil could be, for example, resultant from low sheet erodibility index (susceptibility to being washed away by surface runoff), which varied from 1.9 to 2.1 [11]. Low percent slope of 13.4% on average, was another factor which limited water erosion, as well as localisation of the experimental field at the lower part of the mountain side classified as an ecological zone of arable lands, falling into second degree - hence moderate - group with respect to erodibility.

The method employed in our research for evaluation of the soil-protective capability of the cultivated plants in the period counted from harvesting a preceding plant to harvesting a tested proceeding one under assessment, is of innovative character. So far soil losses have been determined for periods from sowing to harvesting tested plants [24, 27]. Such an approach, however, seems relevant for direct sowing only [32]. Another method, frequently applied in such studies, is determination of soil protective properties for water half-years or years [6]. Disadvantage of such a method, with respect to proper land and plant cultivation practice [17], is an artificial division of the cultivation period of plants from their vegetation period by the dates May, 1st and November, 1st. In numerous studies concerned with the soil-protective capacities of plants the authors did not define the periods for which they determined erosion; quite often neither initiate nor closing dates of the measurements are given [21, 29].

Clear definition of the initial and final points - harvest of a preceding plants and assessed plants, respectively, stems directly from classic assumptions relevant for any crop protection studies [17]. Relevancy of the approach is most rewarding in studies aimed at determining soil protective capacities for spring crops, whose forecrops were root crops or leguminous plants. After harvesting the plants, used as pioneer crops for spring crops, tillage is usually applied. Erosion taking place in ploughed fields throughout autumn, winter and early spring seasons, shall be attributed to spring crops, which were subjected to test. In our opinion such attitude is of utmost significance nowadays when marketing strategies entered bravely the cultivation practice. It is a standard practise to select plants for crop rotations on the basis of their economic worth, which leads to choosing economically efficient plants. Quite often then spring crops, like horse bean, are the selected ones. In consequence fields are ploughed for autumn and winter, hence remain deprived of plant cover protecting the soil from erosion. It proves that the erosion occurring at the ploughed field prepared properly for sowing any spring crops shall be attributed the very crop.

Intensity of soil losses at sites with plants covered by the present study are gathered in Table 2. It is clearly demonstrated that soil losses measured for periods from sowing to harvesting the tested plants were less intense when compared to soil losses measured for harvest-to-harvest periods for a preceding and proceeding plants, respectively. For fodder beet the difference amounted to 10.7 kg $\cdot$ ha^{-1} $\cdot$ year^{-1}, which corresponds to reduction of sheet erosion by 12.3%. The respective differences and percentage for oat, horse bean and winter triticale gave the values of 8 kg $\cdot$ ha^{-1} $\cdot$ year^{-1} (33.1%), 4.8 kg $\cdot$ ha^{-1} $\cdot$ year^{-1} (21.7%), and a mere 0.4 kg $\cdot$ ha$^{-1}\cdot$year^{-1} (1.1%). The smaller number of days for sowing-to-harvest periods for the assesed plants when compared to pre-crop harvest-to- pro-crop harvest of the assessed plant, contributed gravely to such differences in values. The smaller number of days was equall to 243, 213, 243 and 6 days for fodder beet, oat, horse bean and winter triticale, respectively.

Table 2. Intensity of sheet flow-induced soil losses (kg $\cdot$ ha^{-1} $\cdot$ year^{-1}) at stands cultivated with selected plants determined for different measurement periods.

Measurement periods	Absolute values for intensity of sheet flow-induced soil losses (kg $\cdot$ ha^{-1} $\cdot$ year^{-1}) under assessed plants							
	Fodder beet		Oat		Horse bean		Winter wheatrye	
Pre-plant harvest-to-pro-plant harvest (assessed)	87.3	100%	24.2	100%	22.1	100%	19.6	100%
Sowing-to-harvest of the assessed plant	76.6	87.7	16.2	66.9	17.3	78.3	19.4	98.9
Winter half- water year 1 Nov.-30 Apr.	5.9	6.7	5.9	24.4	5.9	26.7	11.6	59.2
Summer half- water year 1 May – 31 Oct.	78.2	89.6	18.6	76.8	14.8	66.9	8.1	41.3
Full water year 1 Nov. – 31 Oct.)	84.1	96.3	24.5	101.2	20.7	93.7	19.7	100.5

It can be claimed therefore, that the value of soil loss intensity determined for harvest-to-harvest periods for preceding and assessed plants, respectively, represents a reliable measure of soil-protective capabilities of the considered plant. Shorter sow-to-harvest periods give no correction for erosion occurring between sowing the preceding plant to sowing the assessed one.

Data presented in Table 3 are further confirmation for proper definition of periods as preceding plant harvest-to-proceeding (assessed) plant harvest. Defining measurement periods as sowing-to-harvest of the assessed plant leads to comparing significantly different periods, i.e. 340 days for winter triticale and merely 122 days for oat. Accepting such assumptions could possibly lead to drawing a false conclusion that among crops, oat is more soil-protective capable than winter triticale for which the respective values of soil losses were determined as 16.2 kg $\cdot$ ha^{-1} $\cdot$ year^{-1}, see Tab.2 and 19.4 kg $\cdot$ ha^{-1} $\cdot$ year^{-1}. Such a miss-conclusion is easily disprovable when we realise that for triticale the soil losses has been measured throughout autumn, winter and early spring season, while in case of oat, sown most often in the first decade of April, sheet erosion for the same periods simply did not contribute to triticale soil-protective capability.

Table 3. Average number of days for measurement periods

Measurement periods	Assessed plants							
	Fodder beet		Oat		Horse bean		Winter wheatrye	
	Number of days	Measurement period	Number of days	Measurement period	Number of days	Measurement period	Number of days	Measurement period
Pre-plant harvest-to-pro-plant harvest (assessed)	396	from 3 Aug. till 3 Sept.*	335	from 3 Sept. till 3 Aug.*	406	from 3 Aug. till 3 Sept.*	346	from 3 Sept. till 3 Aug.*
Sowing-to-harvest of the assessed plant	153	from 3 Apr. till 3 Sept.*	122	from 3 Apr. till 3 Aug.*	163	from 3 Apr. till 3 Sept.*	340	from 3 Sept. till 3 Aug.*
Winter half-water year 1 Nov.-30 Apr.	182		182		182		182	
Summer half-water year 1 May – 31 Oct.	183		183		183		183	
Full water year 1 Nov. – 31 Oct.	365		365		365		365	

*** – for month decades Arabic notation id used**

CONCLUSIONS

5. The intensity of soil loss (y) was directly proportional to the number of days (x) without plant cover, counted for each crop rotation as preceding plant harvest-to-proceeding plant sowing. The relationship can be expressed in terms of a regression equation $y = 0.168x + 9.828$ [$kg \cdot ha^{-1} \cdot year^{-1}$]; with $n = 136$, $\alpha = 0.01$ and $r = 0.723$.
6. Increasing the number of days without plant cover by one day for all studied crop rotations gave rise to the soil loss intensity by 0.168 kg per hectare per year.
7. For all crop rotations their soil-protective capability improved with increasing contribution of plants of highly anti-erosive properties.
8. The plants applied in the studied crop rotations can be rated with regard to their anti-erosion efficiency from the highest to poorest, in the following order: fodder beet, oat, horse bean, winter wheat-rye, red clover , mixture of red clover with timothy.
9. Soil-protective capabilities of plants cultivated on arable lands shall be performed for periods between sowing a preceding plant to harvesting the proceeding plant which is under assessment.

REFERENCES

1. Adams J.E., Richardson C.W., Brunett E. 1978. Influence of Row Spacing of Grain, Sorgum on Ground Clover, Runoff, and Erosion. Soil Sci. Soc. Am. J., vol. 42, 959-962.
2. Chomicz K. 1951. Ulewy i deszcze nawalne w Polsce [Haevy rainfalls and deluges in Poland]. Wiad. Służby Hydrol. 3, 5-88 [in Polish].
3. De Ploey J. 1981. Some Laboratory Techniques for Investigating Land Erosion. Erosion and Sediment Transport Measurements. (Proceedings of the Florence Symp., June 1981). IAHS Publ., 133, 423-431.
4. Ellison W. 1945. Some Effects of Raindrops and Surface-Flow on Soil Erosion and Infiltration. Trans. Am. Geoph. Un., 26, 415-429.
5. Froehlich W. 1992. Mechanizm erozji i transportu fluwialnego w zlewniach beskidzkich [Erosion and Fluvial Trasport Mechanisms in Beskid Catchment Areas]. Prace Geogr. IGiPZ PAN, 155, 171-189 [in Polish].
6. Gil E. 1994. Monitoring obiegu wody i trasportu fluwialnego na stokach [Monitoring Water Circulation and Fluvial Transport on Slopes]. Biblioteka Monitoringu Środowiska. Warsaw, p.66-87 [in Polish].
7. Guilford J.P. 1964. Podstawowe metody statystyczne [Basic Methods in Statictics], PWN, Warsaw.
8. Instrukcja nr 3 Ministrów Rolnictwa oraz Leśnictwa i Przemysłu Drzewnego z 6.03.1973 r w sprawie określania gruntów rolnych i leśnych zagrożonych erozją oraz zasad i trybu przeciwdziałania erozji [Manual no 3, Ministry for Agriculture and Ministry for Forestry and Wood Industry, dated 06/03/73 on determination of erodible arable lands and woodlands; rules and terms of soil conservation practice]. Dz. U. nr 48, poz. 283 [in Polish].
9. Jankauskas B. 1998. Soil Erosion under Different Crop Rotations in Zhemaichiai Upland, Lithuania. Int. conf. 'Water resources and soil conservation', Moreano, Italy, April 1998, 307-313.
10. Jankauskas B., Jankauskiene G. 1998. The Extent of Soil Degradation on Hilly Relief of Western Lithuania and Antierosion Agrophytocenoses. Advances in GeoEcology, 31, Catena Verl. Reiskirchen, 389-393.
11. Janowski B., Koreleski K., Jagła., Michalczewski M. 1968. Charakterystyka występowania erozji powierzchniowej na terenie województwa rzeszowskiego [Sheet Erosion Characteristics in Rzeszów Voivodship]. Probl. Zagos. Ziem Górs. 6/19; 88-105 [in Polish].
12. Józefaciuk C., Józefaciuk A. 1975. Komentarz do instrukcji w sprawie inwentaryzacji gruntów zagrożonych erozją [Commentary to Manual to Inventory of Erodible Lands]. Wyd. IUNG, Puławy, 1-20 [in Polish].
13. Józefaciuk A., Józefaciuk Cz. 1993. Próba prognozowania wodnej erozji gleb na podstawie zintegrowanych danych konwencjonalnych i teledektycznych. [Integrated Conventional and Teledectic Data as the Base for Approach to Prognosing Water Erosion in Soils] IUNG, Puławy, P (54), 1-44 [in Polish].
14. Józefaciuk A., Józefaciuk C. 1996. Mechanizm i wskazówki metodyczne badania procesów erozji [Erosion Processes Studies: Mechanism and Applied Metodology]. Państ.Insp. Ochr. Środ. ser. Biblioteka Monitoringu Środowiska, Warszawa, 1-148 [in Polish].
15. Kaczorowska Z. 1962. Opady w Polsce w przekroju wieloletnim [Longterm Profile of Rainfalls in Poland]. Prace Geogr. IG PAN, 33, 1-107 [in Polish].
16. Koreleski K,. 1992. Próby oceny natężenia erozji wodnej [Water Erosion Intensity - Assessment Approaches]. Zesz. Nauk. AR w Krakowie. 271, 91-100 [in Polish].
17. Könnecke G. 1967. Fruchtfolgen [Crop revision]. VEB Deutscher Landwirts. Berlin, 1-394 [in Germany].
18. Niewiadomski W. 1991. Regionalizacja ekologiczno-ekonomiczna wzorcowych płodozmianów w Polsce [Region Related Ecological and Economical Model Crop Rotation Patterns in Poland]. V Seminarium płodozmianowe. ART Olsztyn - VSZ Brno, 159-170 [in Polish].
19. Mazur Z., Orlik T. 1972. Pomiary zmywu gleby na kilku użytkach za pomocą sztucznie wywołanego opadu [Artificial Rainfall Induced Sheet Erosion - Measurements on Selected Croplands]. Zesz. Probl. Post. Nauk Rol., 130, 117-127 [in Polish].
20. Moeyersons J., De Ploey J. 1976. Quantitative Data on Splash Erosion Simulated on Unvegetated Slopes. Z. für Geomorph. Bd., 25, 120-131.

PRINT

21. Prochal P., Mierzwa W. 1992. Erozja gleb i melioracje przeciwerozyjne w terenach górskich [Soil Erosion and Soil Conservation Melioration in Mountain Areas]. Zesz. Nauk. AR w Krakowie, ser. Sesja Naukowa, 35, 23-35. [in Polish]
22. Rejman J. 1990. Splash Detachment on a Silt Loam Soil with and without a Plant Cover on Triticale. Zesz. Probl. Post. Nauk Rol, 388, 161-168.
23. Rejman J., Usowicz B. 1998. Zastosowanie modelu USLE do prognozowania natężenia erozji wodnej gleb płowych Wyżyny Lubelskiej: teoria i praktyka [USLE Model Applied to Prognosing Intesity of Water Erosion in Silt Soils at Lubelska Highland: Theory and Practice]. Bibliot. Fragm. Agronom. 4A/98, 231–244 [in Polish].
24. Sharpley A.N., Smith A.N., Williams J.R.., Jones O.R.. Coleman G.A. 1991. Water Quality Impacts Associated with Sorgum Culture in the Southern Plaints. J. Environ. Qual. 20, 239-244.
25. Schwertmann U., Vogl W. 1986. Landbewirtachaftung und Bodenerosion [Land use and soil erosion]. VDLUFA-Schriftenreihe, Konressband, 16, 7-17 [in Germany].
26. Słupik J. 1975. Conditions of Infiltration and Surface Run-off in the Sant Catchment Basin. Biul. De l'Academie Pol. des Scien., ser. des Scien. de la Terre, vol 23, no 3-4,233-236.
27. Smith S.J., Sharpley A.N., Naney J.W., Berg W.A., Jones O.R. 1991. Water Quality Impacts Associated with Wheat Culture in the Southern Plaints. J. Environ. Qual. 20, 244-249.
28. Stach A. 1996. Zastosowanie metod magnetycznych i radioizotopowych w badaniach erozji gleb [Magnetic and Radioisotopic Methods Applied in Soil Erosion Studies]. Prace Naukowe IUNG, K (11/2), Puławy, 177-201 [in Polish].
29. Unger P.W. 1984. Tillage and Residue Effects on Wheat, Sorgum, and Sunflower Grown in Rotation. Soil Sci. Soc. Am. J. 48, 885-891
30. Unger P.W., Sharpley A.N., Steiner J.L., Papendick R.I., Edwards W.M. 1998. Soil Management Research for Water Conservation and Quality. [in:] Soil and Water Conservation, Red. F.J. Pierce i W.W. Frye. Sleeping Bear Press, Inc., Chelsea USA, 69-97.
31. Wischmeier W. H., Smith D.D. 1978. Predicting Rainfall Erosion Losses. Agricult. Handbook No 537, Sci. and Educ. Admin. U.S. Dept. Agr., Washington D.C., 1-58.
32. Zhu J.C, Gantzer C.J., Anderson S.H., Alberts E.E., Beuselinck P.R. 1989. Runoff, Soil, and Dissolved Nutrient Losses from No-Till Soybean with Winter Cover Crops. Soil Sci. Soc. Am. J. 53, 1210-1214.

Kazimierz Klima
Department of Soil and Plant Cultivation
Agricultural University of Cracow
al. Mickiewicza 21, 31-120 Cracow, Poland
phone (+4812) 66 24 365
e-mail: rrklima@cyf-kr.edu.pl