doi: 10.17221/639/2015-PSE

# The interdependence between the leaf area index value and soil-protecting effectiveness of selected plants

**K. Klima[1], B. Wiśniowska-Kielian[2], A. Lepiarczyk[1]**

[1]*Department of Agrotechnology and Agricultural Ecology, Faculty of Agriculture and Economics, University of Agriculture in Krakow, Krakow, Poland*
[2]*Department of Agricultural and Environmental Chemistry, Faculty of Agriculture and Economics, University of Agriculture in Krakow, Krakow, Poland*

**ABSTRACT**

The study presents results of the one-factor field experiment carried out in years 2005–2011 located on a slope with an inclination of 9%, in the mountain region (southern Poland, 545 m a.s.l.). Soil-protection effectiveness of potato, spring barley and meadow was studied on the basis of vegetation cover forming during whole plant vegetation period, expressed as LAI (leaf area index). The mass of surface runoff from the plots was measured after precipitation and snowmelts causing surface wash-out. The plots were arranged in a randomized block design, in four repetitions. Surface wash-outs were caught in the Słupik's catchers. The soil-protection effectiveness of potato starts when plants cover 80% of the soil surface, in spring barley it was 60%, and for meadow 10%. Reduction of the intensity of surface wash as a result of an increase in the surface of the plants aerial-parts is described in the following simple regression equations: $y = -1480.7x + 4094.2$ ($r = 0.63$, $n = 216$) for potato; $y = -59.2x + 157.4$ ($r = 0.69$, $n = 200$) for spring barley, and $y = -1.5097x + 11.6$ ($r = 0.37$, $n = 236$) for meadow. Meadow protects soil against water erosion 6.8-times more effectively than spring barley and 324-times better than potato. The results enabled verification of the nomograms determining the carbon indicator value in the USLE equation for tested plants under similar conditions.

**Keywords**: rainfall; *Solanum tuberosum* L.; *Hordeum vulgare*; evaporation; soil protection

Vegetation cover is one of elements that determine many properties of arable land soils, among others the total number of colony-forming units (CFU) occurring in soil arable layer (Patkowska and Konopiński 2013) and soil-protecting in extreme summer periods (Kalmár et al. 2013). Vegetation cover reduces soil evaporation (Mullan and Reynolds 2010), and is also one of the elements affecting the intensity of water erosion occurring on arable lands (Klima and Wiśniowska-Kielian 2007). The leaf area index (LAI) is the ratio between the vegetation area and the soil surface unit (dimensionless quantity) (Watson 1947). Ground cover (GC) indicates the part of soil surface covered by vegetation and is significant in soil protection estimate. There is a close connection between these two indices, because ground cover increases along with the LAI, and their values depend on plant species (Bréda 2003, Klima and Wiśniowska-Kielian 2006, Ramirez-Garcia et al. 2012). Anti-erosion effectiveness depends on the rate of increase in the surface of the above-ground parts of plants which reduce splash and decide on the size of interception (Rejman et al. 1990). The available literature lacks publications describing the anti-erosion effectiveness of crops in the period between sowing and harvest, based on multi-year field studies. Many authors draw attention to the purposefulness of and need for such studies (Licznar et al. 2002). It arises, among other things, from the regional character of the plant cover index (C) (Bolline 1985), as the plant cover index is a component of the universal soil losses equation (USLE) (Wischmeier and Smith 1978).

The research was aimed at determining the effect of increase in the surface of the above-ground

doi: 10.17221/639/2015-PSE

parts of potato, spring barley, and meadow sward on the intensity of soil surface wash.

## MATERIAL AND METHODS

**Site description and experimental design**. The one-factor field experiment was carried out in the years 2005–2011 on a slope with an inclination of 9%, in the Mountain Experimental Station in Czyrna near Krynica (545 m a.s.l., southern Poland). It compared the mass of surface runoff from meadow and the plots on which potato and spring barley were cultivated. Atmospheric precipitation and snowmelts were the factors that caused water erosion. The studied plants were cultivated on plots with dimensions of 22.13 × 1.82 m, arranged on the slope in a randomized block design in four repetitions. The surface wash was measured by the direct method with the use of Słupik's bag catchers (Słupik 1975). A catcher consists of a plastic bag, attached to a steel rack with an inlet of 1.82 m width, disposed at the bottom edge of each plot. The catchers were emptied after each precipitation or the snowmelt causing the surface runoff. Volume of the surface runoff was measured, and 1 $dm^3$ from the suspension was randomly collected and after filtrating through a medium hard filter the mass of the surface runoff was determined. The sediment together with the filter were dried at a temperature of 105°C, then cooled in a desiccator and weighed on an electronic analytical balance with accuracy up to 0.0001 g. The obtained result was reduced by the mass of a dry filter. The above-ground parts of the test plants were measured using apparatus for measuring the leaf area index, manufactured by the Sun Scan Canopy Analysis System company. Measurements of the surface runoff mass involved three different time intervals: (a) plant vegetation period, from spring barley sowing or potato planting to harvest, and a period from the beginning until the end of meadow sward vegetation; (b) annual periods, i.e. from 1 January to 31 December, which also include snowmelt runoff; (c) periods proposed by Schwertmann et al. (1987): for spring barley – from harvest of potato to skimming after the harvest of spring barley, for potato – from skimming after the harvest of spring barley until harvest of potato. This method does not concern meadow sward.

Two crop rotation segments, (1) potatoes; (2) spring barley, were applied. Seed-potatoes were planted generally in mid-April. Spring barley was sown at the end of the first decade of April. The meadow sward vegetation usually began at the end of the first decade of April. The studied plants were cultivated according to principles of appropriate agricultural engineering. Barley harvest generally followed in mid-August, and potato harvest in the first decade of September. The first swath was harvested in the third decade of May, and aftermath was harvested at the end of the first decade of September.

**Conditions of experiment conducting**. The experimental soil belonged to cambisoils formed from weathered flysch rocks with texture of medium, shale clay. The soil according to the Polish criteria (Mocek 2014) was classified to the $5^{th}$ soil quality class and $12^{th}$ mountain oats-and-potatoes complex. The average thickness of its humus horizon was 24 cm (Table 1). The index of soil susceptibility to washing out (the relation between dust fraction and colloidal clay) was 1.81 (Janowski et al. 1968, Józefaciuk and Józefaciuk 1996).

The research area is located in the moderately warm climatic zone, where the mean annual temperature is within a range 6–8°C. Precipitation

Table 1. Granulometric composition of soil

| Genetic horizon* | Depth (cm) | Contents of skeletal particles ω | Percentage of earth particles with diameter (mm) | | | | | | Sieved particles | Type of soil |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1–0.1 | 0.1–0.05 | 0.05–0.02 | 0.02–0.006 | 0.006–0.002 | < 0.002 | | |
| | | (%) | | | | | | | | |
| Ap | 0–24 | 9 | 24 | 10 | 19 | 18 | 13 | 16 | 47 | medium heavy silty loam |
| BbrC | 24–48 | 21 | 20 | 9 | 19 | 18 | 21 | 13 | 52 | heavy silty loam |
| C1g | 48–115 | 60 | 33 | 10 | 14 | 20 | 12 | 11 | 43 | medium heavy loam |
| C2g | 115–160 | 53 | 9 | 3 | 8 | 26 | 24 | 30 | 80 | clay |

*according to Polish Society of Soil Science (1989)

doi: 10.17221/639/2015-PSE

Table 2. Precipitation totals (mm) measured in the Czyrna station, Poland

| Year | Month | | | | | | | | | | | | IV–VIII | I–XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | | |
| 2005 | 75.3 | 39.1 | 27.3 | 44.4 | 82.8 | 121.3 | 94.6 | 161.0 | 63.0 | 10.6 | 33.0 | 55.3 | 504.1 | 807.7 |
| 2006 | 62.6 | 44.9 | 45.1 | 59.3 | 111.6 | 239.1 | 22.8 | 97.4 | 31.6 | 32.0 | 25.9 | 18.4 | 530.2 | 790.7 |
| 2007 | 108.5 | 54.5 | 73.0 | 25.8 | 60.0 | 94.2 | 54.6 | 58.0 | 212.0 | 57.7 | 104.7 | 27.5 | 292.6 | 930.5 |
| 2008 | 43.1 | 25.4 | 95.2 | 46.8 | 40.3 | 39.7 | 185.1 | 60.6 | 124.0 | 68.5 | 60.9 | 68.0 | 372.5 | 857.6 |
| 2009 | 38.6 | 54.5 | 77.8 | 15.5 | 123.7 | 135.3 | 96.2 | 66.4 | 69.7 | 50.3 | 42.8 | 51.3 | 437.1 | 822.1 |
| 2010 | 31.9 | 33.3 | 26.9 | 65.8 | 234.2 | 226.6 | 131.6 | 144.5 | 172.1 | 28.4 | 30.1 | 45.3 | 802.7 | 1170.7 |
| 2011 | 36.7 | 15.1 | 27.6 | 106.3 | 72.1 | 44.4 | 278.4 | 85.6 | 15.9 | 34.0 | 1.1 | 15.0 | 586.8 | 732.2 |
| 1961–2000 | 43.9 | 39.4 | 45.7 | 62.0 | 99.6 | 118.6 | 111.2 | 91.0 | 76.6 | 54.7 | 42.6 | 53.6 | 482.3 | 838.9 |

totals in the vegetation period were varied (Table 2). The course of weather conditions in winter did not cause intensified rill erosion since snow thawing took place during solar snowmelts. The mean total precipitation in summer hydrological half-years was almost twice higher than in winter ones.

In general, increased intensity of water erosion in spring exceeding 20 mm, occurred mainly during precipitation. Precipitation below 20 mm rarely caused erosion since almost all the rainwater percolated into the soil profile. During the research period, runoffs occurred in 6 snowmelt periods and after 59 rainfalls. According to rainfall classification (Gil 1994), a 6 low-intensity precipitation, 39 short-term rains and 14 short-term downpours were recorded.

**Statistical analyses**. The data were statistically elaborated to determine the significance of relation between plant cover expressed as LAI value and the amount of soil losses as an effect of surface runoff. Statistical analyses were performed at least at a significance level $\alpha = 0.05$. To determine whether the studied plants differently affected soil-protecting effectiveness the least significant difference (*LSD*) test at $\alpha = 0.05$ was used.

## RESULTS AND DISCUSSION

Kalmár et al. (2013) stated that leaving the soil without cover or having it with insufficient cover (< 15%) entails risks for soil. According to their findings, the optimum crumb structure is formed under 50–55% plant cover in an average season, and under a 55–60% cover in a wet season. In turn, this type of structure ensures maximum stability of soil aggregates. In the authors' own research, it was established that soil-protection effectiveness of potato began when 80% of the soil surface was covered with the above-ground parts of plant, on average, which corresponds to the average LAI value of 0.8 (Figure 1). Setting this LAI value as the beginning of soil-protection effectiveness of potato comes from the fact that sudden decrease in the mass of surface runoff from potato plots started from the LAI value of 0.8. At the LAI value of 0.85, the mass of surface runoff was 2.8 t/ha, on average (Figure 1), which constituted 13% of the runoff mass for potato in the vegetation period (Table 3).

The soil-protection effectiveness of spring barley began when 60% of the soil was covered with plant, which corresponded to LAI value of 0.6 (Figure 2). Starting from this LAI value, a distinct decrease in the mass of surface runoff took place. At the LAI value of 0.6, the mass of surface runoff reached 60 kg/ha, on average (Figure 2), which constituted 13.2% of the runoff mass for spring barley in the vegetation period (Table 3).

The soil-protection effectiveness of meadow began when 10% of the soil was covered with meadow sward, which corresponded to LAI value of 0.1 (Figure 3). Starting from this LAI value, a steady decrease in the mass of surface runoff took place during meadow sward vegetation. At the LAI value of 0.1, the mass of surface runoff reached on average 10 kg/ha (Figure 3), which constituted 15% of the runoff mass for meadow in vegetation period amounting to 66.1 kg/ha (Table 3).

The effect of increase in the surface of the above-ground parts of the plants on reducing the intensity of surface wash, expressed by the surface runoff mass, is described in the following linear regression equations:

$y = -1480.7x + 4094.2$ ($r = 0.63$, $n = 216$) for potato;

doi: 10.17221/639/2015-PSE

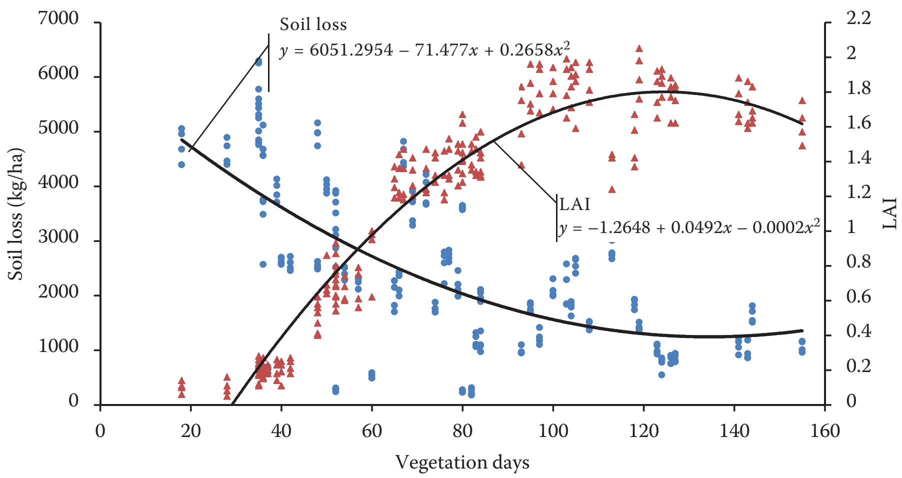


Figure 1. The soil-protection effectiveness of potato; LAI – leaf area index

$y = -59.2x + 157.4$ ($r = 0.69$, $n = 200$) for spring barley;

$y = -1.5097x + 11.6$ ($r = 0.37$, $n = 236$) for meadow.

This regression was significant below probability level $\alpha = 0.01$.

These results can be useful in verification of the C index value (type of vegetation cover) that occurs in the universal equation of soil losses (USLE) (Wischmeier and Smith 1978) in the region of the research (i.e. southern Poland). Presently, the C index value is read from nomograms. It is a considerable simplification due to a lack of precision in erosion forecasting. For greater precision, the surface runoff mass decrease with an LAI increase in the vegetation period of plants needs to be taken into account. Licznar et al. (2002) also point out this necessity. Therefore, it can be stated that the results obtained can be useful in verification of nomograms determining the value of C index used in the USLE equation for potato, spring barley, and meadow under conditions in southern Poland.

In the few previously published papers dealing with the issue of soil-protection of plants, a view that anti-erosion effectiveness of crops starts from 20–30% of soil coverage may be noted (Rejman et al. 1990, Rejman and Brodowski 1999). It is a considerable simplification, as evidenced by the results of our research which showed that LAI values of soil coverage with plants, to which soil-protection effectiveness of crops is related, are different for individual crops. This LAI values are: 0.8 for potato, 0.6 for spring barley, and 0.1 for meadow.

In other studies concerning the effect of LAI value increase on the intensity of surface wash, it was found that the increase in LAI is directly proportional to interception (Appelmans et al. 1980, Bui and Box 1992, Foody 2002, Kołodziej et al. 2005) and inversely proportional to splash intensity (Rejman et al. 1990). However, the cited authors did not describe the dependencies as a mathematical formula, e.g. a regression equation.

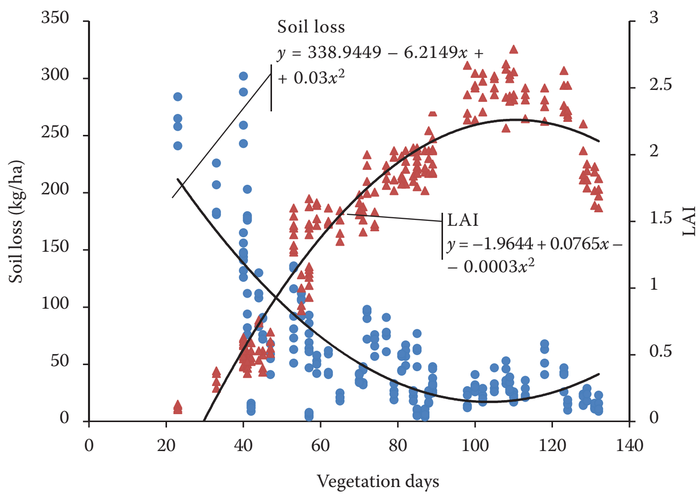


Figure 2. The soil-protection effectiveness of spring barley; LAI – leaf area index

doi: 10.17221/639/2015-PSE

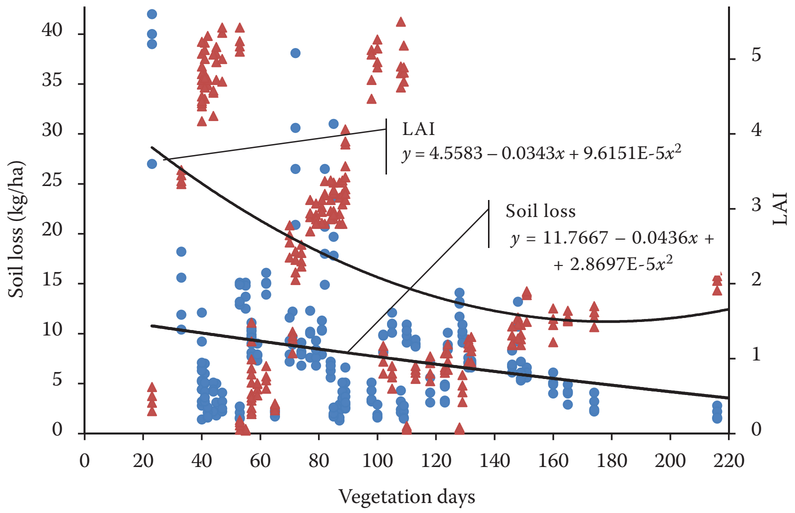


Figure 3. The soil-protection effectiveness of meadow; LAI – leaf area index

In the present research, regression analysis was possible because the seven-year observations provided a considerable number of data pairs: 216 for potato, 200 for spring barley, and 236 for meadow.

Taking into account the mean surface runoff mass determined on meadow in vegetation period (Table 3), it can be stated that meadow protected soil against water erosion 6.8-times more effectively than spring barley, and even 324-times better than potato. Similar relationships occurred when comparing the surface runoff masses within a calendar year, i.e. between 1 January and 31 December. Taking into account the surface runoff mass determined in periods adopted by Schwertmann et al. (1987) (Table 3), it can be stated that spring barley protected soil against water erosion 8.5-times more effectively than potato. Schwertmann et al. (1987) assumed that the runoff mass for a given crop should be determined from skimming after fore crop harvest, until skimming after the harvest of a crop under evaluation. A consequence of runoff is a reduced soil profile thickness on a slope due to erosion and overbuilt at the foot as an effect of accumulation of eroded mass. Rejman et al. (2014) found that total mass of eroded soil amounted 4394 t, and 88% of that mass stayed inside the eroded area. It causes transformation of the terrain resulting in a slope inclination decrease.

The present findings confirm the results of the earlier studies conducted both in the mountain and upland areas on the slopes of varying inclination. A high soil-protection value of meadow and a low one of root crops were found, as well as large losses of fertiliser elements (Klima and Wiśniowska-Kielian 2006, 2007, Wiśniowska-Kielian and Klima 2007). It was noted, for example, that soil protective efficiency of the fodder beet, horse bean and winter triticale started at about 60, 30 and 15% of the soil surface cover, respectively.

The mean LAI value determined in vegetation periods reached 1.12 for potato (for 216 measurements), 1.67 for spring barley (for 200 measurements), and 2.52 for meadow (for 236 measurements). Ramirez-Garcia et al. (2012) stated that ground cover, depending on plant species, corresponded to different values of LAI; for example for barley it reaches 100% when the LAI is over 4, and for vetch and rape when LAI is near to 3.

Table 3. Soil-protective effectiveness of potato, barley and meadows expressed as mass surface runoff (kg/ha)

| Evaluated period | Potato | Spring barley | Meadow | Mean |
|---|---|---|---|---|
| (a) From sowing or planting to harvest spring barley and potato, and from the beginning to the end of meadow vegetation | 21428.0 | 451.6 | 66.1 | 7315.2 |
| $LSD_{0.05}$ | | 376.40 | | |
| (b) Annual periods, i.e. from 1 January to 31 December | 22725.0 | 1841.1 | 98.3 | 8221.4 |
| $LSD_{0.05}$ | | 441.58 | | |
| (c) Periods according to Schwertann et al. (1987) | 2347.7 | 20030.6 | not applicable | |
| $LSD_{0.05}$ | 1087.92 | | | |

doi: 10.17221/639/2015-PSE

Summing up, the soil-protection effectiveness of potato starts at 80% of the soil cover, of spring barley at 60%, and of meadow at 10%. Reducing the intensity of surface wash expressed by the surface runoff mass as a result of increase in the surface of the aerial-parts of the test plants, is well described in the above-presented simple regression equations. Meadow protects soil against water erosion in vegetation period 6.8-times more effectively than spring barley and 324-times better than potato.

## REFERENCES

Appelmans F., Van Hove J., De Leenheer L. (1980): Rain interception by wheat and fodder beet crops. In: de Boodt M., Gabriels D. (eds.): Assessment of Erosion. Chichester, J. Wiley & Sons, 227–235.

Bolline A. (1985): Adjusting the universal soil loss equation for use in Western Europe. In: El-Swaify S.A., MoldenhauerW.C., Lo A. (eds): Soil Erosion and Conservation. Ankeny, 206–213.

Bréda N.J.J. (2003): Ground-based measurements of leaf area index: A review of methods, instruments and current controversies. Journal of Experimental Botany, 54: 2403–2417.

Bui E.N., Box J.E. (1992): Stemflow, rain throughfall, and erosion under canopies of corn and sorghum. Soil Science Society of America Journal, 56: 242–247.

Foody G.M. (2002): Status of land cover classification accuracy assessment. Remote Sensing of Environment, 80: 185–201.

Gil E. (1994): Monitoring of water circulation and rinsing on the slopes. In collective work: Starkel L., Gil E. (eds.): Integrated monitoring of the natural environment. The base station Szymbark (Flysch Carpathians). Warszawa, Environmental Monitoring Library, 66–87. (In Polish)

Janowski B., Koreleski K., Jagła S., Michalczewski M. (1968): Characteristics of the occurrence of surface erosion in the Rzeszow province. Mountain Regions Management Issues, 6: 88–105. (In Polish)

Józefaciuk A., Józefaciuk C. (1996): Mechanism and the guidelines of the study erosion processes. State Inspectorate for Environmental Protection, Series Environmental Monitoring Library, Warsaw, 1–148. (In Polish)

Kalmár T., Bottlik L., Kisić I., Gyuricza C., Birkás M. (2013): Soil protecting effect of the surface cover in extreme summer periods. Plant, Soil and Environment, 59: 404–409.

Klima K., Wiśniowska-Kielian B. (2006): Anti-erosion effectiveness of selected crops and the relation to leaf area index (LAI). Plant, Soil and Environment, 52: 35–40.

Klima K., Wiśniowska-Kielian B. (2007): Estimation of soil losses resulting from the surface run-off in the upland region depending on the type of land use. Advances of Agricultural Sciences Problem Issues, 520: 821–827. (In Polish)

Kołodziej J., Liniewicz K., Bednarek H. (2005): Rainfall interception in cereal fields. Acta Agrophysica, 6: 381–391. (In Polish)

Licznar P., Sasik J., Żmuda R. (2002): Prediction of water erosion in small agricultural catchments Trzebnickie hills. Advances of Agricultural Sciences Problem Issues, 487: 137–146. (In Polish)

Mocek A. (2014): Soil Science. Warszawa, Scientific Publishers PWN, 464. (In Polish)

Mullan D.J., Reynolds M.P. (2010): Quantifying genetic effects of ground cover on soil water evaporation using digital imaging. Functional Plant Biology, 37: 703–712.

Patkowska E., Konopiński M. (2013): Effect of cover crops on the microorganisms communitiesin in the soil under scorzonera cultivation. Plant, Soil and Environment, 59: 460–464.

Ramirez-Garcia J., Almendros P., Quemada M. (2012): Ground cover and leaf area index relationship in a grass, legume and crucifer crop. Plant, Soil and Environment, 58: 385–390.

Polish Society of Soil Science (1989): Systematics of Polish soil. Issue IV. Soil Science Annual, 40: 150. (In Polish)

Rejman J., Brodowski R. (1999): Determination of plant cover C ratio in USLE model for the cultivation of sugar beet. In: Physical Soil Degradation: Forecasting, Methods of Protection and Reclamation. Lublin, Institute of Agrophysics, 86–89. (In Polish)

Rejman J., Michiels P., Cadron W., Gabriels D., Dębicki R. (1990): Splash detachment on silt loam with and without a plant cover of triticale. Advances of Agricultural Sciences Problem Issues, 388: 161–168.

Rejman J., Rafalska-Przysucha A., Rodzik J. (2014): The effect of land use change on transformation of relief and modification of soils in undulating loess area of East Poland. The Scientific World Journal, Hindawi Publishing Corporation, 2014: 11.

Schwertmann U., Vogl W., Kainz M. (1987): Bodenerosion durch Wasser: Vorhersage des Abtrags und Bewertung von Gegenmaßnahmen. Stuttgart, Ulmer, 64: 96.

Słupik J. (1975): Conditions of infiltration and surface runoff in the Sant Catchment basin. Bulletin de L'Academie Polonaise des Sciences, Série des Sciences de la Terre, 23: 233–236.

Watson D.J. (1947): Comparative physiological studies in the growth of field crops. I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years. Annals of Botany, 11: 41–76.

Wischmeier W.H., Smith D.D. (1978): Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. Washington, Sciemce and Educatin Admin. U.S. Department Agronomy, 58.

Wiśniowska-Kielian B., Klima K. (2007): Estimate of fertiliser elements losses with surface runoffs in a mountain region dependent on kind of land use. Fragmenta Agronomica, 93: 254–261.

Received on October 14, 2015
Accepted on March 7, 2016

*Corresponding author:*

Prof. dr. hab. inż. Barbara Wiśniowska-Kielian, University of Agriculture in Krakow, Department of Agricultural and Environmental Chemistry, Al. A. Mickiewicza 21, 31 120 Krakow, Poland; e-mail: rrkielia@cyf-kr.edu.pl