Journal of Elementology ISSN 1644-2296

Chowaniak M., Klima K., Niemiec M. 2016. *Impact of slope gradient, tillage system, and plant cover on soil losses of calcium and magnesium*. J. Elem., 21(2): 361-372. DOI: 10.5601/jelem.2015.20.2.873

IMPACT OF SLOPE GRADIENT, TILLAGE SYSTEM AND PLANT COVER ON SOIL LOSSES OF CALCIUM AND MAGNESIUM

Maciej Chowaniak[1], Kazimierz Klima[1], Marcin Niemiec[2]

[1]Chair of Agritechnology and Agricultural Ecology
[2]Chair of Agricultural and Environmental Chemistry
University of Agriculture in Kraków

Abstract

In 2007-2010, a three-factor field experiment was conducted at the Experimental Station in Mydlniki near Kraków. The objective was to determine the impact of a tillage system and plant cover on soil losses of magnesium and calcium by water erosion depending on a slope gradient. The first factor in the experiment was a slope gradient (9% and 16%), the second one consisted of a tillage system (plough system and direct sowing system) and the third one comprised plant cover (horse beans, spring wheat, and winter rapeseed). The experimental plots were 22 m x 2 m in size. Modified Słupik bag catchers were placed at the bottom borderline of each plot for the purpose of catching the material washed down. The ICP-OES method was applied to determine the content of calcium and magnesium. Calcium and magnesium losses were calculated based on the content of these elements in the soil washed down and in the runoff water. Analysis of Variance (Anova) was performed to analyze the results statistically. The significance of mean differences among the objects was tested with the use of multiple comparisons procedures and a Tukey's range test at $\alpha = 0.05$ level of significance. The studies showed that losses of Ca ranged from 3.11 to 9.20 kg $year^{-1}$ ha^{-1} and losses of Mg varied from 0.97 to 2.12 kg $year^{-1}$ ha^{-1}. The losses of Ca were about 25% higher from the plots situated on the slopes with the 16% gradient than on the slopes with the 9% gradient; the difference in the losses of Mg from the plots on both slopes was similar and equalled about 26%. Compared to the conventional plough system, direct sowing (the ploughless system) reduced the losses of Ca and Mg by 36% and 20%, respectively. Of all the plants analyzed, the value of winter rapeseed as a soil protection agent was the highest.

Keywords: soil erosion, tillage systems, direct sowing system, slope gradient.

dr inż. Maciej Chowaniak, Chair of Agrotechnology and Agricultural Ecology, University of Agriculture in Krakow, al. Mickiewicza 21, 31-120 Krakow, phone +48 12 662 4366, e-mail: maciejchowaniak@tlen.pl

INTRODUCTION

Water erosion is a major factor responsible for physical and chemical degradation of soils, thus causing large losses in agriculture and natural environment. Large financial outlays are required to protect soils against water erosion. Surface runoff occurs when soils are unable to absorb precipitation waters or when water cannot be stored on the soil surface. Initially, a slope process initiated by surface runoff is usually a laminar flow, after which it becomes a concentrated (turbulent) flow and makes rill erosion to develop (BRODOWSKI, REJMAN 2004). Losses of the nutrients carried away by surface runoff waters constitute a serious problem since they decrease the soil productivity and contribute to the pollution of the environment due to the eutrophication of water bodies (CASTRO et al. 1991, POTE et al. 1996, BERTOLA et al. 2007). Soils in Poland are deficient in magnesium and calcium, which are two nutrients with significant yield-forming effects and therefore essential for sustaining the proper growth of plants. The extent of magnesium and calcium losses depends on many water-erosion related factors, whose origin is natural (slope gradient, soil type and precipitation intensity) or anthropogenic (tillage system, plant cultivar) (GASCHO et al. 1998). RICHARDSON and KING (1995) and KISIC et al. (2002) proved that implementation of adequate agro-technical measures, including a simplified tillage system and direct (ploughless) sowing, helped to reduce losses of soil and nutrients. However, few references tackle the question of what impact tillage systems have on the soil protecting function of plants in different phases of their development and in different periods of growth.

The objective of our study was to determine the impact of a slope gradient, tillage system and plant cover on soil losses of calcium and magnesium caused by water erosion.

MATERIAL AND METHODS

The experiment started on 20 August 2007, when winter rapeseed was sown, and continued until 30 September 2010, when horse bean was harvested. The experiment was conducted at the Experimental Station in Mydlniki, situated within the administrative borders of Kraków, in the western part of the city. The Experimental Station belongs to the Department of Agritechnology and Agricultural Ecology, University of Agriculture in Kraków. All of the experimental plots were situated on a southern slope.

A three-factor experiment with crop rotation was set up on plots sized 44 m^2 each, with the use of a method of randomized sub-blocks, in a dependent system, in four replications.

The first factor of the experiment was a slope gradient; this factor included a 9% (the lower zone of the slope) and a 16% slope gradient (the upper zone of the slope).

Two tillage systems, conventional tillage (plough) and direct sowing, were the second factor of the experiment. In the conventional tillage system, the horse bean harvest was followed by primary tillage (shallow plough at a depth performed to the of 10 cm) and harrowing with the use of a light weight seed harrow. On plots with winter rapeseed, the secondary tillage (ploughing for sowing) was applied to a depth of 20 cm, after which the soil was harrowed with a light weight seed harrow; as for the spring crops grown, a deep pre-winter plough was applied to the depth of 30 cm. The pre-sowing measures performed in the spring comprised stirring the soil to the depth of 10 cm by a cultivator. A traditional seed drill was used for sowing.

In the direct sowing (ploughless tillage) variant, the post-harvest tillage included the spraying of a non-selective herbicide (glyphosate; at the dose 720 g ha^{-1}); in the case of winter rapeseed, direct sowing with a seed drill followed the spraying of the above herbicide. Regarding horse beans and spring wheat, spring pre-sowing measures included the spraying of glyphosate at 720 g ha^{-1}. Sowing was done into the stubble with a Vredo disc seed drill designed for direct sowing.

The third factor was plant cover made up of crops cultivated in the following crop rotation system: horse beans, spring wheat, winter rapeseed. All crops were sown annually throughout the whole experiment. The doses of fertilizers were determined based on the soil fertility and the crop species and cultivar (Tables 1 and 2).

The experiment was set up on brown soil formed from loess with some fluvioglacial sand; its grain-size distribution resembled that of common silt. An average thickness of the humus horizon was between 28 and 30 cm. Along with the

Table 1

Doses of nutrients applied in experiment

Plants	Fertilizers		
	ammonium sulphate (34% N)	superphosphate (40% P_2O_5)	potassium chlorate (60% K_2O)
	doses of nutrients (kg ha^{-1})		
	N	P_2O_5	K_2O
Horse beans	30	69	89
Spring wheat	120	67	80
Winter rapeseed	150	84	96

Table 2

Sowing rate and plant density

Plants	Variety	Sowing rate (kg ha^{-1})	Plant density (pcs. m^{-2})
Horse beans	Kasztelan	250	50
Spring wheat	Bombona	250	500
Winter rapeseed	Baldur F1	3.5	60

changing slope gradient, the percentage of floatable fractions (<0.02 mm) rose from 21 to 28%. The soil erodibility is represented by the ratio of the silt fraction (0.1 - 0.02 mm) to the colloid clay fraction (<0.002 mm); in the humus layer submitted to our investigation, this ratio was 5.9 in the zone with the slope gradient of 9% and 8.2 in the zone on the 16% gradient slope.

The plots were 22 x 2 m in size. Generally, this is the size of plots used in erosion research (Wischmeier, Smith 1978, Klima, Chowaniak 2009). At the bottom borderline of each plot, modified Słupik bag catchers (Słupik 1986, Smolska 2002, Klima, Chowaniak 2008) were placed for collection of the material being washed down. The catchers were emptied after each precipitation event or after a thawing period that caused the soil material to be washed down, and the volume of water and soil suspension was measured (runoff). In order to determine the mass of the leached matter (eluviation), one (1) dm^3 of the water and soil suspension was filtered through a medium hard filter paper and next dried at a temperature of 105°C (Brański 1968). The dried filter papers were weighed on an electronic laboratory scale, with an accuracy to 0.0001 g, having been cooled in an exicator. Meanwhile, for the purpose of determining chemical properties of the material washed down, two 1 dm^3 samples of the water and soil suspension were collected from each catcher; these samples were filtered through a medium hard filter paper, after which both the filter paper and the material it absorbed underwent a drying process and the filtrate was preserved by adding nitric (V) at the amount of 2 cm^3 per 100 cm^3 of water. Next, the samples were delivered to a laboratory. The volume of a laboratory water sample was 1 dm^3. The sediment accumulated on the filter paper was dried at 65°C and sieved through a sieve with 1 mm mesh; next, it was crushed in a mortar. The samples were wet-mineralized in a closed system, with the use of microwave energy. The mineralization process was performed in a microwave reactor produced by Anton Paar Company. A weighed portion was Ca 0.5 g of dry matter. The samples were dissolved in a mixture of HNO_3 and HCl, mixed at a volume ratio of 1:3, v/v. The quantitative soil to reagents ratio was 1:10. Concentration levels of Ca and Mg were determined in all samples on a Perkin Elmer's Optima 7600 DV ICP-AES spectrometer (ICP-AES, i.e. Inductively Coupled Plasma - Atomic Emission Spectrometry). Table 3 present wavelengths at which the concentrations of the elements analyzed were determined and LODs (Limits of Detection) pertaining to the methods applied in the experiment. Certified AGH S-1 reference material and internal reference material were used to check the accuracy of the analyses of the elements. Table 3 also contains results of the analyses of the reference material; based on the analyses replicated four times, the values of the recovered elements were assessed.

Each year during the experiment, the harvest of the crops was followed by collecting soil samples (from depth 0 - 30 cm) with an Edger's sampling stick; the laboratory samples weighed approximately 500 g in terms of dry matter. The pH value of the soil material sieved was measured potentiometrically with a calomel and glass electrodes; all other chemical properties of the soil were determined analogously to determinations of the parameters of the sediment.

Table 3

Reference material

Parameters	Wave lenghts	Limit detection	Concentration in certificated material	Measured	Recovery
	(nm)	(g dm^{-3})	(g kg^{-1})	(g kg^{-1})	(%)
Ca	317.933	0.0100	2.60	2.710	104.2
Mg	285.208	0.0016	2.72	2.904	106.8

During the vegetative growth of crops, LAI (Leaf Area Index) was determined in sqm (m^2) of the green area of the aerial parts of plants per 1 m^2. The measurements were taken every 20 days with a Scan Canopy System type SS1. These measurements were performed so often because the results, which represented changes in the plant cover on the soil, had to be correlated with the loss rate of calcium and magnesium.

Anova was applied to statistically analyze the results. The significance of mean differences among the objects was tested with the multiple comparison procedure and the Tukey's range test was applied at a significance level of a = 0.05.

RESULTS

The factors of the experiment differently affected physical and chemical properties of the soil and losses of the elements. The pH values of soil (Table 4)

Table 4

Impact of slope gradient, tillage system and plant cover on pH level of soil (depth 0-30cm)

Slope gradient	Tillage systems	Horse beans	Spring wheat	Winter rapeseed
9%	direct sowing	5.74*af**±0.13	5.80*c*±0.04	5.57*e*±0.06
	conventional	5.90*b*±0.10	5.85*bc*±0.08	5.68*f*±0.05
16%	direct sowing	5.75*a*±0.12	5.75*a*±0.02	5.49*e*±0.08
	conventional	5.91*b*±0.08	5.84*d*±0.03	5.64±0.04
Means for slope gradient				
9%			5.75*a*±0.61	
16%			5.73*a*±0.54	
Means for tillage system				
Direct sowing			5.68*a*±0.07	
Conventional			5.60*b*±0.05	
Means for plant cover				
Horse beans			5.82*a*±0.08	
Spring wheat			5.81*a*±0.15	
Winter rapeseed			5.59*b*±0.12	

* means followed by the same letters do not differ significantly at a < 0.05 according to the *t*-Tukey test

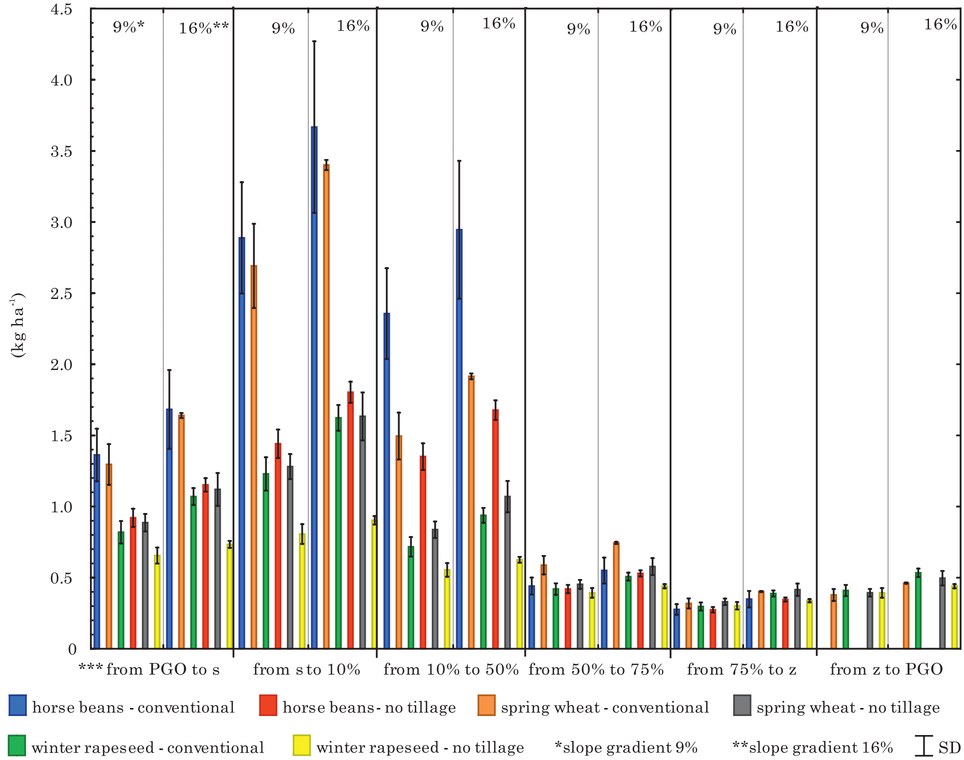

Fig. 1. Mean loss of calcium (kg ha^{-1}) in different periods of crop management. Periods of management after SCHWERTMANN et al. (1987): PGO to s period from shallow ploughing (stubble covering) to sowing of new plants; from s to 10% – period starting when plants are sown until they cover 10% of the entire plot surface; from 10% to 50% – period when the cover of plants on the plot is between 10% and 50%; from 50% to 75% – period when the cover of plants on the plot is between 50% and 75%; from 75% to z – period starting when the cover of plants on the plot is 75% until the harvest; from z to PG – period from the harvest to shallow ploughing (stubble covering)

were significantly different in the two soil tillage systems compared. On the plots where direct sowing was applied, the pH value of soil was higher. A similar result was reported by OWCZARZAK et al. (2009). As regards the impact of the crops cultivated on the pH level, the lowest soil pH was determined under winter rapeseed. This fact was attributed to a higher dose of physiologically acidic fertilizers applied to winter rapeseed (Table 1). Based on the content analysis of calcium and magnesium, it was found that the tillage system was a significantly differentiating factor (Table 5, 6). On average, the content of calcium in the soil under plots with direct sowing was 2.7% higher (Table 5), and the content of magnesium was 2.1% higher (Table 6) compared to the plots with conventional tillage. Literature contains different opinions as regards the effect of tillage systems on the content of micro- and micronutrients in soil. WOŹNIAK and MAKARSKI (2012) report that the aeration of soil while ploughing increases the mobility of selected macro- and micro-elements. Thus, higher mobility of these elements together with higher superficial eluviation in this tillage system decreased the concentration of the analyzed elements in the soil.

While the experiment was conducted, surface runoffs occurred during two thaw periods and 37 precipitation events; they resulted in losses of the analyzed elements.

The loss rate of calcium and magnesium changed along with the development of plant cover. Figures 1 and 2 show the rate of calcium and magnesium losses during consecutive phases of crop cultivation and development. The phases as mentioned above refer to the tillage measures under the conventional tillage system applied and follow the scheme of SCHWERTMANN et al. (1987). In the present research, the results obtained from the plots with direct sowing were classified in relation to the cultivation phases under the conventional tillage system, because the phases distinguished by SCHWERTMANN et al. (1987) do not comprise the direct sowing system. In the two tillage systems, the highest losses were found during the phase that started at

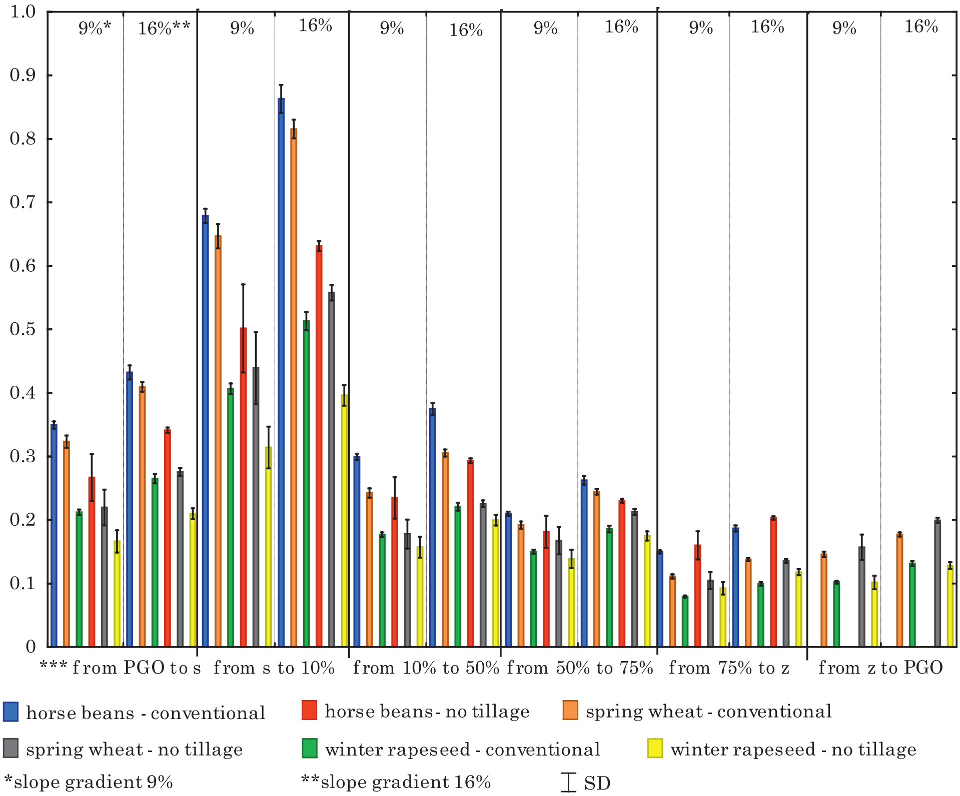

Fig. 2. Mean loss of magnesium (kg ha^{-1}) in different periods of crop management. Periods of management after SCHWERTMANN et al. (1987) – see Figure 1

Table 5

Impact of slope gradient, tillage system and plant cover on content of calcium in soil (mg kg^{-1}±SD)

Slope gradient	Tillage systems	Horse beans	Spring wheat	Winter rapeseed
9%	direct sowing	1544.2*a**±52.96	1540.1*a*±40.34	1623.8*e*±34.31
	conventional	1498.3*b*±34.56	1537.2*a*±26.94	1562.2*b*±61.03
16%	direct sowing	1521.1*ab*±26.59	1513.3*ab*±32.21	1618.3*e*±57.24
	conventional	1429.5*d*±25.32	1498.1*b*±30.28	1415.2*f*±8.50
Means for slope gradient				
9%			1550.9*a*±58.70	
16%			1499.7*a*±72.78	
Means for tillage system				
Direct sowing			1559.1*a*±56.47	
Conventional			1489.0*b*±61.97	
Means for plant cover				
Horse beans			1498.2*a*±55.20*a*	
Spring wheat			1522.1*a*±31.37*a*	
Winter rapeseed			1554.8*a*±94.16*a*	

* means followed by the same letters do not differ significantly at $a < 0.05$ according to the *t*-Tukey test

Table 6

Impact of slope gradient, tillage system and plant cover on content of magnesium in soil (mg kg^{-1}±SD)

Slope gradient	Tillage systems	Horse beans	Spring wheat	Winter rapeseed
9%	direct sowing	442.2*a**±15.44	443.4*a*±11.80	456.4*d*±9.89
	conventional	415.2*b*±9.90	432.2*c*±7.77	428.3*c*±17.34
16%	direct sowing	436.1*ec*±7.76	442.7*e*±9.51	456.2*d*±16.53
	conventional	421.3*b*±7.51	429.3*c*±8.83	449.4*ad*±2.63
Means for slope gradient				
9%			436.2*a*±17.29	
16%			439.1*a*±12.61	
Means for tillage system				
Direct sowing			445.1*a*±13.04	
Conventional			429.2*b*±14.42	
Means for plant cover				
Horse beans			428.7*a*±15.31	
Spring wheat			436.9*ab*±11.88	
Winter rapeseed			447.5*b*±15.82	

* means followed by the same letters do not differ significantly at $a < 0.05$ according to the *t*-Tukey test

sowing and lasted until the plant cover on the soil reached 10%. Those losses constituted, on average, 34% of all the calcium losses and 36% of all the magnesium losses. In the subsequent phases, along with the growth of plant cover, the losses of the analyzed elements decreased. This dependence was also noted by KLIMA and WIŚNIOWSKA-KIELIAN (2006), XU et al. (2006), ZUAZO and PLEGUEZUELO (2008), JUYING et al. (2009). The soil protective function of plant cover reduced the occurrence of water erosion; consequently, there was a decrease in the amount of nutrients that were carried away from the soil. In all the crops, during the first three periods distinguished, essential differences were reported between the two tillage systems as regards the calcium and magnesium losses: on the plots with direct sowing, the losses of calcium were from 43 to 96% lower, and these of magnesium were from 25 to 38% lower than on the plots with the conventional system. The efficiency of soil protection by the direct sowing system results from the protective role of both the stubble and the forecrop post-harvest residues left over on the soil surface (OLSON et al. 2013), which are able to protect soil from pluvial erosion; pluvial erosion intensifies superficial eluviation and surface runoff processes. The development of plant cover in the consecutive phases reduced the differences between the two tillage systems to a statistically insignificant level. In the two tillage systems, the losses of the two elements were comparable in the soil under the stubble left after the harvest. Considering the development of the plant cover (Figure 1), a distinct decline was observable in the losses of calcium and magnesium during the phase when the plants covered from 50 to 75% of the soil. In that phase, the plant cover of the soil ensured effective protection. It absorbed some of the precipitation and protected the soil against direct hits by raindrops, which intensify the runoff and eluviation processes, both inducing calcium and magnesium losses.

The highest annual average losses of calcium and magnesium were determined on the plots situated on the 16% gradient slopes; those losses were significantly higher (on average, 25% higher as for calcium and 26% higher as for magnesium) than the losses on the plots situated on the slopes with the gradient of 9% (Tables 7, 8). Considering the tillage system, both the calcium and magnesium losses were higher on the plots with the conventional tillage system, the difference being 36 and 20%, respectively. The studies performed by BERTOL et al. (2005) confirm that direct sowing reduces the losses of calcium and magnesium. Our analysis of the impact of the crops on the calcium and magnesium losses proves that winter rapeseed distinguished itself owing to its soil protective role. Its high soil protection efficiency is attributed to the length of the plant growing period. On average, the growing period from the day of sowing to harvest was 320 days for winter rapeseed, 153 days for horse beans and 133 days for spring wheat.

Table 7

Impact of slope gradient, tillage system and plant cover on soil losses of calcium (kg ha^{-1} $year^{-1}$±SD)

Slope gradient	Tillage systems	Horse beans	spring wheat	winter rapeseed
9%	direct sowing	4.41*a**±0.06	4.18*ab*±0.06	3.11*c*±0.05
	conventional	7.32*d*±0.20	6.77*e*±0.15	3.89*b*±0.07
16%	direct sowing	5.51*f*±0.05	5.32*gh*±0.11	3.48*i*±0.02
	conventional	9.20*j*±0.30	8.57*k*±0.02	5.06*h*±0.06
Means for slope gradient				
9%			4.95*a*±1.58	
16%			6.19*b*±2.06	
Means for tillage system				
Direct sowing			4.33*a*±0.91	
Conventional			6.80*b*±1.93	
Means for plant cover				
Horse beans			6.61*a*±1.89	
Spring wheat			6.21*a*±1.70	
Winter rapeseed			3.89*b*±0.76	

* means followed by the same letters do not differ significantly at $a < 0.05$ according to the *t* - Tukey test

Table 8

Impact of slope gradient, tillage system and plant cover on soil losses of magnesium (kg ha^{-1} $year^{-1}$±SD)

Slope gradient	Tillage systems	Horse beans	spring wheat	winter rapeseed
9%	direct sowing	1.34*a**±0.02	1.27*b*±0.02	0.97*c*±0.01
	conventional	1.69*de*±0.01	1.66*d*±0.01	1.13*f*±0.01
16%	direct sowing	1.70*e*±0.01	1.61*g*±0.01	1.23*h*±0.01
	conventional	2.12*i*±0.01	2.08*j*±0.01	1.42*k*±0.01
Means for slope gradient				
9%			1.34*a*±0.26	
16%			1.69*b*±0.33	
Means for tillage system				
Direct sowing			1.35*a*±0.24	
Conventional			1.68*b*±0.35	
Means for plant cover				
Horse beans			1.71*a*±0.28	
Spring wheat			1.66*a*±0.30	
Winter rapeseed			1.18*b*±0.16	

* means followed by the same letters do not differ significantly at $a < 0.05$ according to the *t* - Tukey test.

CONCLUSIONS

1. The direct sowing system significantly reduces losses of calcium and magnesium in soil during water erosion events.

2. The significance of differences in losses of calcium and magnesium depends on the development of plant cover during the plant growing phase, and as the plant cover grows larger, differences in the losses of the two elements decrease.

3. Owing to the long growing period of winter rapeseed, this crop appeared to be the best plant to prevent calcium and magnesium losses from soil.

REFERENCES

Bertola I., Engela F.L., Mafraa A.L., Bertolb O.J., Rittera S.R. 2007. *Phosphorus, potassium and organic carbon concentrations in runoff water and sediments under different soil tillage systems during soybean growth*. Soil Till. Res., 94: 142-150. DOI: 10.1016/j.still.2006.07.008

Brański J. 1968. *Determination of sediment amounts with the gravimetric method and paper filters*. PIHM, 94: 13-21. (in Polish)

Brodowski R., Rejman J. 2004. *Effect of soil moisture content and surface conditions on runoff and wash on loamy sand*. Acta Agroph., 112, 4(3): 619-624. (in Polish)

Castro Filho C., Henklain, J.C., Vieira M.J., Casao Junior R. 1991. *Tillage methods and soil and water conservation in Southern Brazil*. Soil Till. Res., 20: 271-283. DOI: 10.1016/0167-1987(91)90043-W

Gascho G. J., Wauchope R.D., Davis J.G., Truman C.C., Dowler C.C., Hook, J.E., Sumner H.R., Johnson A.W. 1998. *Nitrate-nitrogen, soluble, and bioavailable phosphorus runoff from simulated rainfall after fertilizer application*. Soil Sci. Soc. Am. J., 62: 711-718. DOI: 10.2136/sssaj1998.03615995006200060032x

Hugo V., Zuazo D., Rocío C., Pleguezuelo R. 2008. *Soil-erosion and runoff prevention by plant covers*. Agron. Sustain. Dev. 28: 65-86. DOI: 10.1051/agro:2007062

Jiao J., Zou H., Jia Y., Wang N. 2009. *Research progress on the effects of soil erosion on vegetation*. Acta Ecol. Sin., 29: 85-91. DOI:10.1016/j.chnaes.2009.05.001

Kisic I., Basic F., Nestroy O., Mesic M., Butorac A. 2002. *Soil erosion under different tillage methods in Central Croatia*. Bodenkultur. 53(4): 199-206.

Klima K., Chowaniak M. 2008. *The effect of slope gradient on plant cover index (C) of faba bean crops grown on loess soil*. Ann. Warsaw Univ. of Life Sci. – SGGW, Land Reclam., 39: 69-76. DOI: 10.2478/v10060-008-0006-5

Klima K., Chowaniak M. 2009.*The effect of slope gradient on plant cover index (C) of fodder beet crops grown on eroded loess soil*. Soil Sci. Ann., 60(4):50-56. (in Polish)

Klima K., Wiśniowska-Kielian B. 2006. *Anti-erosion effectiveness of selected crops and the relation to leaf area index (LAI)*. Plant Soil Environ., 52(1): 35-40.

Olson K. R., Ebelhar S. A., Lang J. M. 2013. *Effects of 24 years of conservation tillage systems on soil organic carbon and soil productivity*. Appl. Environ. Soil Sci., 1: 1-10. DOI: 10.1155/2013/617504

Owczarzak W., Mocek A., Dubas A. 2009. *The impact of cultivation simplifications in corn monoculture on formation of topsoil level structure*. Inż. Rol., 5(114): 219-228. (in Polish)

Pote D.H., Daniel T.C., Sharpley A.N., Moore Junior P.A., Edwards D.R., Nichols D.J. 1996. *Relating extracted soil phosphorus to phosphorus losses in runoff*. Soil Sci. Soc. Am. J., 60: 855-859. DOI: 10.2136/sssaj1996.03615995006000030025x

Richardson C.W., King K.W. 1995. *Erosion and nutrient losses from zero tillage on clay soil.* J. Agric. Eng. Res., 61: 81-86. DOI:10.1006/jaer.1995.1034

Schwertmann U., Vogl W., Kainz M. 1987. *Soil erosion: prediction and evaluation of countermeasures*. Ulmer, Stuttgart, 1- 64. (in German)

Smolska E. 2002. *The intensity of soil erosion in agricultural areas in north-eastern Poland.* Landform Anal., 3: 25-33

Słupik J. 1986 *Evaluation of methods for testing the role of land use in the process of runoff and soil erosion in the Carpathians*. Prz. Geogr., 58(1/2): 41-48 (in Polish).

Woźniak A, Makarski B. 2012. *Content of minerals in grain of spring wheat cv. Koksa depending on cultivation conditions.* J. Elem., 17(3): 517-523. DOI: 10.5601/jelem.2012.17.3.13

Wischmeier W.H., Smith. D.D. 1978. P*redicting Rainfall Erosion Losses: A Guide to Conservation Planning.* Agriculture USDA/Science and Education Administration, US. Govt. Printing Office, Washington, DC, *earch review of the relationship between vegetation and soil loss.* Acta Ecol. Sin., 26(9): 3137-3143. DOI: 10.2489/jswc.68.2.138

Zuazo, V. H. D., Pleguezuelo C. R .R. 2008. *Soil-erosion and runoff prevention by plant covers.* Agron. Sustain. Dev., 28(1): 65-86. DOI: 10.1051/agro:2007062