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ORIGINAL PAPER

EFFECT OF A TILLAGE SYSTEM AND PLANT COVER ON PHOSPHORUS AND POTASSIUM LOSSES DUE TO SURFACE RUNOFF*

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Abstract

The goal of the study was to evaluate the effect of a tillage system and plant cover on the intensity of P and K losses due to surface runoff in a six-year research period, taking into account tillage stages and development of the plant cover. A two-factor field experiment was carried out during the six-year research period. The investigated factors included no-tillage system (NT) and conventional tillage system (CT) as well as the cultivated plant: horse bean, spring wheat and winter oilseed rape. The results demonstrated that the content of P and K in the soil was 9.5% higher in the NT system than in the CT system. The NT system showed better soil-protection effectiveness preventing P and K losses from soil. Significant differences between the NT and CT systems were observed in the period without plant cover when soil in the CT system was subjected to tillage treatments, as well as in the period from sowing to 50% cover of soil by plants. It was observed that differences in P losses between the systems were lower in the initial period of the research than in the years that followed, namely the difference in 2008 was 11.6%, in 2009 57.3%, and from 59.5 to 65.4% in the years 2010-2013. Similar results were obtained for K, as the differences between the systems in in K losses were: 25.6% in 2008, 64.1% in 2009, and from 66.0 to 70.9% in the years 2010-2013. The investigated plants can be ranked according to soil-protection properties in the following order, starting from the most effective one: winter rape>spring wheat>horse bean.

Keywords: phosphorus loss, potassium loss, no-tillage system, erosion.

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INTRODUCTION

Phosphorus (P) and potassium (K) have a fundamental effect on plant productivity and crop quality. Loss of P and K by surface runoff is a serious problem, associated with environmental pollution as well as with soil impoverishment (Yaşar Korkança, Dorum 2019). Total losses of P due to transport of soil particles by surface runoff could range from 0.1 up to 13 kg ha^{-1} per year (Weil, Brady 2017). The loss of K by erosion could exceed that of P, varying from a few kilos to a few hundred kilos per hectare per year (Lemma et al. 2017, Weil, Brady 2017, Bashagaluke et al. 2018). Fertilization is one of the factors that intensify this process. The date of applying fertilizers relative to rainfall, and the form of fertilizer influence nutrient losses due to surface runoff, soil erosion. P and K fertilizers are mostly used before sowing, or as top dressing fertilizers in the early stages of plant development, hence the lack of plant cover or underdeveloped plant cover in this period increase the risk of P and K losses caused by erosive rainfalls (Bertola et al. 2007). Along with plant development and growth of the surface cover by terrestrial parts, the intensity of soil erosion processes reduces significantly (Klima, Wiśniowska-Kielian 2006, Wilson et al. 2008, Krutz et al. 2009, Cerdan et al. 2010, Klima et al. 2019). The effects of plant cover, cultivated species and plant developmental cycle relative to erosive precipitation events in a given region on the intensity of erosion is important. The intensity of surface runoff that transports soil with nutrients also depends on a tillage system. The literature is dominated by studies suggesting that no-tillage systems (NT) protect soil against erosion and nutrient loss better than conventional ones (CT) (DeLaune, Sij 2012, Mwango et al. 2016, Bogunovic et al. 2018). Biomass from crop residues (left on the soil surface in an NT system) plays an important role in protecting soil against erosion. Plant residue such as stubble from the preceding crops receives the energy of raindrops and surface runoff, thus mitigating the intensity thereof or the saturation of flowing rainwater with soil particles and nutrients (Alavinia et al. 2018). Assessment of the anti-erosion efficiency of a given system requires an analysis of many factors, considering how much time elapsed since a given system was launched. In an NT system, changes in physical and chemical properties in soil take place in the first years. Their intensity is determined by the type of soil on which the system is used, and by the type of a crop. Numerous authors (Shia et al. 2013, Obour et al. 2017, Bogunovic et al. 2018) compare tillage systems in terms of the impact of their long-term A complete picture showing the soil-protection effectiveness of a given system should take into account different stages, including the period directly after its implementtaion. When comparing two different tillage systems, it is important to consider the stages of a tillage system and the development of plant cover.

The goal of the study was to evaluate the effect of the tillage system and plant cover on the intensity of P and K losses in surface runoff in a six-year research period starting with the introduction of direct sowing, taking into account tillage stages and development of plant cover.

MATERIALS AND METHODS

The research experiment was conducted at the Experimental Station located in Mydlniki near Krakow (50°05′21.1″N 19°51′21.3″E), from August 2007 to September 2013. The climate of the experiment site is temperate continental. The average annual precipitation is 681 mm, and the mean daily temp. is approximately 7.4°C. The experiment was conducted on a plot with Eutric Cambisols soils developed from loess mixed with fluvioglacial sand (IUSS Working Group WRB 2015). The average content of soil organic carbon (0-30 cm depth) was 8.91 g kg^{-1}, total P was 101.22 mg kg^{-1}, total K was 213.35 mg kg^{-1} and pH 5.82.

A two-factor field experiment was carried out using a split-plot design replicated four times on 44 m^2 plots. The size of a plot was 22 x 2 m (Bogunovic et al. 2018). The plots were situated on a slope with a 9% gradient. The first factor in the experiment was the tillage system: conventional tillage system (CT) and 'no-tillage' system (NT). The experiment began in August 2007, when winter oilseed rape was sown. The preceding crop for all the crops analysed was winter wheat harvested in July 2007. Where the CT system was applied, the harvest was followed by primary tillage (shallow ploughing at a depth of 10 cm) and harrowing with a light seed harrow. On the plots for winter oilseed rape sowing, secondary tillage (ploughing for sowing) was applied to a depth of 20 cm; next, the soil was harrowed with a light seed harrow. As regards the spring wheat, a deep pre-winter ploughing was applied to a depth of 30 cm. The pre-sowing measures performed in the spring involved stirring the soil to a depth of 10 cm using a cultivator. A traditional seed drill was used for sowing. In the NT variant, the post-harvest treatment included spraying a non-selective herbicide (glyphosate at a dose of 720 g ha^{-1}); in the case of winter oilseed rape, the herbicide spraying was followed by direct sowing with a seed drill. For horse bean and spring wheat, the spring pre-sowing treatment included spraying glyphosate at 720 g ha^{-1} followed by sowing into the stubble using a modified Vredo disc seed drill (Vredo Dodewaard B.V., NL) designed for direct sowing.

The second factor was plant cover: horse bean, spring wheat and winter oilseed rape obtained from the crops grown in the following crop rotation: horse bean, spring wheat, and winter oilseed rape. All the cultivated plants were sown every year during the research experiment. The fertilizer doses were determined based on soil fertility and expected yield. They were as follows: horse bean – 30 kg N ha^{-1}, 30 kg P ha^{-1}, 73 kg K ha^{-1}; spring wheat – 120 kg N ha^{-1}, 29 kg P ha^{-1}, 66 kg K ha^{-1}; winter oilseed rape – 150 kg N ha^{-1}, 37 kg P ha^{-1}, 80 kg K ha^{-1}. Nitrogen was applied in the form of ammonium nitrate, 34% N, P in the form of triple super phosphate, 46% P_2O_5, and K in the form of potassium chloride, 60% K_2O.

Before the experiment and every year after harvesting of crops, soil samples were collected from a layer of soil at a depth ranging from 0 to 15 cm.

To assess the volume of soil, water, P and K loss, catchers were installed at the lower edge of every plot to collect the washed-away material. The measurement period for every cultivated plant started on the date of previous crop harvest and lasted until the harvest of the next (evaluated) crop. After every rainfall event or after the thawing period, which washed away the soil mass, the catchers were emptied and the volume of the collected water-soil suspension (runoff) was determined. To determine the content of P and K in the washed away material, two 1 dm^3 samples of water-soil suspension were collected from every catcher; those samples were filtered through a medium hard filter paper. The filtrate and sediment samples were transported to a laboratory, where P and K were determined.

In order to determine the content of P and K in the filtrate, the samples were acidified by adding 2 cm^3 nitric acid per 100 cm^3 water. In the laboratory, the samples of filtrate were concentrated five-fold and then the content of elements was determined in the prepared solutions. The samples of soil and sediment were subjected to wet mineralization in a closed system with the use of microwave energy. An Anton Paar Multiwave 3000 microwave system was used for mineralization. The samples were mineralized in a mixture of nitric acid and hydrochloric acid at a volumetric ratio 1:3. The maximum mass of analytical sample was 0.5 g dry matter.

Concentrations of P and K in the solutions were determined by inductively coupled plasma atomic emission spectrometry, using an Optima 7600 DV manufactured by PerkinElmer. P was determined at a wavelength of 213.617 nm, whereas K – at 766.490 nm. Values of detection limits for these elements were 0.076 mg dm^{-3} and 0.048 mg dm^{-3}. Internal reference materials were used to verify the correctness of the analyses. The recovery coefficient for individual parameters ranged between 91.52% and 103.96%.

Phosphorus and potassium losses were calculated for every crop plant and tillage system at six different crop stages: fallow, seedbed, three different canopy cover stages, and harvest, according to Wischmeier and Smith (1978) – Table 1. The development of plant cover (%) was determined with digital images captured 2 m above the canopy using ImageJ software.

ANOVA was applied to 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 α = 0.05. Analyses were performed using the statistical software package Statistica v. 12.0 (StatSoft Inc. Tulsa, USA).

Table 1

Periods of cultivation

Periods of cultivation*	Tillage system		Average intervals for periods of cultivation (months)		
	CT	NT	horse bean	spring wheat	winter oilseed rape
Fallow (F)	from ploughing to secondary tillage for seedbed	from stubble treated with total herbicide to sowing	09 - 04	10 - 04	08
Seedbed (SB)	from secondary tillage for seedbed to 10% crop cover	from sowing to 10% crop cover	04 - 05	04 - 05	08 - 09
Establishment (1)	from 10 to 50% crop cover		05 - 06	05 - 06	09 - 03
Development (2)	from 50 to 75% crop cover		06 - 07	06 - 07	03 – 04
Maturity (3)	from 75% crop cover to harvest		07 - 09	07 - 08	04 - 07
Residue or stubble (4)	from harvest to ploughing	from harvest to total herbicide use	09 - 10	08	07 - 08

* According Wishmeier and Smith (1978)

RESULTS AND DISCUSSION

It was found that the P content in soil from the NT system was, on average, 9.5% higher than that from the CT system. There were no statistically significant differences between the tillage systems in the soil P content in the in the first three years (2008-2010) of the experiment, with just a tendency for increasing the soil P content in the NT system. In the years 2011-2013, the tillage systems significantly differentiated the P content in soil: the P content in soil in the NT system was from 12.5% to 17.5% higher than in the CT system (Figure 1). An analogous dependence was observed for the K content in soil, which on average was 7.9% higher from the NT system than from the CT system. In the case of K, no significant differences between the systems were observed in the first two years of the experiment. In the four years that followed, the K content in soil from the NT system was much higher than that from the CT system. The differences ranged from 10.7% to 12.6% on average (Figure 2). Higher content of P and K in soil in the NT system has often been confirmed by other authors (Jiang, Xie 2009, Zhang et al. 2013). This has to do with the accumulation of plant residue on the soil surface in the NT system and with the lack of treatments mixing soil and dispersing the concentration of nutrients. Statistically significant differences in the content of P and K in soil between the

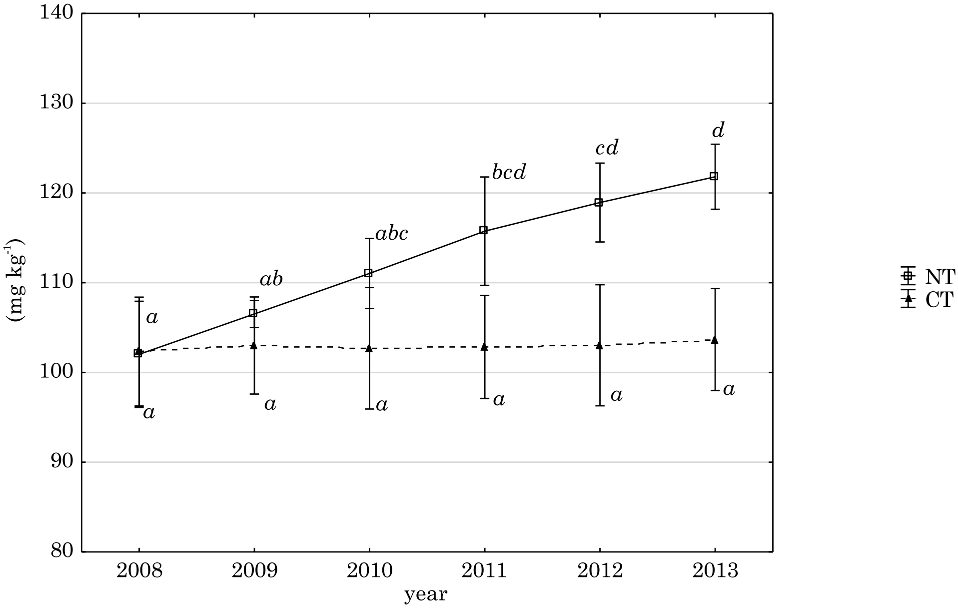

Fig. 1. Content of total P (mg kg^{-1}) in the 0-15 cm soil layer, 2008-2013, by tillage system. Values with different letters are significantly different ($p < 0.05$) among the treatments, error bars represent the standard deviation

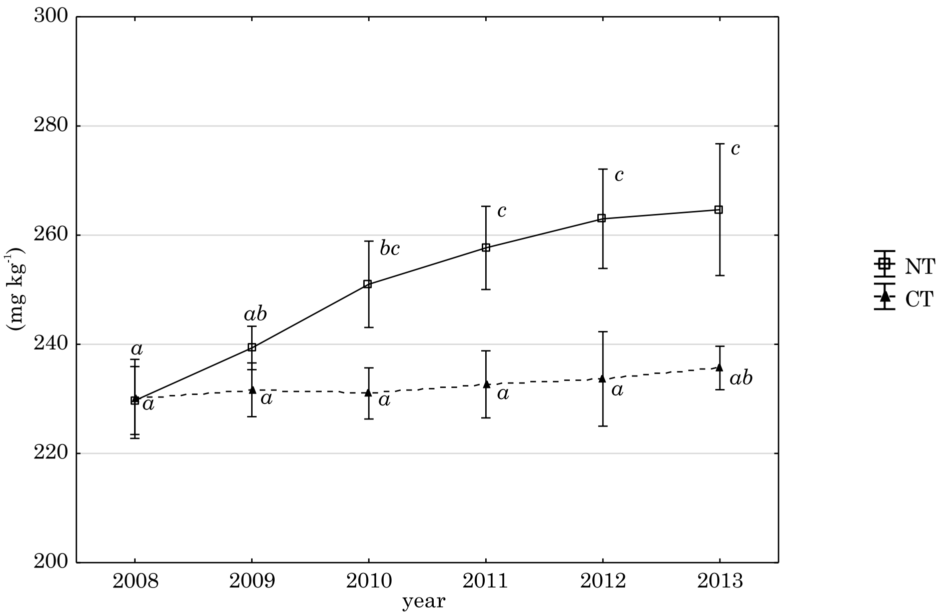

Fig. 2. Content of total P (mg kg^{-1}) in the 0-15 cm soil layer, 2008-2013, by tillage system. Values with different letters are significantly different ($p < 0.05$) among the treatments, error bars represent the standard deviation

Table 2

Losses of total P (kg ha^{-1}) from soil; average from 2008-2013 years for periods of cultivation

Tillage system	Crop	Periods of cultivation#					
		F	SB	1	2	3	4
NT	horse bean	0.20*b*	0.57*b*	0.52*c*	0.22*c*	0.12*c*	0.11*a*
	spring wheat	0.19*b*	0.51*b*	0.38*b*	0.19*b*	0.08*b*	0.12*a*
	winter oilseed rape	0.11*a*	0.29*a*	0.21*a*	0.09*a*	0.06*a*	0.17*b*
CT	horse bean	0.86*d*	1.78*e*	1.23*f*	0.23*c*	0.12*c*	0.11*a*
	spring wheat	0.83*d*	1.21*d*	0.89*e*	0.21*b*	0.07*b*	0.12*a*
	winter oilseed rape	0.45*c*	0.70*c*	0.58*d*	0.11*a*	0.06*a*	0.17*b*
Means for tillage system							
NT		0.17*a*	0.46*a*	0.37*a*	0.17*a*	0.08*a*	0.13*a*
CT		0.72*b*	1.23*b*	0.90*b*	0.18*a*	0.08*a*	0.13*a*
Means for crop							
Horse bean		0.53*b*	1.18*c*	0.88*c*	0.23*c*	0.12*c*	0.11*a*
Spring wheat		0.51*b*	0.86*b*	0.64*b*	0.20*b*	0.08*b*	0.12*a*
Winter oilseed rape		0.28*a*	0.50*a*	0.40*a*	0.10*a*	0.06*a*	0.17*b*

Description see Table 1. Values with different letters are significantly different ($p < 0.05$) among the treatments.

Table 3

Losses of total K (kg ha^{-1}) from soil; average from 2008-2013 years for periods of cultivation

Tillage system	Crop	Periods of cultivation#					
		F	SB	1	2	3	4
NT	horse bean	0.79*c*	1.72*c*	1.56*c*	0.66*c*	0.50*c*	0.53*a*
	spring wheat	0.74*b*	1.60*b*	1.21*b*	0.59*b*	0.35*ab*	0.52*a*
	winter oilseed rape	0.65*a*	0.93*a*	0.65*a*	0.34*a*	0.30*a*	0.52*b*
CT	horse bean	4.33*f*	6.70*f*	4.66*f*	0.70*c*	0.54*c*	0.53*a*
	spring wheat	3.42*e*	4.57*e*	4.12*e*	0.61*b*	0.35*ab*	0.53*a*
	winter oilseed rape	1.32*d*	3.42*d*	2.89*d*	0.38*a*	0.32*a*	0.50*b*
Means for tillage system							
NT		0.73*a*	1.13*a*	1.14*a*	0.53*a*	0.38*a*	0.52*a*
CT		3.02*b*	4.89*b*	3.89*b*	0.56*a*	0.40*a*	0.52*a*
Means for crop							
Horse bean		2.56*c*	4.21*c*	3.11*c*	0.68*c*	0.52*c*	0.53*b*
Spring wheat		2.08*b*	2.66*b*	2.67*b*	0.60*b*	0.35*b*	0.53*b*
Winter oilseed rape		0.99*a*	2.18*a*	1.77*a*	0.36*a*	0.31*a*	0.51*a*

Description see Table 1. Values with different letters are significantly different ($p < 0.05$) among the treatments.

Table 4

Rainfall events and periods of thawing causing runoff and soil loss.
Rainfall events separated from other rain periods by more than 6 hours

Rainfalls and thawing periods	(mm)	Rainfalls and thawing periods	(mm)	Rainfalls and thawing periods	(mm)
19.04.2008	9.9	07.05.2010	17.6	25.07.2011	24.6
24.06.2008	16.7	13.05.2010	12.9	16.08.2011	19.6
04.07.2008	19.7	15-18.05.2010	106.06	08.10.2011	15.1
13.07.2008	12.7	20.05.2010	7.1	08.04.2012	13.1
25.07.2008	28.6	20-21.05.2010	8.1	04.06.2012	23.1
15-16.08.2008	15.6	22.05.2010	7.87	11.06.2012	43.4
04.09.2008	25.5	30.05.2010	7.5	15.06.2012	25.4
16.10.2008	14.4	1-2.06.2010	40.5	04.07.2012	18.5
21.11.2008	12.5	04.06.2010	16.1	19.07.2012	14.5
23.02-11.03.2009*	41	15.06.2010	8.8	03.08.2012	30.0
12.05.2009	12	22.06.2010	8.4	29.09.2012	8.9
19.05.2009	18	25.06.2010	19.5	04.10.2012	19.3
22.05.2009	7.9	19.07.2010	20.07	08.10.2012	14.5
02.06.2009	3.0	29.07.2010	27.6	28.10.2012	20.8
26.06.2009	6.3	03.08.2010	10.7	01.04.2013	8.9
29.06.2009	9.8	7-8.08.2010	10.0	03.05.2013	34.3
16.07.2009	11	17.08.2010	34.3	31.05.2013	24.9
16.09.2009	15.6	01.09.2010	24.7	02.06.2013	30.1
12-21.03.2010*	33.0	25.04.2011	26.7	05.06.2013	24.1
15.04.2010	7.11	30.04.2011	25.9	25.07.2013	71.9
04.05.2010	8.6	20.07.2011	41.2		

* thawing periods

Table 5

Results of two-way repeated measures ANOVA to detect the effects of tillage systems and crop on losses of total P from soil for periods of cultivation

Item	d.f.	Periods of cultivation#					
		F	SB	1	2	3	4
Tillage (T)	1	***	***	***	ns	ns	ns
Crop (C)	2	***	***	***	***	***	ns
TxC	2	***	***	***	ns	ns	ns

Description see Table 1; *** $p < 0.001$, ns – not significant at a $p < 0.05$; d.f. – degrees of freedom.

Table 6

Results of two-way repeated measures ANOVA to detect the effects of tillage systems and crop on losses of total K from soil for periods of cultivation

Item	d.f.	Periods of cultivation#					
		F	SB	1	2	3	4
Tillage (T)	1	***	***	***	ns	ns	ns
Crop (C)	2	***	***	***	***	*	ns
TxC	2	***	***	***	ns	ns	ns

Description see Table 1, * $p < 0.05$, *** $p < 0.001$, ns – not significant at a $p < 0.05$, d.f. – degrees of freedom.

Table 7

Results of two-way repeated measures ANOVA to detect the effects of tillage systems and crop on losses of total P from soil for years 2008-2013

Item	d.f.	Year					
		2008	2009	2010	2011	2012	2013
Tillage (T)	1	**	***	***	***	***	***
Crop (C)	2	**	***	***	***	***	***
TxC	2	*	***	***	***	***	***

Description see Table 1, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, d.f. – degrees of freedom.

systems appeared in the second and third year of the study. Accumulation of plant residue in the surface layer continued with time and the crop rotation sequence (Reicosky, Allmaras 2003).

Both the tillage systems and the plant cover had a significant effect on the intensity of P and K losses caused by surface runoff. When analyzing the investigated tillage periods, the greatest losses of P and K for all the investigated experimental factors were observed in the seedbed period (SB) – Tables 2, 3. This results from the fact that fertilizers were applied in the mentioned period. The seedbed period is characterized by poorly developed plant cover or lack thereof. Additionally, it needs to be highlighted that in the case of spring plants in the SB period there was about 32.1% precipitation causing surface runoff (Table 4). Phosphorus losses in that period constituted, on average, 33.1 and 37.1% total losses for NT and CT, respectively. In the case of K, losses for that period constituted on average, 29.7 and 36.9% total losses for NT and CT, respectively. Along with the increase of plant cover, a reduction of P and K losses was observed. The investigated plants can be ranked according to soil-protection properties in the following order, starting from the best protection: winter rape>spring wheat>horse bean. Soil-protection effectiveness of winter rape is associated, with the length of the vegetative period and plant development phases with respect to occurring precipitation. In May and June, when the highest number of erosive precipitation events in the study region was recorded,

Table 8

Results of two-way repeated measures ANOVA to detect the effects of tillage systems and crop on losses of total P from soil for years 2008-2013

Item	d.f.	Year					
		2008	2009	2010	2011	2012	2013
Tillage (T)	1	**	***	***	***	***	***
Crop (C)	2	**	***	***	***	***	***
TxC	2	*	***	***	***	***	***

Description see Table 1, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, d.f. – degrees of freedom.

the winter rape cover is a sufficient barrier to limit erosion and nutrient losses.

Phosphorus and potassium losses were lower in the NT system than in the CT system by 37.1% and 43.9%. on average. Statistically significant differences between the investigated tillage systems were observed in the first three periods of the study, both in the case of P and K (Tables 5, 6). The mentioned periods were characterized by poorly developed or absent plant cover. In the NT system, P losses for these periods were from 59.1% to 77.4% lower than in the CT system, in the case of K – from 71.2% to 76.0%. The higher anti-erosion efficiency of the NT system in the first tillage periods results from protecting the soil by preceding crop stubble; as years go by,

Table 9

Losses of total P (kg ha^{-1}) from the soil in different years depending on tillage system and crop

Tillage system	Crop	Year					
		2008	2009	2010	2011	2012	2013
NT	horse bean	2.57*de*	1.34*c*	3.01*c*	0.84*c*	1.83*c*	0.83*c*
	spring wheat	2.26*c*	1.12*b*	2.47*b*	0.70*b*	1.49*b*	0.68*b*
	winter oilseed rape	1.36*ab*	0.79*a*	1.75*a*	0.54*a*	1.12*a*	0.59*a*
CT	horse bean	3.41*f*	3.39*f*	9.18*f*	2.25*f*	5.51*f*	2.54*f*
	spring wheat	2.51*d*	2.57*e*	7.01*e*	1.73*e*	4.17*e*	1.92*e*
	winter oilseed rape	1.11*a*	1.68*d*	4.67*d*	1.17*d*	2.99*d*	1.43*d*
Means for tillage system							
NT		2.06*a*	1.08*a*	2.41*a*	0.69*a*	1.48*a*	0.70*a*
CT		2.34*b*	2.54*b*	6.95*b*	1.72*b*	4.22*b*	1.96*b*
Means for crop							
Horse bean		2.99*c*	2.37*c*	6.10*c*	1.55*c*	3.67*c*	1.69*c*
Spring wheat		2.39*b*	1.85*b*	4.74*b*	1.22*b*	2.83*b*	1.30*b*
Winter oilseed rape		1.24*a*	1.24*a*	3.21*a*	0.86*a*	2.06*a*	1.01*a*

Description see Table 1. Values with different letters are significantly different ($p < 0.05$) among the treatments.

Table 10

Losses of total K (kg ha^{-1}) from the soil in different years depending on tillage system and crop

Tillage system	Crop	Year					
		2008	2009	2010	2011	2012	2013
NT	horse bean	8.56*de*	4.48*c*	9.95*c*	2.79*c*	6.10*c*	2.77*c*
	spring wheat	7.80*c*	3.88*b*	8.47*b*	2.25*b*	5.16*b*	2.30*b*
	winter oilseed rape	4.97*ab*	2.86*a*	6.36*a*	1.98*a*	4.08*a*	2.15*a*
CT	horse bean	13.65*f*	13.61*f*	36.82*f*	9.05*f*	22.12*f*	10.21*f*
	spring wheat	10.28*d*	10.54*e*	28.72*e*	7.11*e*	17.13*e*	7.91*e*
	winter oilseed rape	4.69*a*	7.13*d*	19.77*d*	4.98*d*	12.64*d*	6.04*d*
Means for tillage system							
NT		7.11*a*	3.74*a*	8.26*a*	2.34*a*	5.11*a*	2.41*a*
CT		9.54*b*	10.43*b*	28.44*b*	7.05*b*	17.30*b*	8.05*b*
Means for crop							
Horse bean		11.11*c*	9.05*c*	23.39*c*	5.92*c*	14.11*c*	6.49*c*
Spring wheat		9.04*b*	7.21*b*	18.60*b*	4.68*b*	11.15*b*	5.11*b*
Winter oilseed rape		4.83*a*	4.995*a*	13.07*a*	3.48*a*	8.36*a*	4.10*a*

Description see Table 1. Values with different letters are significantly different ($p < 0.05$) among the treatments.

accumulation of some of the previous crop stubble takes place, increasing the soil-protection effectiveness of this system (Kisic et al. 2002, Lal 2007, Nishigaki et al. 2016) and reducing P and K losses. At the same time, the soil in the CT system is uncovered and disturbed by tillage. No statistically significant difference between the tillage systems were observed in the periods that followed. According to various authors (Kalamar et al. 2013, Klima et al. 2019), significant increase in the effectiveness of plant cover in preventing soil erosion may begin no sooner than at 50% coverage of soil. In our study, the plant cover factor leveled the difference between the investigated systems starting at 50% coverage of soil with plants.

In all the years, the average annual P and K losses were significantly differentiated by all factors of the experiment (Tables 7, 8). The greatest P and K losses were observed in 2010 (Table 9, 10). This related to the frequency of erosive precipitation events occurring in the region of the study in that year, namely 21 events causing surface runoff were recorded then (Table 4). In each year of the study, P and K losses were much lower in the NT system than in the CT system. The differences in P losses between the systems were lower in the initial period of research than in the years that followed, that is 11.6%, in 2008, 57.3% in 2009, and from 59.5 to 65.4% in the years 2010-2013. In the case of K, the results were analogous, and the differences in K losses between the systems were: 25.6% in 2008, 64.1% in 2009, and from 66.0 to 70.9% in the years 2010-2013. Changes in the losses between the systems were associated with accumulation of plant residue after preceding crops on the soil surface in the NT system (DELAUNE, SIJ 2012), where accumulation of decomposing post-harvest residue on the surface protecting the soil against erosion takes place year after year.

CONCLUSIONS

1. The content of P and K in the soil was higher in the NT system than in CT system. For P statistically significant differences between the systems were observed in the fourth year after introduction of the NT system. In the case of K, statistically significant differences between the systems were observed in the third year after launching the NT system.

2. The NT system better protected the soil against P and K losses. Significant differences between the NT and CT system were observed in the period without plant cover when soil in the CT system was subjected to tillage treatments, as well as in period from sowing to 50% cover of soil by plants.

3. As years passed, the difference in P and K losses between the systems increased, which resulted from the accumulation of plant residue on the soil surface in the NT system.

4. The investigated plants can be ranked according to soil-protection properties in the following order, starting from the one providing the best protection: winter rape>spring wheat>horse bean.

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