Changes of soil-available P and K on eroded slopes of West Lithuania

Dalia Feizienė[1], Virginijus Feiza[2]

[1] *Lithuanian Institute of Agriculture, Department of Agrochemistry,*
[2] *Lithuanian Institute of Agriculture, Department of Soil and Crop Management, Dotnuva–Akademija, Kėdainiai district.*
E-mail: virgis@lzi.lt

Levels of soil-available P and K responses to traditional deep plough tillage compared to three sustainable tillage systems with shallow ploughing to winter cereals and various combinations of ploughless tillage and glyphosate spraying to spring cereals were investigated at three fertilisation levels in a crop rotation on sloping, nutrient-deficient agricultural land during 1995–2000 at the Kaltinėnai Research Station of the Lithuanian Institute of Agriculture. The soil is an *Alboluvisol* with sandy loam laying over sandy loam texture.

Sustainable tillage caused weak stratification of soil P content at the end of 4th year of experiment. Sustainable tillage decreased soil erosion by 68–90%. In the sustainable tillage systems the fertiliser had no significant positive influence on soil P and K changes in the 0–10 cm layer. The sustainable tillage systems without deep soil mixing predetermined the best positive changes of avalable P and K in the 10–20 cm soil layer.

The determinants of soil P changes in the 0–10 cm layer were presowing tillage depth and soil P losses; in the 10–20 cm layer these were changes of soil bulk density, primary tillage depth, P offtake and soil P losses. The determinants of soil K changes in the 0–10 cm layer were presowing tillage depth and K offtake; in the 10–20 cm layer these were changes of aggregation characteristics, presowing tillage depth, K offtake and soil K losses.

Key words: tillage, fertilisation, P offtake, cereals, sloping landscape, Path analysis

INTRODUCTION

The hilly region in the western part of Lithuania (Žemaičiai Upland) occupies about 14% (9,200 km^2). Lithuania is characterised as having cool and humid climatic conditions, influenced by the proximity to the Baltic Sea [6].

Potassium status in the soil is modified by soil-climatic conditions and by the intensity of soil use. The recommendations for potassium enrichment in the soil should be based on investigations of potassium status. Nowadays the decision-making is dependent on the requirements for the rational application of fertilisers.

The lower mobility of P often results in the accumulation of this nutrient near the surface when fertilisers are surface broadcast in reduced tillage systems. Heavy doses of fertilisers applied in multiple cropping systems lead to the accumulation of large amounts of P in soil [1, 7, 10, 13]. Ploughless soil tillage has an influence on K distribution and accumulation within plough soil layers. This nutrient migrates into a deeper soil layer applying reduced or no-tillage systems. In that case, its concentration is the greatest in the crop root zone. Potassium utilisation reduces when no-till systems are used [1, 15].

On hilly soils susceptible to erosion, nutrients are often insufficient for successful crop production, and application of fertilisers is vital. P-application is slightly greater than P-removal, but surveys in 1985–1993 showed that 62% of soils in the whole country had very low or low levels of P, while in the Western part the proportion was 71% [8, 9].

For a long time in Lithuania, as elsewhere, traditional soil tillage on flat and sloping land has been deep autumn ploughing followed by harrowing before sowing. Unfortunately, on slopes this contributes to water erosion. At the Kaltinėnai Research Station of the Lithuanian Institute of Agriculture, intensive tillage on hilly land has been successfully replaced by less intensive tillage methods [4]. It was also found that the application of fertilisers should be differentiated according to the variation in a hilly relief [5]. Several problems initiated field experiments at the Kaltinėnai Research Station. Changes in soil management lead to soil health, quality of food and feed alterations. Soil health can continue to decline in areas of intensive cropping and marginal land, where sustainable management methods are not used. It is holding steady or improving in areas where sustainable practices have been fit to problems of soil degradation. The impact of sustainable soil management and technologies (reduced or no-till systems with specific pest and fertiliser application) must be investigated. Soil health trends can develop first of all through scientific investigations of soil chemical and physical properties. The integrated effects of the factors that comprise different soil management systems were not investigated in Lithuania. Soil management systems have both direct and indirect effects on the quality of food and feed. Fertiliser requirements in conventional tillage, their influence on the quality of production are generally investigated. It is vital to obtain data on fertiliser requirements in reduced-tillage and no-till systems.

The aim of the current work was to reveal soil-available P and K changes depending on different tillage and fertilisation systems on the slope of a hill of morainic landscape in Western Lithuania during a four-course crop rotation. Such investigations have not been carried out in Lithuania before. We do not present the results and their detailed comments of a fifth-course crop.

2. MATERIALS AND METHODS

2.1. Site and soil description. The study site is located at the Kaltinėnai Research Station on a cultivated field with the typical undulating relief of Western Lithuania (55°31' N and 22°51' E). The field experiment was set up on a slope in July 1995. The total area under experiment occupied 0.72 ha. The slope was approximately 70 m in length and had an inclination of 6^0 with a westerly aspect. It was weakly eroded. The soil was an *Alboluvisol* according to the FAO soil classification system [14], with sandy loam over loam texture. Table 1 presents soil characteristics of the site.

2.2. Experimental design. The field experiment consisted of four replicates of a randomized split-plot design. Each replicate included 4 soil tillage treatments as main plots (Factor A), which were split into 3 subplots with different fertiliser application rates (Factor B). The net size of subplots was 115 m^2. Table 2 shows the tillage and fertilisation treatments and Table 3 the fertiliser application rates.

Before sowing, P (granular superphosphate, 20% of P_2O_5) and K (potassium chloride, 60% of K_2O) fertilisers were broadcast and incorporated by shallow tillage. Nitrogen was given as ammonium nitrate (34% N). For winter wheat it was broadcast on the soil surface in spring just after growth recommencement, and for spring cereals it was broadcast on the soil surface before emergence.

Crop rotation: 1) winter wheat (*Triticum aestivum* L.) cv. 'Moskovskaya nizkostebelnaya'; the normal yield expected for this crop was 3.0 t ha^{-1} with moderate fertiliser rates and 3.8 t ha^{-1} with high fertiliser rates; 2) spring barley (*Hordeum vulgare* L.) cv. 'Auksiniai 3'; the yield expected for this crop was 2.8 t ha^{-1} with moderate fertiliser rates and 3.5 t ha^{-1} with high fertiliser rates; 3) oats (*Avena sativa* L.) cv. 'Jaugila'; the yield expected for this crop was 3.0 t ha^{-1} with moderate fertiliser rates and 3.8 t ha^{-1} with high fertiliser rates; 4) spring barley cv. 'Auksiniai 3'; the yield expected for this crop was 2.8 t ha^{-1} with moderate fertiliser rates and 3.5 t ha^{-1} with high fertiliser rates; 5) ley – red clover (*Trifolium pratense,* L.) cv. 'Liepsna' + timothy cv. (*Phleum pratense,* L.) 'Gintaras II'.

For winter wheat primary tillage was carried out on 15 August 1995. For spring cereals, spraying with glyphosate and all primary tillage operations in TT, RTGCh and AGRT treatments were finished by 1 October. During the autumn–winter period no tillage operations were carried out. Spraying with glyphosate in the SGRT treatment was done 10 days (for spring barley) and 14 days (for oats) before sowing. Presowing tillage for all crops in all treatments was done at the same day as sowing.

2.3. Analyses and calculating methods. The application rates of mineral P and K fertilisers (Table

Table 1. **Soil characteristics at the establishment of the trials (mean indices ± standard errors)**

Dry soil bulk density Mg m^{-3}		Available P (A–L) mg kg^{-1}		Available K (A–L) mg kg^{-1}		Humus %		pH_{KCl}	
0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10cm	10–20 cm
1.39 ± 0.03	1.47 ± 0.02	20 ± 8	15 ± 7	149 ± 26	116 ± 19	2.09 ± 0.32	2.17 ± 0.30	5.2 ± 0.1	5.3 ± 0.1

Table 2. **Experimental treatments of the field trials**

Treatment*	Crop rotation	Factor A – tillage systems: Primary soil tillage	Presowing soil tillage
TT	Winter cereal	Deep ploughing 22 cm	Cultivation 8 cm + harrowing 5 cm
	Spring cereal	Deep ploughing 22 cm	Cultivation 8 cm + harrowing 5 cm
RTGCh	Winter cereal	Shallow ploughing 15 cm	Cultivation 8 cm + harrowing 5 cm
	Spring cereal	Glyphosate+chiselling 20 cm	Cultivation 8 cm + harrowing 5 cm
AGRT	Winter cereal	Shallow ploughing 15 cm	Harrowing with a narrow tine rotary harrow 6 cm
	Spring cereal	Glyphosate, no-tillage	Harrowing with a narrow tine rotary harrow 6 cm
SGRT	Winter cereal	Shallow ploughing 15 cm	Harrowing with a narrow tine rotary harrow 6 cm
	Spring cereal	No-tillage	Glyphosate + harrowing with a narrow tine rotary harrow 6 cm
Factor B – mineral fertilisation			
1	Not fertilised.		
2	Moderate rates: NPK fertilisers according to soil nutrient status and expected yield.		
3	High rates: NPK fertilisers according to soil nutrient status and yield by 25% greater than expected.		

* TT – traditional tillage system; RTGCh – reduced tillage with glyphosate in autumn and chiselling; AGRT – reduced tillage with glyphosate in autumn; SGRT – reduced tillage with glyphosate in spring.

Table 3. **Fertiliser application to cereals (kg ha^{-1} N:P:K)***

Treatment**	Application to cereals***: Winter wheat, 1996	Spring barley, 1997	Oats, 1998	Spring barley, 1999	overall rate of fertiliser during rotation
TT–2	45:125:31	87:38:35	105:43:53	134:9:36	371:215:158
TT–3	90:175:64	124:78:59	147:90:90	168:51:79	529:394:292
RTGCh–2	45:137:22	90:38:15	105:51:43	123:21:32	373:247:112
RTGCh–3	90:178:58	122:84:44	147:85:89	169:58:69	528:405:260
AGRT–2	45:130:17	89:29:22	107:48:50	132:13:45	373:220:134
AGRT–3	90:174:59	127:61:50	145:96:92	168:46:68	530:377:269
SGRT–2	45:128:23	88:35:14	112:53:56	133:13:25	378:229:118
SGRT–3	90:176:56	127:64:46	149:89:89	169:12:52	535:341:243

* Phosphorus and potassium are presented as oxides (P_2O_5 and K_2O). ** Treatments TT-1, RTGCh-1, AGRT-1 and SGRT-1 were nofertilised. *** Ley was not fertilised.

2) were calculated according to the following formula [11]:

$$D = (10 \times Q \times a - 0.3 \times b \times K_b) / (K_t \times C), \qquad 1)$$

where D is the application rate of a fertiliser (physical weight of fertiliser, in Mg ha^{-1}), Q is the crop yield expected (Mg ha^{-1}), a is the amount of nutrient offtake in the crop (kg Mg^{-1}), b is the amount of available nutrients (P_2O_5 and K_2O) in the soil (mg kg^{-1}), K_b is the coefficient of utilisation of available nutrients from the soil (on average 10% for all cereals), K_t is the coefficient of utilisation of nutrients from a fertiliser (on average 20%), and C is the percentage of nutrient in a fertiliser.

The amounts of soil-available phosphorus and potassium (kg ha^{-1}) were calculated using separate dry soil bulk density (Mg m^{-3}) values for the 0–10 cm and 10–20 cm depths:

$$\text{Soil P or K kg ha}^{-1} = \text{soil P or K mg kg}^{-1} \times \text{dry soil bulk density Mg m}^{-3}. \qquad 2)$$

Available P and K in the soil were determined by ammonium lactate (A–L) extraction [3], humus was measured by the method of Thurin

[18], dry soil bulk density according to Kachinsky, the amount of soil <0.25 – >7 mm aggregates by Savinov [17].

The coefficient for determination of soil aggregation characteristics was calculated according to the following formula [17]:

$$= \frac{\text{content } 0.25-7 \text{ mm of soil aggregates}}{\text{content of} > 7 \text{ mm aggregates} + \text{content of } < 0.25 \text{ mm aggregates}}. \qquad 3)$$

Soil samples were taken at the establishment of the trials (August 1995) and every year after harvesting. Weediness was established after the presowing crop of winter wheat harvesting (1995) and every year after harvesting.

2.4. Statistics. Analysis of variance and correlation-regression analyses were performed using the STATENG computer programme [16]. This programme was developed at the Lithuanian Institute of Agriculture on the basis of the procedures described by Brewbaker [2]. Statistical indices (probability level P, LSD_{05}, correlation coefficient of determination R^2) were calculated for the treatment factor A, factor B, and for their interaction. The path coefficients were calculated for all treatment in the 0–10 and 10–20 cm soil layers.

In the article are analysed changes of soil-available P and K (not P_2O_5 and K_2O), changes of soil physical properties, changes of humus and weediness. The initial data (at trial establishment) and final data are presented in the figures.

2.5. Climatic conditions. The winter of 1995–1996 was cooler and drier than usual. The spring was late. The vegetation period was drier than usual also. June and July in 1997 were dry and warm. The amount of precipitation during these months reached only 53.3% of that described as a long-term annual level. 1998 was unusually wet. The amount of precipitation in the June–August period was by 55.6% greater than a long-term one. In 1999, the vegetation period was warm, but precipitation deficit occurred in May and July. The precipitation reached only 73% of the long-term annual level.

3. RESULTS

3.1. Changes of soil available P and K amount. Soil-available P at trial establishment varied from 24 to 32 in the 0–10 cm and from 19 to 25 kg ha^{-1} in the 10–20 cm layer. Soil-available K at trial establishment varied from 196 to 225 in the 0–10 cm and from 146 to 181 kg ha^{-1} in the 10–20 cm layer. Changes of soil P in plough layer (0–20 cm depth) with all tillage treatments without fertilisers were not significant. Application of moderate and high rates of fertilisers with all tillage treatments increased soil P levels in this layer.

A more significant increase with all tillage treatments was found in the layer of 10–20 cm than 0–10 cm depth (Fig. 1). The moderate rate of fertili-

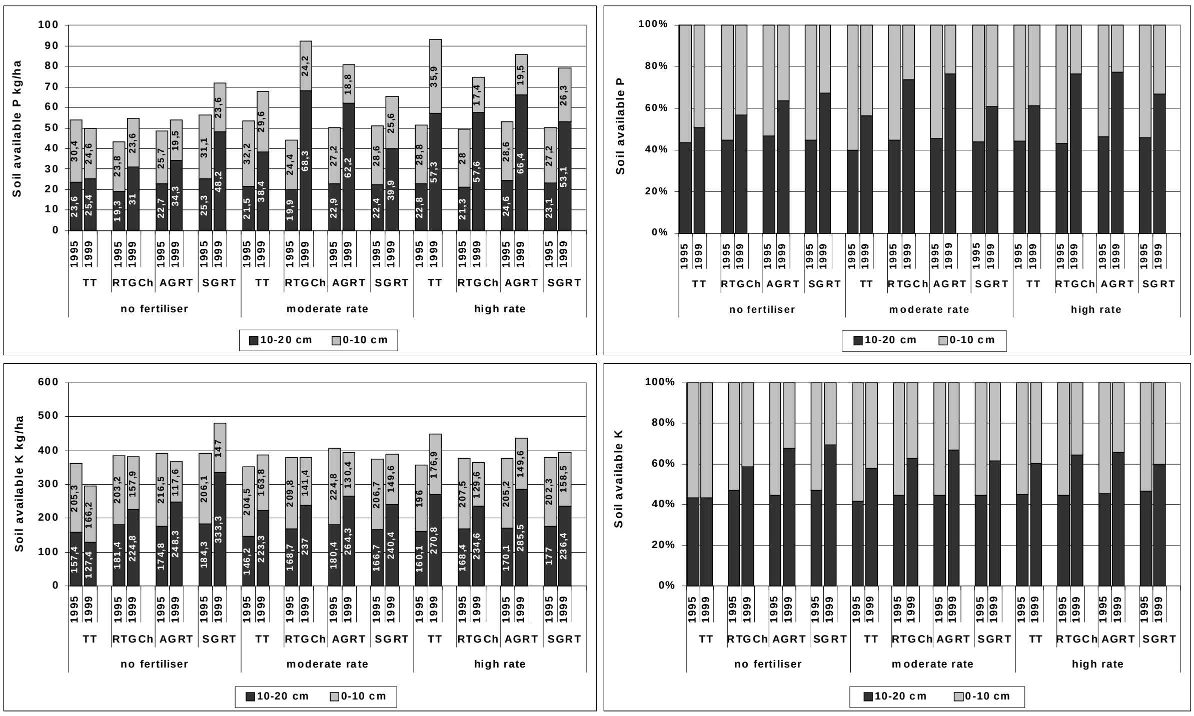

Fig. 1. Changes of soil-available P and K in 0–10 cm and 10–20 cm soil layers during crop rotation period, as affected by tillage system and fertiliser rate

sers did not increase the available soil P in the 0–10 cm layer with all tillage treatments, but the higher rate of fertilisers resulted in greatest changes in this layer only with TT tillage treatments compared with no fertiliser and the moderate rate. In the 10–20 cm soil layer, an increase of available soil P under moderate fertilisation was significant in all tillage treatments compared with no fertiliser. The high rate of fertiliser caused the greatest changes in this layer under TT and SGRT tillage treatments as compared to the moderate rate.

Sustainable tillage systems caused a weak stratification of soil P amount at the end of the 4th year of experiment, *i.e.* in the 0–10 cm soil layer a more significant decrease and in the 10–20 cm layer a more significant increase of P compared to TT treatment were registered. Soil P amount in the 0–10 cm layer with RTGCh, AGRT and SGRT tillage treatments reached 28–35% compared to P content in the whole plough layer, while in TT treatment it reached 44%.

Ley (5th year of experiment) began to unify differences in soil P content at different layers, while P content in the 0–10 cm layer with AGRT and SGRT tillage treatments remained by 6–11% less than at the oufset of experiment.

Changes of soil K in the plough layer (0–20 cm deep) in all tillage treatments and with all fertilisation levels were not significant. More significant changes were found at different soil depths. All tillage systems caused an increase in soil K level in the 10–20 cm layer (by mean 43%) and a decrease in the 0–10 cm layer (by mean 28%). Negative changes of this index with TT and RTGCh tillage treatments in the 0–10 cm soil layer were by 8% higher than under AGRT and SGRT treatments. Soil K increase in the 10–20 cm layer was higher by 19% with AGRT and SGRT than with TT and RTGCh tillage treatments.

3.2. Soil erosion. Sustainable tillage decreased soil erosion (Table 4). In the RTGCh tillage treatment soil losses were by 68% less than in TT treatment. Soil losses in AGRT and SGRT treatments were by 90% less than in TT treatment and by 68% less than in RTGCh treatment. In RTGCh treatment, P losses were by 69% less and K losses by 74% less than in TT treatment. P losses with AGRT and SGRT treatments were by 88–90% less and K losses by 89–91% less than in tillage TT treatment.

3.3. Changes in soil physical properties. The TT and RTGCh tillage systems significantly improved soil aggregation characteristics in the 0–10 cm layer (Fig. 2). In the 10–20 cm layer only the RTGCh system improved these indices. Soil aggregation characteristics did not vary much with AGRT and SGRT tillage systems in both soil layers.

Table 4. **Water erosion extent and soil P and K losses in different tillage-fertilisation systems in the crop rotation period**

Indices	Treatments							
	TT		RTGCh		AGRT		SGRT	
	no fertiliser	high rate	no fertiliser	high rate	no fertiliser	high rate	no fertiliser	high rate
Dry soil losses, t ha^{-1}	19.12	21.33	7.11	5.93	2.27	2.47	1.91	1.71
Available P loss, kg	8.22	9.39	2.77	2,73	0.89	1.28	0.78	0.94
Available K loss, kg	56.98	67.19	14.22	17.79	5.92	8.23	4.74	5.93

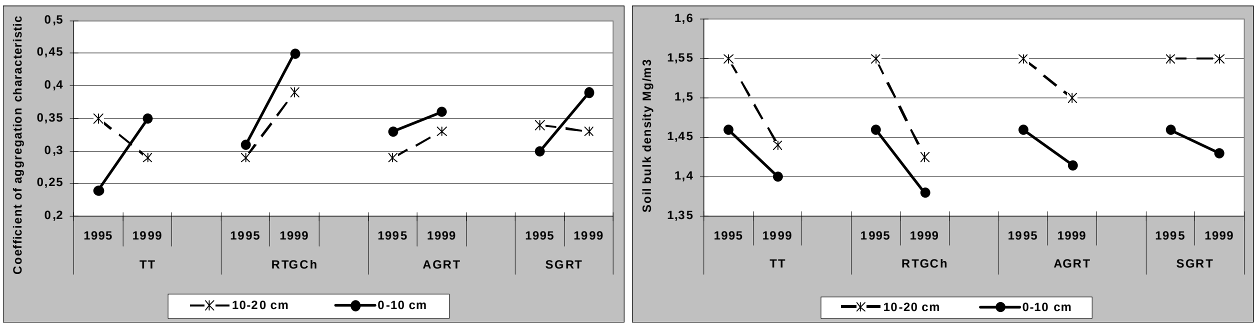

Fig. 2. Changes of soil physical properties in the 0–10 cm and 10–20 cm soil layers during the crop rotation period under different tillage systems

The TT and RTGCh tillage systems improved soil bulk density (Fig. 2). In the 0–10 cm soil layer, the bulk density under TT and RTGCh treatments decreased from 1.46 to 1.39 Mg m^{-3}, in the 10–20 cm layer it decreased from 1.55 to 1.43 Mg m^{-3}. The AGRT and SGRT tillage systems evoked no significant changes in soil bulk density of both layers (LSD_{05} = 0.056 and 0.098 respectively, in the 0–10 and 10–20 cm layers).

3.4. Changes of humus. Humus content at the end of crop rotation in the 0–10 cm soil layer was by mean 0.18% less and in the 10–20 cm depth by 0.30% less than at the outset of trial (Fig. 3). The fertiliser did not cause changes in humus content, but tillage influenced this process. In the both soil layers humus content decreased under TT, RTGCh and AGRT tillage treatments, while application of SGRT tillage treatment saved humus content unchanged in both soil layers.

3.5. Changes of perennial weeds amount. All the tillage systems studied noticeably reduced weediness over the four-course crop rotation period. The effectiveness of TT, RTGCh and SGRT tillage in annihilating weeds was evident. The effectiveness of the AGRT tillage system was weakest as compared to the other systems (Fig. 3). The decrease of perenial weeds during crop rotation in TT, RTGCh, AGRT and SGRT tillage systems reached 79%, 87%, 42% and 73%, respectively.

3.6. P and K offtake. As only straw and grain were analysed, we use the term *P and K offtake* as distinct from *uptake*, which also includes P and K in roots. We presented the overall data of a 4-year crop rotation.

The tillage systems did not influence P offtake, while K offtake significantly increased under AGRT and SGRT tillage treatments. K offtake in these treatments was by 15–21% higher than in TT treatment and by 10–16% higher compared to RTGCh treatment (Fig. 4).

P offtake during the 4 years depended on fertilisation level. The moderate rate of fertilisers significantly increased P offtake in all tillage systems. High rates of fertilisers under RTGCh, AGRT and SGRT tillage caused no significant changes of P offtake as compared to moderate fertilisation. P offtake under the TT tillage system was greatest at a high fertilisation level. K offtake consistently and significantly increased with increasing mineral fertilisers rate in all tillage systems.

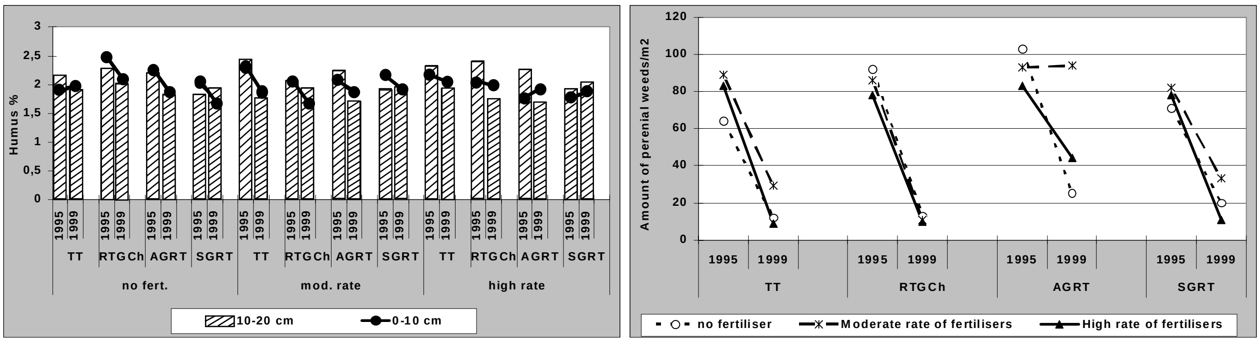

Fig. 3. Changes in soil humus content in the 0–10 cm and 10–20 cm soil layers and weediness during the crop rotation period under different by tillage systems and fertilisation rates

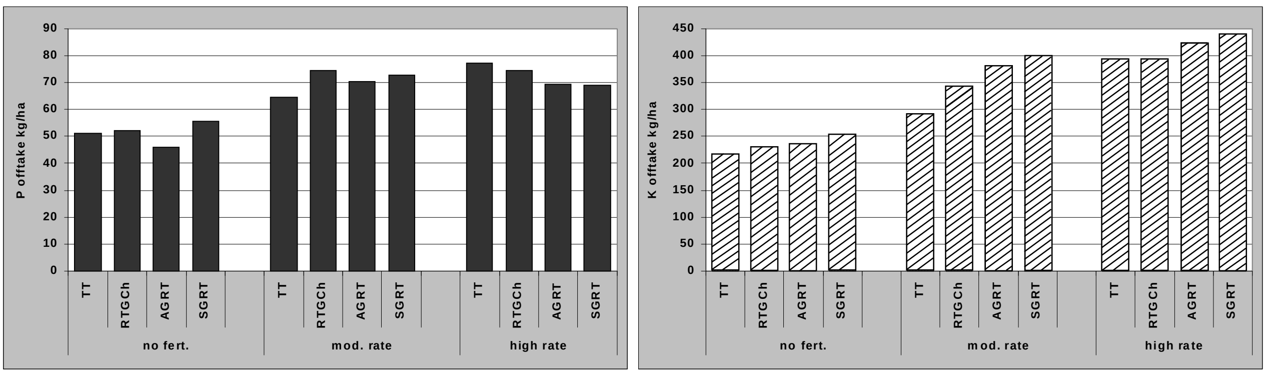

Fig. 4. P and K offtake in the crop rotation period under different tillage systems and fertilisation rates

4. PATH ANALYSIS

Tillage and fertilisation created different soil conditions, weediness, influenced P and K offtake. Changes of soil P and K content during crop rotation depended on the integrated action of these factors.

A usual regression analysis did not reveal a statistically significant relationship between soil P and K changes and one of the above-mentioned factors. In many cases the correlation coefficient was low or very low. Therefore, the evaluation of causality of soil P and K changes was impossible. For a deeper evaluation of the experiment data, the Path method of statistical analysis was employed. This method showed the after-effect of individual factors on soil P and K changes, made clearer the causality of these after-effects and also revealed the degree of influence of all the factors studied on soil P and K levels (Table 5). The integrated action of these factors caused changes in soil-available P and K content. The interrelation of different factors and the after-effect of one factor on the other gave the final result, *i.e.* a picture of a substantial influence of tillage and fertilisation on changes of soil-available P and K content. The correlation coefficient (total sum of effects) showed the strength of this influence (Fig. 5).

A more significant influence on changes in soil-available P at a 0–10 cm level had the depth of primary and presowing tillage (r = 0.41 and 0.40, respectively), changes of perennial weed amount during crop rotation (r = –0.51), changes of soil aggregation characteristics (r = 0.42) and soil P losses (r = 0.49). The degree of influence of the above-mentioned indices on P changes reached 12, 12, 14, 12 and 13%, respectively. Expansion of the correlation coefficients showed that direct effects of primary tillage depth, changes of perennial weediness soil aggregation characteristics and soil P losses were not strong (Path coefficients –4.05, –0.05, 4.57, 5.02, respectively). The influence of these indices on soil P changes developed through indirect effects (after-effect of one factor to other).

An example of expansion of the correlation coefficient:

The direct effect of presowing tillage depth on soil P changes in the 0–10 cm layer was very strong (Path coefficient –15.09), but the other factors (especially changes of soil bulk density) reduced this effect.

The main factors that predetermined changes of soil P content in the 0–10 cm layer and the correlation among all indices were presowing tillage depth and soil P losses.

In accordance with all the above-mentioned comments and comments in Chapter 3, we can suggest that application of the TT and RTGCh tillage systems evoked more significant positive changes in soil properties, best control of weeds, and these systems (deep tillage depth) could be the best for improving P levels in the 0–10 cm soil depth in cases when fertilisation rate is high.

A more significant influence on changes of soil-available P in the 10–20 cm level had P offtake (r = 0.79) and mineral fertilisation (r = 0.75). The degrees of influence of these indices on P changes were 24% and 23%, respectively. The direct effect of P offtake on soil P changes was strong (Path coefficient 0.71). The direct effect of the fertiliser was weak (Path coefficient 0.12), but some other factors (P offtake and soil P losses) increased this effect. The main factors that predetermined changes of soil P content in the 10–20 cm layer were changes of soil bulk density, primary tillage depth, P offtake and soil P losses. Hence, application of the AGRT and SGRT sustainable tillage systems (shallow tillage depth) could provide the best conditions for positive changes of avalable P in soil at a depth of 10–20 cm.

A more significant influence on changes of soil-available K in the 0–10 cm level was exerted by primary and presowing tillage depth (r = 0.47 and 0.44, respectively), initial K content at the trial outset (r = –0.90), changes of aggregation characteristics (r = 0.47) and soil K losses (r = 0.66). The degree of influence of these factors on K changes were 11%, 10%, 22%, 11% and 16%, respectively. The expansion of the correlation coefficients showed that direct effects of primary tillage depth, basic K

Correlation between P changes in the 0–10 cm soil layer and changes of soil aggregation characteristic		**0.42**
Direct effect:		4.56
Indirect effect:	reciprocity of soil aggregation characteristics and initial soil P content in 1995	0.07
	reciprocity of soil aggregation characteristics and changes of humus	0.03
	reciprocity of soil aggregation characteristics and changes of soil bulk density	8.99
	reciprocity of soil aggregation characteristics and changes of perennial weediness	0.03
	reciprocity of soil aggregation characteristics and primary tillage depth	–3.19
	reciprocity of soil aggregation characteristics and presowing tillage depth	–12.19
	reciprocity of soil aggregation characteristics and P offtake	0.03
	reciprocity of soil aggregation characteristics and fertiliser	–0.00
	reciprocity of soil aggregation characteristics and soil P losses	2.08
	Total sum of effects	**0.42**

content, changes of aggregation characteristics and soil K losses were not strong (Path coefficients 0.53, –1.00, –1.58 and –0.78, respectively). The influence of these indices on soil K changes developed through indirect effects. The direct effect of presowing tillage depth on soil K changes in the 0–10 cm layer was very strong (Path coefficient 6.62), but some other factors (changes of soil bulk density and of aggregation characteristics) reduced this effect. The predominant factors that modified changes of soil K content in the 0–10 cm layer and a correlation among all indices were presowing tillage depth and K offtake. We can suggest that the application of TT and RTGCh tillage systems provided for more significant positive changes in soil properties, better control of weeds, and these systems could be best for improving K content in the 0–10 cm soil layer depth in cases when the fertiliser rate is high.

Only primary and presowing tillage depth caused more significant changes in soil-available K in the 10–20 cm layer (r = –0.43 and –0.43, respectively). The degree of influence were 15% and 15%. The direct effect of primary tillage depth was weak (Path coefficient 7.02). The direct effect of presowing tillage depth was strong (Path coefficient –13.58), but some other factors (primary tillage depth and soil K losses) reduced this effect. The main factors that predetermined changes of soil K content in the 10–20 cm layer were changes of aggregation characteristics, presowing tillage depth, K offtake and soil K losses. In accordance with all the above-mentioned comments and comments on experiment results in Chapter 3, we can suppose that the AGRT and SGRT sustainable tillage systems could predetermine the best soil available content in the 10–20 cm layer.

Table 5. **Determinants (x) of the soil P and K changes (y) during crop rotation**

Factors (*x*)	Path coefficients										*r*(*y*)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Factorial effects on soil P changes in the 0–10 cm layer (*y*)											
1. * Soil P, kg ha^{-1} in 1995	**–0.91**	–0.03	–1.48	–0.36	–0.02	–0.08	0.45	0.01	–0.01	2.24	–0.19
2. * Changes of humus, %	–0.16	**–0.18**	–2.21	–0.83	–0.01	0.65	2.60	0.04	–0.05	–0.05	–0.20
3. * Changes of soil bulk density, Mg m^{-3}	–0.11	–0.03	**–12.17**	–3.37	–0.02	3.96	14.88	–0.01	0.00	–3.46	–0.33
4. * Changes of aggregation characteristic	0.07	0.03	8.99	**4.57**	0.03	–3.19	–12.19	0.03	–0.00	2.08	0.42
5. Changes of perennial weeds amount	–0.28	–0.05	–5.54	–2.69	**–0.05**	1.91	7.35	0.03	–0.01	–1.17	–0.51
6. Primary tillage depth, cm	–0.02	0.03	11.92	3.59	0.02	**–4.05**	–15.05	0.01	–0.00	3.96	0.41
7. Presowing tillage depth, cm	0.03	0.03	12.01	3.68	0.02	–4.04	**–15.09**	0.01	–0.00	3.74	0.40
8. P offtake, kg ha^{-1}	–0.03	–0.05	0.92	0.76	–0.01	–0.34	–1.36	**0.16**	–0.10	0.27	0.23
9. Fertiliser, kg ha^{-1}	–0.07	–0.08	0.30	0.04	–0.01	–0.10	–0.35	0.14	**–0.12**	0.39	0.15
10. Soil P losses, kg ha^{-1}	–0.40	0.00	8.39	1.89	0.01	–3.18	–11.23	0.01	–0.01	**5.02**	0.49
Residual effect											0.13
Factorial effects on soil P changes in the 10–20 cm layer (*y*)											
1. ** Soil, kg ha^{-1} in 1995	**0.43**	0.04	–0.07	–0.74	0.01	0.52	0.07	–0.08	0.00	–0.18	0.01
2. ** Changes of humus, %	0.07	**0.28**	–0.09	–0.18	0.00	0.31	0.04	–0.10	–0.04	–0.51	–0.21
3. ** Changes of soil bulk density, Mg m^{-3}	0.26	0.20	**–0.12**	–0.57	0.01	0.65	0.09	0.00	0.00	–0.62	–0.11
4. ** Changes of aggregation characteristics	–0.23	–0.04	0.05	**1.38**	0.00	0.02	0.00	0.04	0.00	–0.83	0.38
5. Changes of perennial weeds amount	0.20	–0.05	–0.03	–0.18	**0.02**	0.42	0.06	0.13	0.01	–0.33	0.25
6. Primary tillage depth, cm	–0.25	–0.10	0.09	–0.03	–0.01	**–0.89**	–0.11	0.06	0.00	1.11	–0.14
7. Presowing tillage depth, cm	–0.27	–0.10	0.09	0.06	-0.01	–0.89	**-0.11**	0.06	0.00	1.05	–0.11
8. P offtake, kg ha^{-1}	–0.05	–0.04	0.00	0.07	0.00	–0.07	-0.01	**0.71**	0.10	0.08	0.79
9. Fertiliser, kg ha^{-1}	0.00	–0.09	0.00	0.00	0.00	–0.02	0.00	0.64	**0.12**	0.11	0.75
10. Soil P losses, kg ha^{-1}	–0.05	–0.10	0.05	–0.82	–0.01	–0.70	–0.08	0.04	0.01	**1.40**	–0.26
Residual effect											0.30
Factorial effects on soil K changes in the 0–10 cm layer (*y*)											
1. * Soil K, kg ha^{-1} in 1995	**–1.00**	0.02	1.58	0.88	0.14	–0.23	–2.78	–0.09	0.20	0.38	–0.90
2. * Changes of humus, %	0.23	**–0.11**	0.90	0.29	0.07	–0.09	–1.14	0.47	–0.38	–0.01	0.23
3. * Changes of soil bulk density, Mg m^{-3}	–0.32	–0.02	**4.96**	1.17	0.11	–0.52	–6.53	0.30	0.02	0.51	–0.33

Table 5 (continued)

1	2	3	4	5	6	7	8	9	10	11	12
4. * Changes of aggregation characteristics	0.55	0.02	–3.66	**–1.58**	–0.14	0.42	5.35	–0.18	–0.01	–0.29	0.47
5. Changes of perennial weeds amount	–0.57	–0.03	2.26	0.93	**0.24**	–0.25	–3.22	0.27	–0.09	0.16	–0.31
6. Primary tillage depth, cm	0.44	0.02	–4.86	–1.25	–0.11	**0.53**	6.61	–0.30	–0.02	–0.59	0.47
7. Presowing tillage depth, cm	0.42	0.02	–4.89	–1.28	–0.12	0.53	**6.62**	–0.30	–0.02	–0.55	0.44
8. K offtake, kg ha^{-1}	0.09	–0.05	1.56	0.30	0.07	–0.17	–2.06	**0.95**	–0.78	0.15	0.07
9. Fertiliser, kg ha^{-1}	0.24	–0.05	–0.12	–0.01	0.03	0.01	0.16	0.87	**–0.85**	–0.08	0.18
10. Soil K losses, kg ha^{-1}	0.49	0.00	–3.22	–0.59	–0.05	0.40	4.67	–0.18	–0.09	**–0.78**	0.66
Residual effect											0.14
Factorial effects on soil K changes in the 10–20 cm layer (*y*)											
1. ** Soil K, kg ha^{-1} in 1995	**–0.49**	0.34	2.00	6.95	0.12	–4.20	7.58	–0.01	–0.50	–11.50	0.29
2. ** Changes of humus, %	–0.21	**0.81**	4.53	–1.62	–0.14	–2.45	4.63	0.10	–0.58	–5.08	0.00
3. ** Changes of soil bulk density, Mg m^{-3}	–0.16	0.58	**6.35**	–5.20	0.17	–5.16	10.18	–0.76	–0.05	–5.63	0.33
4. ** Changes of aggregation characteristics	–0.27	–0.10	–2.61	**12.66**	–0.10	–0.15	–0.57	–0.06	0.00	–8.77	0.02
5. Changes of perennial weeds amount	–0.08	–0.15	1.49	–1.69	**0.73**	–3.31	6.61	–0.79	0.20	–2.85	0.15
6. Primary tillage depth, cm	0.29	–0.28	-4.67	–0.28	–0.34	**7.02**	–13.55	0.88	0.04	10.44	–0.43
7. Presowing tillage depth, cm	0.28	–0.28	–4.76	0.53	–0.36	7.00	**–13.58**	0.87	0.04	9.81	–0.43
8. K offtake, kg ha^{-1}	0.00	–0.03	1.72	0.26	0.21	–2.20	4.22	**–2.82**	1.69	–2.70	0.35
9. Fertiliser, kg ha^{-1}	0.13	–0.25	–0.16	–0.03	0.08	0.17	–0.32	–2.57	**1.85**	1.39	0.29
10. Soil K losses, kg ha^{-1}	0.41	–0.30	–2.57	–7.99	–0.15	5.27	–9.58	0.55	0.19	**13.90**	–0.27
Residual effect											0.35

Note. Bold – direct effect, underlined – the main determinant (dominating factor); * – factors in the 0–10 cm soil layer; ** – factors in the 10–20 cm soil layer.

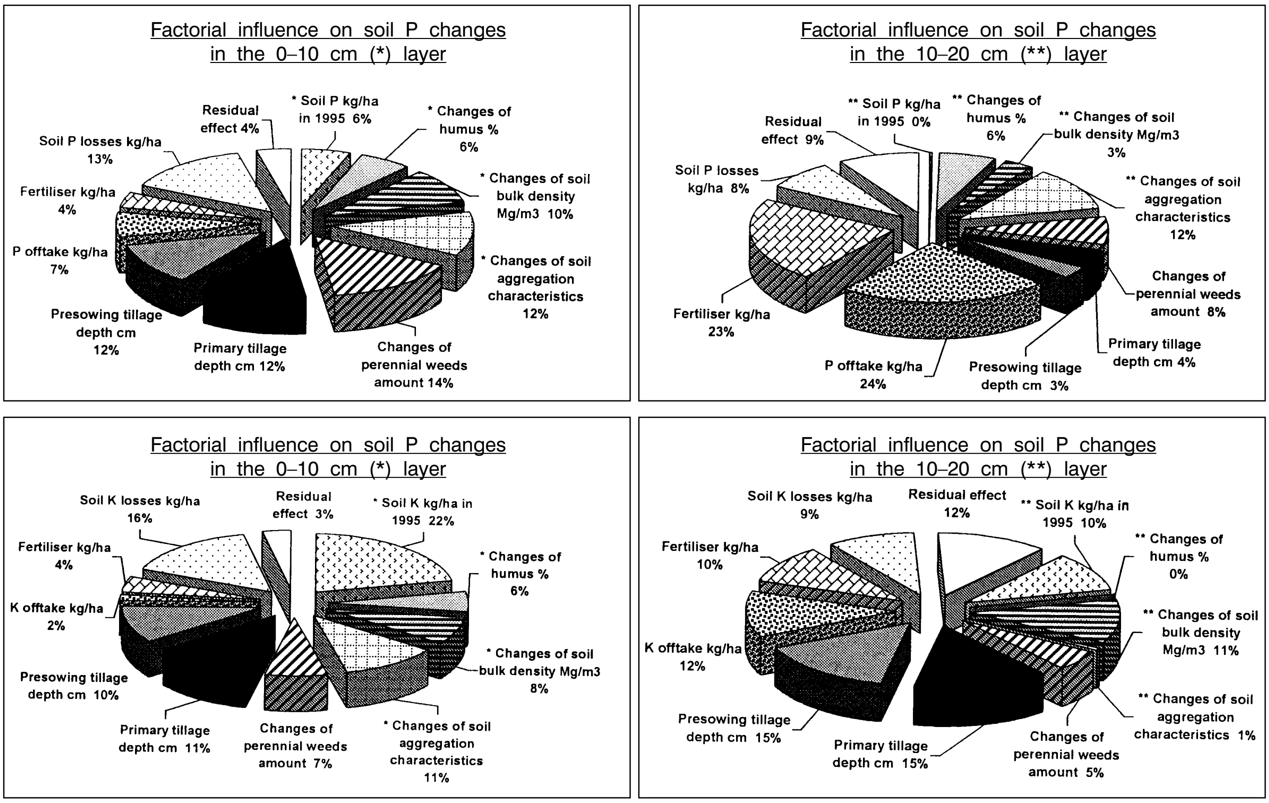

Fig. 5. Factorial influence on soil P and K changes in the 0–10 cm (*) and 10–20 cm layers (**)

CONCLUSIONS

1. Sustainable tillage systems caused weak stratification of soil P content at the end of the 4th year of experiment, *i.e.* in the 0–10 cm soil depth a more significant decrease was registered, in the 10–20 cm layer a more significant increase of P compared to TT treatment.

2. Soil K amount increase in the 10–20 cm depth was higher on average by 19%, and the decrease in the 0–10 cm layer was higher by 8% with AGRT and SGRT, compared to TT and RTGCh tillage treatments.

3. Sustainable tillage reduced soil erosion by 68–90%.

4. The TT tillage system with a high fertilisation rate was the best for increasing available P in the 0–10 cm soil layer.

5. The AGRT and SGRT sustainable tillage systems predetermined the best positive changes of avalable P and K in the 10–20 cm soil layer.

6. The Path analysis showed the real causality of the determinants of soil P and K changes during crop rotation. Presowing tillage depth and soil P losses predetermined changes of soil P amount in the 0–10 cm layer; changes of soil bulk density, primary tillage depth, P offtake and soil P losses modified changes of soil P levels in the 10–20 cm layer. The main factors that predetermined changes of soil K levels in the 0–10 cm layer were presowing tillage depth and K offtake; in the 10–20 cm layer these were changes of aggregation characteristics, presowing tillage depth, K offtake and soil K losses.

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References

1. Bordol J. M., Mallarino A. P. Deep and shallow banding of phosphorus and potassium as alternatives to broadcast fertilization for no-till corn. Agronomy Journal. 1998. Vol. 90. P. 27–33.
2. Brewbaker J. L. Experimental design on a spreadsheet. University of Hawaii. Honolulu, 1995. P. 175.
3. Egner H., Riehm H., Domingo W. R. Untersuchungen über die chemische Boden-Analyse als Grundlage für die Beurteilung des Nährstoffzustandes der Boden. Kungl. Lantbrukshögskolans Annaler. 1960. Vol. 26. P. 199–215.
4. Feiza V. Pagrindinio žemės dirbimo būdų ir intensyvumo tyrimai kalvoto reljefo Vakaru Lietuvos dirvose. Daktaro disertacijos referatas. Lietuvos žemdirbystės institutas, Dotnuva. 1993. 40 p.
5. Feizienė D. Mineralinių trąšų normų efektyvumas miežiams kalvoto reljefo Žemaitijos dirvose. Lietuvos žemdirbytės instituto mokslinių straipsnių rinkinys. Tręšimas. 1994. N 75. P. 73–87.
6. Jankauskas B. Dirvožemio erozija. Vilnius: Margi raštai. 1996. 168 p.
7. Karlen D. L., Berry E. C., Colvin T. S., Kanwar R. S. Twelve-year tillage and crop rotation effect on yields and soil chemical properties in northeast Iowa. Communication in Soil Science and Plant Analysis. 1991. N 22. P. 1985–2003.
8. Lazauskas S., Masauskas V. Prospects of balanced potassium and phosphorus fertilisation in Lithuania. In: Potassium and phosphorus fertilisation effect on soil and crops. Proceedings of the Regional IPI Workshop, October 23–24, 2000, Lithuania. Publisher Arx-Baltica. 2000. P. 206–211.
9. Mažvila J. (sud.). Lietuvos dirvožemių agrocheminės savybės ir jų kaita. Kaunas: Petro ofsetas, 1998. 195 p.
10. McCollum R. E. Buildup and decline in soil phosphorus: 30-year trends on a typic Umprabult. Agronomy Journal. 1991. Vol. 83. P. 77–85.
11. Petraitis V. (sud.). Intensyvios varpinių javų auginimo technologijos. Vilnius: Mintis, 1987. 117 p.
12. Sheldric B. H., Wang C. Particle size distribution. Soil sampling and methods of analysis (Ed. M. R. Carter). Canadian Society of Soil Sciences. Lewis Publishers. 1993. P. 499–568.
13. Schwab A. P., Owensby C. E., Kulyingyong S. Changes in soil chemical properties due to 40 years of fertilization. Soil Sci. 1990. N 149. P. 35–43.
14. Soil Map of the World. FAO-UNESCO. Revised legend with corrections and updates. Technical Paper 20. ISRIC, Wageningen. 1997. 140 p.
15. Vitosh M. L., Darlington W. H., Rice C. W., Christenson D. R. Fertilizer management for conservation tillage. A systems approach to conservation tillage (Ed. D'Itri F. M.). Michigan, USA: Lewis Publishers, Inc., 1985. P. 89–95.
16. Tarakanovas P. Statistinių duomenų apdorojimo programos paketas „Selekcija“. Vilnius: Petro ofsetas, 1999. 57 p.
17. Нерпин С., Чудновский А. Физика почвы. Москва: Наука, 1967. С. 13–18.
18. Сафонов А. К методике подготовки образцов почв для определения гумуса. Гумус и азот в земледелии Нечерноземной зоны РСФСР. Ленинград, 1987. С. 14–16.

Dalia Feizienė, Virginijus Feiza

JUDRIŲJŲ P IR K KIEKIO POKYČIAI VAKARŲ LIETUVOS ERODUOTUOSE ŠLAITUOSE

S a n t r a u k a

Lietuvos žemdirbystės instituto Kaltinėnų bandymų stoties eroduotuose šlaituose 1995–2000 m. nustatyta žemės dirbimo sistemų (tradicinės bei trijų dirvosauginių su glifosatu vasariniams javams), tręšimo lygio bei dirvožemio savybių įtaka judriųjų P ir K pokyčiams per rotaciją.

Dirvosauginių žemės dirbimo sistemų taikymas ketvirtaisiais tyrimo metais sąlygojo judriojo P kiekio diferenciaciją skirtinguose dirvožemio sluoksniuose. Dirvosauginės žemės dirbimo sistemos dirvožemio eroziją sumažino 68–90%. Dirvosauginėse žemės dirbimo sistemose trąšos neturėjo teigiamos įtakos judriųjų P ir K kiekio kitimui 0–10 cm sluoksnyje. Dirvosauginės žemės dirbimo sistemos be gilaus dirvožemio maišymo lėmė didžiausius teigiamus judriųjų P ir K pokyčius 10–20 cm dirvos sluoksnyje.

Vyraujantys veiksniai, nulėmę judriojo P pokyčius 0–10 cm dirvos sluoksnyje, buvo priešsėjinio žemės dirbimo gylis bei P nuostoliai dėl erozijos; 10–20 cm sluoksnyje – dirvožemio tankio pokyčiai per rotaciją, pagrindinio žemės dirbimo gylis, P kiekis augalų derliuje ir P nuostoliai dėl erozijos. Vyraujantys veiksniai, nulėmę judriojo K pokyčius 0–10 cm dirvos sluoksnyje, buvo priešsėjinio žemės dirbimo gylis bei K kiekis augalų derliuje; 10–20 cm sluoksnyje – dirvožemio struktūringumo pokyčiai per rotaciją, priešsėjinio žemės dirbimo gylis, K kiekis augalų derliuje bei K nuostoliai dėl erozijos.

Raktažodžiai: žemės dirbimas, tręšimas, javai, reljefas, Takų analizė

Даля Фейзене, Виргиниюс Фейза

ИЗМЕНЕНИЕ СОДЕРЖАНИЯ ПОДВИЖНЫХ ФОСФОРА И КАЛИЯ НА ЭРОДИРОВАННЫХ СКЛОНАХ ЗАПАДНОЙ ЛИТВЫ

Р е з ю м е

В 1995–2000 гг. на Кальтиненской опытной станции Литовского института земледелия на эродированных склонах изучалось влияние систем обработки почвы (традиционной и трех видов почвозащитной обработки почв с применением глифосата в посевах яровых культур), уровня удобрения и свойств почвы на изменение подвижных форм фосфора и калия в течение ротации севооборота.

Применение почвозащитных систем обработки почвы в течение четырех лет обусловливало дифференциацию количества подвижного фосфора в различных слоях почвы, способствовало снижению эрозии почвы на 68–90%. Удобрение при почвозащитной обработке почвы не оказывало значительного влияния на объём подвижных форм P и K в почвенном слое 0–10 см. Почвозащитные системы обработки почвы обусловили наибольшее положительное изменение подвижных форм P и K в слое 10–20 см.

Установлены доминирующие факторы, оказывающие влияние на изменение содержания подвижных фосфора и калия.

На содержание подвижного фосфора доминирующее влияние оказывают: в верхнем слое почвы (0–10 см) глубина предпосевной обработки почвы и потери фосфора из-за эрозии; в слое 10–20 см – изменение плотности почвы за ротацию, глубина основной обработки почвы; количество фосфора, вынесенного с урожаем сельхозкультур, и его потери в результате эрозии почв.

На содержание подвижного калия в верхнем слое почвы (0–10 см) более всего влияют глубина предпосевной обработки почвы и количество калия, вынесенного с урожаем сельхозкультур, а в слое 10–20 см – изменение структуры почвы за ротацию севооборота, глубина предпосевной обработки почвы, количество калия, вынесенного с урожаем сельхозкультур, и потери калия в результате эрозии почв.

Ключевые слова: обработка почвы, удобрения, зерновые культуры, рельеф, путевой анализ