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Tillage and fertilisation influence on available PK status in unequal soils of Central Lithuania

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Two 2-factorial field experiments were set up at the Lithuanian Institute of Agriculture in 1999–2005. The soil was loam *Endocalcari-Epihypogleyic Cambisol.* Soil according to the main properties is characterised as fertile (first trial) and moderately fertile (second trial). Results of the investigation by managing different tillage and fertilization (according to soil status and expected yield) systems in a 5-year crop rotation revealed that the methodology of fertiliser rate determination and application should differ in different tillage systems and in unequal soils.

The use of pre-established agro-technological measures had a similar effect on the character of P content changes in the arable layer of *fertile* soil: a regular decrease of P content was registered. However, direct drilling leads to a most rapid and significant decrease of P content in the arable layer as compared to traditional and reduced tillage systems in this inherently fertile soil.

The use different fertilisation levels and application of direct drilling in both fertile and moderately fertile soil showed a pronounced stratification of P content in different layers (P increase in the 0–10 cm layer versus to the 10–20 cm layer).

Direct drilling with all fertilisation levels in both fertile and moderately fertile soils leads to stratification of K content in different layers, i.e. to a marked increase in the 0–10 cm layer versus to the 10–20 cm layer.

Key words: tillage, available PK, fertilisation, soil fertility

INTRODUCTION

The current use of phosphate fertilizers in Europe can be considered from two very different points of view. First, as farmers seek to maintain the financial viability of their farms, decreasing inputs of P fertilizers are seen as an option to reduce direct costs. However, such a policy could lead to a serious decline in soil fertility and productivity [19].

Although P is strongly adsorbed by most soils, even in mineral soils such as those used here, significant quantities can leach from the surface layers into the subsoil and, if not retained, would be lost from the profile [2, 9, 10]. Agricultural soils in Europe have received P for many years as fertilizers or organic manures and can retain much of this P in plant-available forms for long periods of time. Thus, the effects of withholding P may not become obvious immediately. Equally, the risk of P transfer from land to water, or in eroded soil, by surface runoff and by leaching, increases in excessively P-enriched soil [4, 6, 8, 9, 10, 13].

Part of Lithuanian soils (20.3%) contain very low levels (up to 50 mg kg^{-1}) of available phosphorus in the humic horizon; 41.5% of soils contain small amounts of phosphorus (51–100 mg kg^{-1}), the average amount (101–150 mg kg^{-1}) is found in 23.3% of soils, and only few soils (15.9%) have a sufficient level (>150 mg kg^{-1}) of phosphorus [18].

Over the last twenty-year period, a decline in phosphorus levels has been registered in soils having a very low content of it (20.3%) and a decline in soils with a sufficient (6.8%) and average (10.8%) phosphorus levels.

One of the main sources of plant nutrition is available potassium. In soils of Lithuania, the content of available potassium is higher than of available phosphorus. Soils with very low levels of available potassium make up 7.6%, with low levels 35.4%, with average levels 33.4% and over 150 mg kg^{-1} (sufficient amount) 23.6% of soils [18].

In consistently and well-tilled soils, P and K are fairly uniformly distributed in the topsoil, because tillage mixes soil and P fertiliser well [1]. In no-till systems, fertilisers are not mixed as thoroughly with soils, and nutrients are not evenly distributed throughout the topsoil [5, 12]. Instead, there is often a distinct vertical stratification, with a highest nutrient content in the top and decreasing levels with depth [1, 7].

No tillage management usually leads to P and K stratification in soils. Both nutrients accumulate in the soil surface – fertilizers and crop residues with soil, limited vertical movement of P and K in most soils and the cycling of nutrients from deep to shallow layers through nutrient uptake by roots [3, 11, 12, 14, 15]. Furthermore, phosphorus sorption and potassium retention by soil constituents in surface layers of no-till soils are often reduced compared with conventionally tilled soils. There is concern that surface application and/or shallow band application of relatively immobile nutrients such as potassium (K) and phosphorous (P) may lead to a substantial accumulation of these nutrients in the surface layer and, potentially, a depletion of nutrients in the deeper layers of soil. Stratification of these essential nutrients may result in yield reductions, especially in dry years [15].

Our objective was to evaluate the differences in P and K stratification over time in unequal soils by applying different tillage – fertilisation systems in the central part of Lithuania.

MATERIALS AND METHODS

Site and soil description. The study site is located at the Lithuanian Institute of Agriculture, Dotnuva (LIA). Two field experiments were set up in July 1999. The soil is an *Endocalcari–Epihypogleyic Cambisol.* Table 1 presents high and moderate fertility soil characteristics of the site.

Experimental design. The field experiment consisted of four replicates of a randomized split-plot design. Each replicate included three tillage treatments as main plots (Factor A), which were split into three subplots with different mineral fertiliser application rates (Factor B). Table 2 shows the tillage and fertilisation treatments.

Crop rotation: 1) winter wheat (*Triticum aestivum* L.) cv 'Sirvinta'; the yield expected for this crop was 5.5 Mg ha^{-1} with moderate fertiliser rates and 7.0 Mg ha^{-1} with high fertiliser rates; 2) sugar beet (*Beta vulgaris* L., var. saccharifera) cv 'Millenium', the yield expected for this crop was 45 Mg ha^{-1} with moderate fertiliser rates and 55 Mg ha^{-1} with high fertiliser rates; 3) spring wheat (*Triticum aestivum* L.) cv 'Munk'; the yield expected for this crop was 4.5 Mg ha^{-1} with moderate fertiliser rates and 6.0 Mg ha^{-1} with high fertiliser rates; 4) spring barley (*Hordeum vulgare* L.) cv 'Luokė'; the yield expected for this crop was 4.0 Mg ha^{-1} with moderate fertiliser rates and 5.5 Mg ha^{-1} with high fertiliser rates; and 5) peas *(Pisum sativum* L.) cv 'Profi', the yield expected for this crop was 4.0 Mg ha^{-1} with

Table 1. **Soil plough layer characteristics of the trials at establishment**
1 lentelė. **Dirvožemio armens charakteristika įrengiant bandymus**

Trial No. / Bandymo Nr.	Plough layer / Armens storis cm	Bulk density / Tankis Mg m^{-3}	Clay content / Fizinio molio kiekis %	Available P / Judrusis P mg kg^{-1}	Available K / Judrusis K mg kg^{-1}	Total N / Bendrasis N %	Humus / Humusas %	pH $_{KCl}$
1 – high fertility soil / našus dirvožemis	34	1.30	25	140	217	0.123	2.10	6.8
2 – moderate fertility soil / vidutiniškai našus dirvožemis	30	1.40	26	47	131	0.108	1.60	6.2

Table 2. **Field experiment design**
2 lentelė. **Tyrimo schema**

Tillage (factor A) / Žemės dirbimas (A veiksnys)		
Treatments / Variantai	Primary tillage / Pagrindinis dirbimas	Presowing tillage / Priešsėjinis dirbimas
CT / Tradicinis dirbimas	Deep ploughing (23–25 cm) / Gilus arimas (23–25 cm)	Spring tine cultivation (4–5 cm) / Purenimas kombinuotu žemės dirbimo agregatu (4–5 cm)
RT / Supaprastintas dirbimas	Shallow ploughing (14–16 cm) / Seklus arimas (14–16 cm)	Spring tine cultivation (4–5 cm) / Purenimas kombinuotu žemės dirbimo agregatu (4–5 cm)
NT / Tiesioginė sėja	No tillage / Nedirbta	Direct drilling / Tiesioginė sėja
Fertilisation (factor B) / Tręšimas (B veiksnys)		
1	Not fertilised / netręšta	
2	Moderate rates: NPK fertilisers according to soil properties and expected yield / Mineralinių NPK trąšų normos apskaičiuotos pagal dirvožemyje esantį maisto medžiagų kiekį ir planuojamą derlių (sąlyginai vidutinės trąšų normos)	
3	High rates: NPK fertilisers according to soil properties and for 25–30% greater expected yield than in treatment 2 / NPK trąšų normos apskaičiuotos pagal dirvožemyje esantį maisto medžiagų kiekį ir planuojamą (6,0 t ha^{-1}) derlių (sąlyginai maksimalios trąšų normos)	

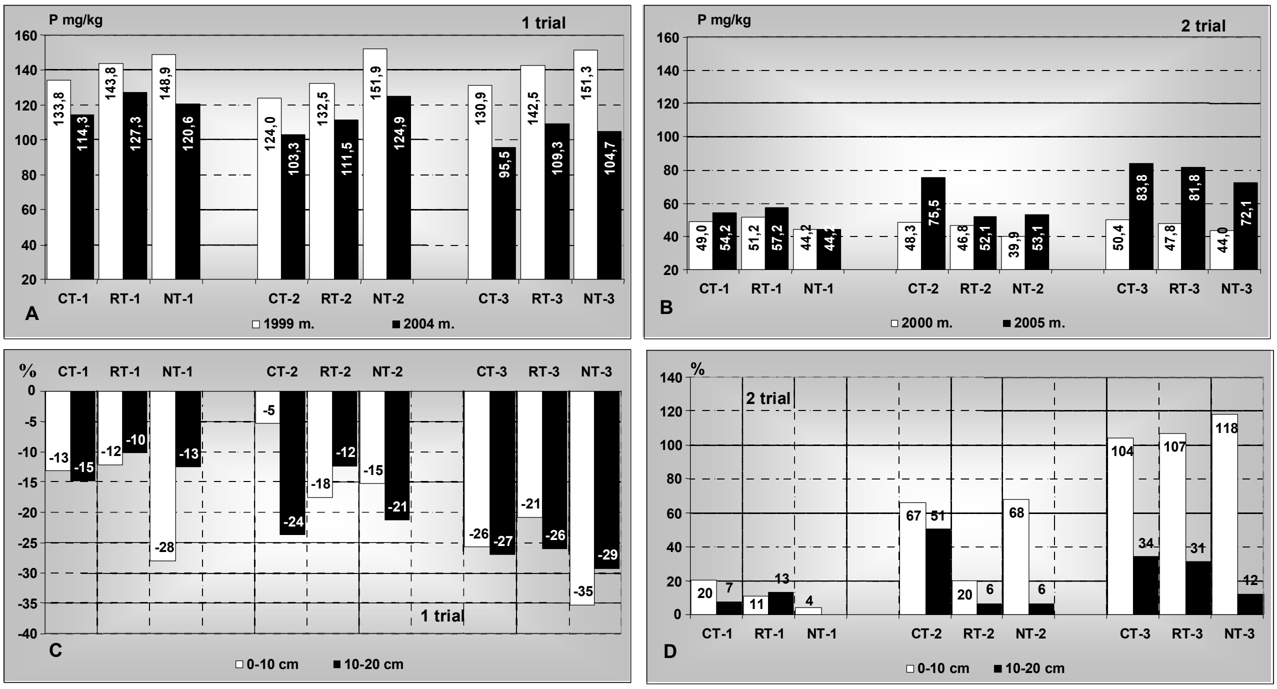

Fig. 1. Actual P content at trial establishment and end in arable layer **(A, B)** and P content changes during crop rotation in different soil layers **(C, D)**, %. A: *1999 – $LSD_{05}(A)$ = 16.01; $LSD_{05}(B)$ = 16.01; $LSD_{05}(AB)$ = 27.74; 2004 – $LSD_{05}(A)$ = 16.24; $LSD_{05}(B)$ = 16.24; $LSD_{05}(AB)$ = 28.12.* B: *2000 – $LSD_{05}(A)$ = 6.13; $LSD_{05}(B)$ = 6.13; $LSD_{05}(AB)$ = 10.61; 2005 – $LSD_{05}(A)$ = 10.99; $LSD_{05}(B)$ = 10.99; $LSD_{05}(AB)$ = 19.04*

1 pav. Fosforo kiekis ariamajame sluoksnyje įrengus bandymus ir juos užbaigus (A, B) bei fosforingumo pokytis skirtinguose sluoksniuose (C, D) per sėjomainos rotaciją %. *Pastaba.* **A**: *1999 – $R_{05}(A)$ = 16,01; $R_{05}(B)$ = 16,01; $R_{05}(AB)$ = 27,74; 2004 – $R_{05}(A)$ = 16,24; $R_{05}(B)$ = 16,24; $R_{05}(AB)$ = 28,12.* **B**: *2000 – $R_{05}(A)$ = 6,13; $R_{05}(B)$ = 6,13; $R_{05}(AB)$ = 10,61; 2005 – $R_{05}(A)$ = 10.99; $R_{05}(B)$ = 10,99; $R_{05}(AB)$ = 19,04*

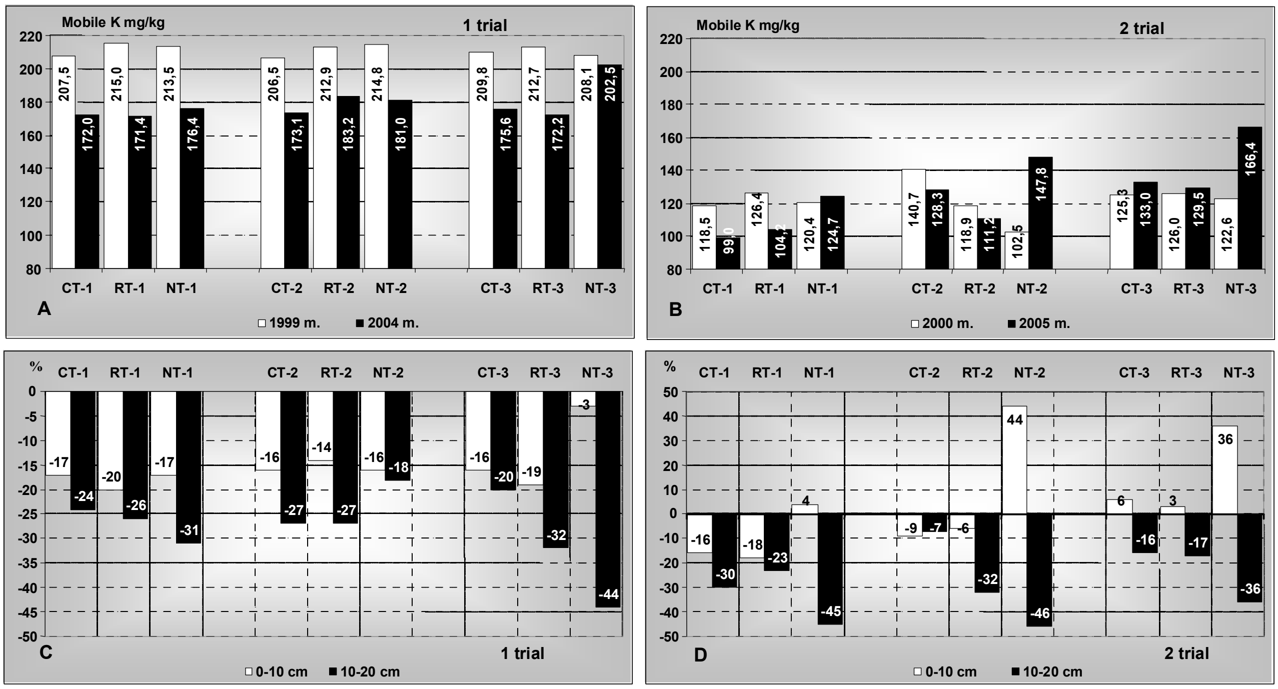

Fig. 2. Actual K content at trials establishment and the end in arable layer **(A, B)** and K content changes during crop rotation in different soil layers **(C, D)**, %. *A: 1999 – $LSD_{05}(A)$ = 12.84; $LSD_{05}(B)$ = 12.84; $LSD_{05}(AB)$ = 22.24; 2004 – $LSD_{05}(A)$ = 13.77; $LSD_{05}(B)$ = 13.77; $LSD_{05}(AB)$ = 23.88. B: 2000 – $LSD_{05}(A)$ = 9.58; $LSD_{05}(B)$ = 9.58; $LSD_{05}(AB)$ = 16.61; 2005 – $LSD_{05}(A)$ = 17.52; $LSD_{05}(B)$ = 17.52; $LSD_{05}(AB)$ = 30.35*

2 pav. Kalio kiekis ariamajame sluoksnyje įrengus bandymus ir juos užbaigus (A, B) bei kalingumo pokytis skirtinguose sluoksniuose (C, D) per sėjomainos rotaciją %. *Pastaba.* **A**: *1999 – $R_{05}(A)$ = 12,84; $R_{05}(B)$ = 12,84; $R_{05}(AB)$ = 22,24; 2004 – $R_{05}(A)$ = 13,77; $R_{05}(B)$ = 13,77; $R_{05}(AB)$ = 23,88.* **B**: *2000 – $R_{05}(A)$ = 9,58; $R_{05}(B)$ = 9,58; $R_{05}(AB)$ = 16,61; 2005 – $R_{05}(A)$ = 17,52; $R_{05}(B)$ = 17,52; $R_{05}(AB)$ = 30,35* moderate fertiliser rates and 5.5 M g ha^{-1} with high fertiliser rates.

Fertilisation. During crop rotation, mineral NPK fertilisers were broadcast and incorporated by shallow harrowing: the 1st trial – moderate rate $N_{285}P_0K_{169}$, high rate $N_{659}P_6K_{260}$; the 2nd trial – moderate rate $N_{435}P_{235}K_{315}$, high rate $N_{768}P_{533}K_{422}$.

Available P and K in the soil were determined by ammonium lactate (A–L) extraction.

Statistics. Analysis of variance was performed using ANOVA and STATENG computer programmes. Statistical indices (probability level P, LSD_{05}, the correlation coefficient of determination R^2) were calculated for treatment factor A, factor B, and for their interaction. Path coefficients were calculated for all treatment at the 0–10 and 10–20 cm soil depth.

RESULTS

Soil P content at the experiment establishment in the 1st trial varied from 124.0 to 151.9 mg kg^{-1} and in the 2nd trial from 39.9 to 50.4 mg kg^{-1} (Fig. 1, A and B). According to Lithuanian soil classification system, the 1st trial is referred to a very high soil phosphorous group and the 2nd trial to a moderate soil phosphorous group. During a 5-year crop rotation, soil P content in the 1st trial decreased and varied from 95.5 to 127.3 mg kg^{-1}, while in the 2nd trial it increased and varied from 44.2 mg kg^{-1} to 83.8 mg kg^{-1}.

Tillage influenced changes in soil mobile P content during crop rotation (Fig. 1, C and D). In the 1st trial, in the tillage system CT in the 0–10 cm soil layer, P content decreased by 15% and in the 10–20 cm layer by 22%. In the tillage systems RT and NT the decrease reached, respectively, 17 and 16%, 26 and 21%. In the 2nd trial, in the system CT in the 0–10 cm soil layer P content increase by 64% and in the 10–20 cm layer by 31%. In the tillage systems RT and NT, the increase reached, respectively, 46 and 17%, 63 and 6%.

The increase of rates of mineral fertilisers determined the decrease of soil P content in the 1st trial, while the effect of fertilisers in the 2nd trial showed an opposite result, i. e. after long-term application of mineral fertilisers there was registered an increase of soil P content.

Soil K content at the experiment establishment in the 1st trial varied from 206.5 to 215.0 mg kg^{-1} and in the 2nd trial from 102.5 to 140.7 mg kg^{-1} (Fig. 2, A and B). According to the Lithuanian soil classification system, the 1st trial is referred to a high soil potassium group and the 2nd trial to a moderate soil potassium group.

During a 5-year crop rotation, soil K content in the 1st trial decreased and varied from 171.4 to 202.5 mg kg^{-1}. In the 2nd trial, in the tillage systems CT and RT, it decreased as well and varied from 99.0 to 133.0 mg kg^{-1}, while in the tillage system NT soil mobile K content marginally increased and varied from 124.7 to 166.4 mg kg^{-1}.

Tillage influenced changes in soil mobile K content during the crop rotation (Fig. 2, C and D). In the 1st trial, in the tillage system CT in the 0–10 cm soil layer, K content decreased by 16% and in the 10–20 cm layer by 24%. In the tillage systems RT and NT the decrease reached, respectively, 18 and 28%, 12 and 31%. In the 2nd trial, in the tillage system CT in the 0–10 cm soil layer, K content decreased on average by 6% and

Table 3. **Change in P and K content ratio between 0–10 cm and 10–20 cm layers during crop rotation (%)**
3 lentelė. **Santykio „P ir K kiekis 0–10 cm sluoksnyje / P ir K kiekis 10–20 cm sluoksnyje“ pokytis per rotaciją (%)**

	Treatments / Variantai								
	CT-1	RT-1	NT-1	CT-2	RT-2	NT-2	CT-3	RT-3	NT-3
P									
1st trial / 1 bandymas									
Ratio / Santykis 1999	1.00	0.97	1.12	1.07	1.02	1.08	0.95	0.92	1.08
Ratio / Santykis 2004	1.01	0.94	0.93	1.13	0.97	0.94	0.97	0.96	0.98
Ratio change / Santykio pokytis %	1	–3	–17	6	–5	–13	2	4	–9
2nd trial / 2 bandymas									
Ratio / Santykis 2000	0.93	0.90	0.99	1.17	1.02	0.92	1.05	0.97	1.00
Ratio / Santykis 2005	1.01	0.89	1.04	1.28	1.09	1.41	1.58	1.54	1.97
Ratio change / Santykio pokytis %	9	-1	5	9	7	53	50	59	97
K									
1st trial / 1 bandymas									
Ratio / Santykis 1999	0.91	0.92	0.96	0.92	0.98	0.98	0.99	0.91	0.97
Ratio / Santykis 2004	0.99	0.99	1.19	1.08	1.17	1.33	1.05	1.10	1.68
Ratio change / Santykio pokytis %	9	8	24	17	19	36	6	21	73
2nd trial / 2 bandymas									
Ratio / Santykis 2000	0.92	0.81	0.91	0.95	0.86	0.74	0.90	0.93	0.87
Ratio / Santykis 2005	0.99	0.96	1.07	1.13	1.16	1.70	1.13	1.15	1.81
Ratio change / Santykio pokytis %	8	19	18	19	35	130	26	24	108

in the 10–20 cm layer by 18%. In the tillage system RT the increase reached, respectively, 7 and 24%. In the tillage system NT, in the 0–10 cm soil layer, K content increased by 28%, while in the 10–20 cm layer it decreased by 42%.

Moderate and high rates of mineral NPK fertilisers had no significant influence on changes of mobile K content in soil during the crop rotation period as compared to non-fertilised soil in the 1st trial. The long-term action of fertilisers in the 2nd trial decreased the decline of mobile K content in the 0–10 cm layer in all tillage systems. Application of mineral fertilisers in the tillage system NT increased K content in the 0–10 cm soil layer, while it had no significant influence on decreasing the negative changes in the 10–20 cm layer.

Soil PK stratification. No-tillage influenced soil phosphorus stratification in the arable layer. Change of the ratio between P content in the 0–10 cm and P content in the 10–20 cm layers during crop rotation in the first trial in the CT and RT systems were inessential (Table 3). For example, at the end of the 1st trial it differed from the initial ratio on average by 3% in the CT system and by 1% in the RT system. P fertilisers in this trial were absent, while the above-mentioned ratio in the NT system during crop rotation decreased on average by 13%. At the end of the 2nd trial the ratio between P content in the 0–10 cm and P content in the 10–20 cm layers differed from the initial ratio on average by 23% in the CT system and by 22% in the RT system. In this trial P fertilisers were used. However change of the above-mentioned ratio in the NT system during crop rotation was more significant and reached 52%. The implication is that P fertilisers remained on the soil surface. This is an unacceptable phenomenon, because a continual broadcast of P fertiliser without incorporation can accumulate P and lower P sorption at the surface compared with the deeper layers of the soil [16, 20].

No-tillage influenced soil potassium stratification in the 0–20 cm layer. The ratio between K content in the 0–10 cm and K content in the 10–20 cm layers at the end of the 1st trial differed from the initial ratio on average by 11% in the CT system and by 16% in the RT system, while the above-mentioned ratio in the NT system during crop rotation decreased on average by 44%.

At the end of the 2nd trial, the ratio between K content in the 0–10 cm and K content in the 10–20 cm layers differed from the initial ratio on average by 18% in the CT system and by 26% in the RT system. However, change of the above-mentioned ratio in the NT system during crop rotation was more significant and reached 85%. The implication is that broadcasted K fertilisers remained on the soil surface.

Crop rotation productivity. Unequal fertility soils produced different crop yields. Overall, crop yield in the fertile soil of the 1st trial was higher by 31.6% as compared to yield in the 2nd trial (Table 4).

In the 1st and the 2nd trials, direct drilling (NT) produced on average 6.9% and 7.9% lower yields compared to

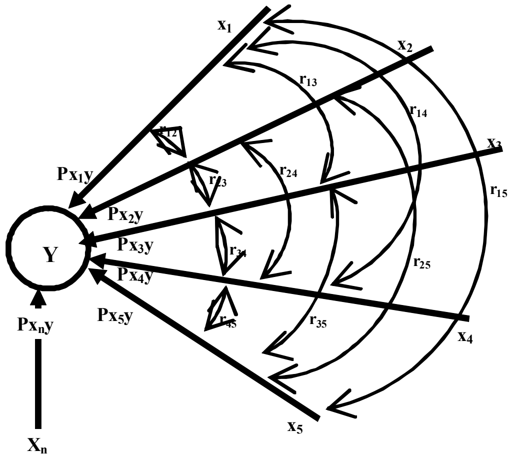

Fig 3. Scheme of Path coefficients (P) and paired (r) correlation (x_1, x_2, x_3, x_4, x_5 – indices, which influenced the main index y)
3 pav. *Takų* koeficientų (P) ir porinės koreliacijos (r) schemos pavyzdys (čia x_1, x_2, x_3, x_4, x_5 – požymiai, turintys įtakos pagrindiniam rodikliui y).

Table 4. **Productivity of crop rotation (metabolisable energy thous. MJ ha^{-1})**
4 lentelė. **Sėjomainos rotacijos produktyvumas (apykaitinės energijos tūkst MJ ha^{-1})**

Tillage (factor A) / Žemės dirbimas (A veiksnys)	Fertilisation (factor B) / Tręšimas (B veiksnys)							
	Trial 1 / 1 bandymas				Trial 2 / 2 bandymas			
	not fertilised / netręšta	moderate rate / vidutinė norma	high rate / padidinta norma	mean A / vidutiniškai A	not fertilised / netręšta	moderate / rate vidutinė norma	high rate / padidinta norma	mean A / vidutiniškai A
CT	322.76	405.75	422.08	383.53	235.02	327.17	340.39	300.86
RT	340.35	430.62	423.81	398.26	218.93	321.15	345.57	295.22
NT	310.89	370.93	409.75	363.85	188.39	301.81	333.35	274.51
men B	324.67	402.43	418.55	381.88	214.11	316.71	339.77	290.20
LSD_{05} (A)	20.803				16.135			
LSD_{05} (B)	20.803				16.135			
LSD_{05} (AB)	36.031				27.946			

Table 5. **Direct and indirect effects of fertilisation on soil PK content changes, % (*y*)**
5 lentelė. **Tiesioginiai ir netiesioginiai tręšimo efektai dirvožemio PK pokyčiams % (*y*)**

Factors / Veiksniai	Correlation matrix / Koreliacija						Path coefficients / Takų koeficientai					1 (rY)
	1	2	3	4	5	6	2	3	4	5	6	
Tillage CT / Tradicinis žemės dirbimas												
1 – P change / P pokytis (0–10)	1.00	–0.75	–0.27	0.40	0.82	0.57						
2 – Soil P / Dirv. P (0–10)		1.00	0.62	–0.13	–0.57	–0.30	**–0.62**	0.25	0.04	–0.48	0.06	–0.75**
3 – Yield ME / AE derlingumas			1.00	0.56	–0.05	0.44	–0.38	**0.40**	–0.16	–0.04	–0.08	–0.27
4 – N fertiliser / N trąšos				1.00	0.67	0.95	0.08	0.22	**–0.29**	0.56	–0.17	0.40*
5 – P fertiliser / P trąšos					1.00	0.80	0.35	–0.02	–0.19	**0.83**	–0.15	0.82**
6 – K fertiliser / K trąšos						1.00	0.18	0.17	–0.27	0.67	**–0.18**	0.57*
Residual effect												0.42
1 – P change / P pokytis (10–20)	1.00	–0.83	–0.38	0.23	0.65	0.44						
2 – Soil P / Dirv. P (10–20)		1.00	0.61	–0.15	–0.61	–0.34	**–0.68**	0.08	0.10	–0.09	–0.24	–0.83**
3 – Yield ME / AE derlingumas			1.00	0.56	–0.05	0.44	–0.41	**0.13**	–0.40	–0.01	0.31	–0.38*
4 – N fertiliser / N trąšos				1.00	0.67	0.95	0.10	0.07	**–0.71**	0.09	0.68	0.23
5 – P fertiliser / P trąšos					1.00	0.80	0.41	–0.01	–0.48	**0.14**	0.58	0.65**
6 – K fertiliser / K trąšos						1.00	0.23	0.01	–0.68	0.12	**0.72**	0.44*
Residual effect												0.49
1 – K change / K pokytis (0–10)	1.00	–0.35	0.05	0.47	0.70	0.55						
2 – Soil K / Dirv. K (0–10)		1.00	0.58	–0.08	–0.54	–0.22	**–0.10**	0.22	–0.01	–0.57	0.11	–0.35*
3 – Yield ME / AE derlingumas			1.00	0.56	–0.05	0.44	–0.06	**0.37**	0.01	–0.06	–0.22	0.05
4 – N fertiliser / N trąšos				1.00	0.67	0.95	0.01	0.21	**0.03**	0.70	–0.48	0.47*
5 – P fertiliser / P trąšos					1.00	0.80	0.06	–0.02	0.02	**1.05**	–0.40	0.70**
6 – K fertiliser / K trąšos						1.00	0.02	0.16	0.03	0.84	**–0.51**	0.55*
Residual effect												0.68
1 – K change /K pokytis (10–20)	1.00	–0.28	0.11	0.35	0.40	0.46						
2 – Soil K / Dirv. K (10–20)		1.00	0.49	–0.15	–0.51	–0.31	**–0.07**	0.01	0.13	0.09	–0.44	–0.28
3 – Yield ME / AE derlingumas			1.00	0.56	–0.05	0.44	–0.04	**0.01**	–0.49	0.01	0.62	0.11
4 – N fertiliser / N trąšos				1.00	0.67	0.95	0.01	0.01	**–0.88**	–0.12	1.34	0.35*
5 – P fertiliser / P trąšos					1.00	0.80	0.04	–0.01	–0.59	**–0.18**	1.13	0.40*
6 – K fertiliser / K trąšos						1.00	0.02	0.01	–0.84	–0.14	**1.41**	0.46*
Residual effect												0.84
Tillage RT / Supaprastintas žemės dirbimas												
1 – P change / P pokytis (0–10)	1.00	–0.56	–0.19	0.45	0.81	0.54						
2 – Soil P / Dirv. P (0–10)		1.00	0.68	–0.16	–0.59	–0.33	**–0.40**	0.24	–0.08	–0.70	0.38	–0.56*
3 – Yield ME / AE derlingumas			1.00	0.48	–0.07	0.37	–0.27	**0.35**	0.25	–0.08	–0.43	–0.19
4 – N fertiliser / N trąšos				1.00	0.67	0.95	0.07	0.17	**0.51**	0.80	–1.10	0.44*
5 – P fertiliser / P trąšos					1.00	0.80	0.23	–0.02	0.35	**1.18**	–0.93	0.81**
6 – K fertiliser / K trąšos						1.00	0.13	0.13	0.49	0.95	**–1.16**	0.54*
Residual effect												0.52
1 – P change / P pokytis (10–20)	1.00	–0.68	–0.48	0.13	0.64	0.27						
2 – Soil P / Dirv. P (10–20)		1.00	0.67	–0.13	–0.59	–0.32	**–0.36**	0.01	–0.01	–0.51	0.19	–0.68**
3 – Yield ME / AE derlingumas			1.00	0.48	–0.07	0.37	–0.24	**0.02**	0.02	–0.06	–0.22	–0.48*
4 – N fertiliser / N trąšos				1.00	0.67	0.95	0.05	0.01	**0.05**	0.59	–0.56	0.13
5 – P fertiliser / P trąšos					1.00	0.80	0.21	–0.01	0.03	**0.87**	–0.48	0.64**
6 – K fertiliser / K trąšos						1.00	0.12	0.01	0.05	0.70	**–0.60**	0.27
Residual effect												0.60
1 – K change / K pokytis (0–10)	1.00	–0.34	–0.04	0.29	0.44	0.37						
2 – Soil K / Dirv. K (0–10)		1.00	0.63	–0.15	–0.60	–0.33	**–0.16**	0.04	0.04	–0.13	–0.13	–0.34
3 – Yield ME / AE derlingumas			1.00	0.48	–0.07	0.37	–0.10	**0.06**	–0.14	–0.02	0.15	–0.04
4 – N fertiliser / N trąšos				1.00	0.67	0.95	0.02	0.03	**–0.30**	0.15	0.38	0.29
5 – P fertiliser / P trąšos					1.00	0.80	0.10	–0.00	–0.20	**0.22**	0.32	0.44*
6 – K fertiliser / K trąšos						1.00	0.05	0.02	–0.28	0.18	**0.40**	0.37*
Residual effect												0.88

Table 5 (continued)
5 lentelė (tęsinys)

1 – K change /K pokytis (10–20)	1.00	–0.11	–0.17	0.03	0.19	0.04						
2 – Soil K / Dirv. K (10–20)		1.00	0.51	–0.23	–0.69	–0.43	**0.23**	–0.11	–0.04	–0.33	0.14	–0.11
3 – Yield ME / AE derlingumas			1.00	0.48	–0.07	0.37	0.12	**–0.21**	0.08	–0.03	–0.12	–0.17
4 – N fertiliser / N trąšos				1.00	0.67	0.95	–0.05	–0.10	**0.17**	0.32	–0.30	0.03
5 – P fertiliser / P trąšos					1.00	0.80	–0.16	0.01	0.11	**0.48**	–0.26	0.19
6 – K fertiliser / K trąšos						1.00	–0.10	–0.08	0.16	0.38	**–0.32**	0.04
Residual effect												0.95
Tillage NT / Tiesioginė sėja į ražieną												
1 – P change / P pokytis (0–10)	1.00	–0.67	–0.16	0.50	0.90	0.67						
2 – Soil P / Dirv. P (0–10)		1.00	0.61	–0.13	–0.57	–0.30	**–0.02**	–0.13	0.06	–0.38	–0.22	–0.67**
3 – Yield ME / AE derlingumas			1.00	0.58	0.04	0.46	–0.01	**–0.21**	–0.29	0.03	0.33	–0.16
4 – N fertiliser / N trąšos				1.00	0.67	0.95	0.01	–0.12	**–0.51**	0.45	0.67	0.50*
5 – P fertiliser / P trąšos					1.00	0.80	0.01	–0.01	–0.34	**0.67**	0.57	0.90**
6 – K fertiliser / K trąšos						1.00	0.01	–0.10	–0.48	0.54	**0.71**	0.67**
Residual effect												0.35
1 – P change / P pokytis (10–20)	1.00	–0.54	–0.34	0.08	0.57	0.25						
2 – Soil P / Dirv. P (10–20)		1.00	0.65	–0.13	–0.58	–0.29	**0.03**	–0.12	0.09	–0.41	–0.13	–0.54*
3 – Yield ME / AE derlingumas			1.00	0.58	0.04	0.46	0.02	**–0.19**	–0.40	0.03	0.20	–0.34*
4 – N fertiliser / N trąšos				1.00	0.67	0.95	–0.00	–0.11	**–0.70**	0.48	0.41	0.08
5 – P fertiliser / P trąšos					1.00	0.80	–0.02	–0.01	–0.47	**0.71**	0.35	0.57*
6 – K fertiliser / K trąšos						1.00	–0.01	–0.09	–0.66	0.57	**0.44**	0.25
Residual effect												0.70
1 – K change / K pokytis (0–10)	1.00	–0.70	–0.15	0.44	0.65	0.58						
2 – Soil K / Dirv. K (0–10)		1.00	0.54	–0.15	–0.57	–0.33	**–0.46**	–0.05	0.03	–0.01	–0.21	–0.70
3 – Yield ME / AE derlingumas			1.00	0.58	0.04	0.46	–0.25	**–0.10**	–0.10	0.00	0.29	–0.15
4 – N fertiliser / N trąšos				1.00	0.67	0.95	0.07	–0.06	**–0.17**	0.01	0.59	0.44*
5 – P fertiliser / P trąšos					1.00	0.80	0.26	–0.014	–0.11	**0.01**	0.50	0.65**
6 – K fertiliser / K trąšos						1.00	0.15	–0.05	–0.16	0.01	**0.62**	0.58*
Residual effect												0.61
1 – K change /K pokytis (10–20)	1.00	0.42	0.30	–0.11	–0.11	–0.10						
2 – Soil K / Dirv. K (10–20)		1.00	0.53	–0.15	–0.56	–0.30	**0.40**	0.25	0.15	–0.24	–0.13	0.42*
3 – Yield ME / AE derlingumas			1.00	0.58	0.04	0.46	0.21	**0.46**	–0.60	0.02	0.20	0.30
4 – N fertiliser / N trąšos				1.00	0.67	0.95	–0.06	0.27	**–1.03**	0.29	0.42	–0.11
5 – P fertiliser / P trąšos					1.00	0.80	–0.22	0.02	–0.69	**0.43**	0.35	–0.11
6 – K fertiliser / K trąšos						1.00	–0.12	0.21	–0.97	0.34	**0.44**	–0.10
Residual effect												0.81

Notes: * and ** show data significance at $P < 0.05$ and $P < 0.01$, respectively; bold – direct effect, underline – dominating effect; P and K changes – in %, soil P and K – in mg kg^{-1}; yield ME – in thousands MJ ha^{-1}; NPK fertilisers – in kg ha^{-1}.
Pastabos: * ir ** duomenys patikimi, esant $P < 0,05$ ir $P < 0,01$ tikimybei; paryškinta – tiesioginis efektas; pabraukta – vyraujantis efektas; P ir K pokyčiai išreikšti %; dirvožemio P ir K – mg kg^{-1}; AE derlius – tūkst. MJ ha^{-1}; NPK trąšos – kg ha^{-1}.

CT and RT tillage systems, respectively. Increased fertilisation rates influenced the further successive increase of yield.

Tillage and fertilisation effects on soil PK status. Tillage and fertilisation created different soil conditions which in turn influenced soil PK content and its changes. A usual regression analysis could not reveal a statistically clear relationship between the indices. For a deeper evaluation of the experimental data, the Path method of statistical analysis was implemented (Fig. 3). This method showed the after-effect of individual factors on soil PK, revealed a clearer causality of these after-effects and the degree of influence of all factors on PK (Table 5). Reciprocity of different factors and an after-effect of one factor on another gave the final result, i. e. a view of a substantial influence of tillage and fertilisation on soil PK status. The correlation coefficient (sum total of the effects) showed the strength of this influence.

The primary status of soil P had a *direct effect* on mobile P changes in the 0–10 cm layer in the CT tillage system during crop rotation (Path coefficient –0.617).

The higher the P content in this layer was registered, the less were the negative changes during rotation. In the RT tillage system this effect was rather pronounced but not dominating (Path coefficient –0.401).

Under the effect of P fertiliser, the negative changes of soil P content tended to decrease. In the NT tillage system, the primary status of soil P had mostly a slight and direct effect on mobile P changes in the 0–10 cm layer and was not dominating (Path coefficient –0.016). The rates of P fertiliser conditioned changes of mobile P content in the 0–10 cm soil layer.

The primary status of soil P had a *direct effect* on mobile P changes in the 10–20 cm soil layer in the CT tillage system during crop rotation (Path coefficient –0.677). The higher P content was determined in this layer, the less were the negative changes during rotation.

In the RT tillage system this effect was rather pronounced but not dominating (Path coefficient –0.361). Under the effect of P fertiliser the negative changes in soil P content tended to decrease. In the NT tillage system the primary status of soil P had the slightest direct effect on mobile P changes in the 10–20 cm soil layer, and it was not dominating (Path coefficient 0.035). The amount of P fertiliser conditioned changes in mobile P content in the 10–20 cm soil layer.

The negative changes in soil mobile K in the CT and RT tillage systems depended on soil primary K status. The higher K content in all arable layer was registered, the less negative changes during rotation were revealed. The primary status of soil K had *no direct effect* on mobile K changes in the 0–10 cm soil layer in the CT tillage system during crop rotation (Path coefficient –0.104). In the RT tillage system this effect was *direct* and dominating (Path coefficient –0.160). In the NT tillage system the primary status of soil K had the slightest *direct and dominating effect* on mobile K changes in the 0–10 cm layer (Path coefficient –0.456). The higher K content in the 0–10 cm layer was registered, the less negative changes during rotation were determined.

The primary status of soil K had *no direct effect* on mobile K changes in the 10–20 cm layer in the CT tillage system during crop rotation (Path coefficient –0.075). In the RT tillage system this effect was *no direct and dominating* (Path coefficient 0.232). In the NT tillage system, the primary status of soil K had the slightest *direct and dominating effect* on mobile K changes in the 10–20 cm soil layer (Path coefficient 0.395), and this effect was different than in CT and RT tillage systems. The higher was K content in the 10–20 cm layer, the higher negative changes during rotation were registered.

A very interesting and complicated action of mineral NPK fertilisers and their influence on soil mobile P changes (on soil mobile K changes too) was determined in these field trials. An increase of mineral NPK rates affected the decrease of soil P and K content in the 0–10 and 10–20 cm layers. Of course, the increase of fertilisation rates determined an increase of total crop rotation productivity and removal of nutrients from soil with yield as well. However, the correlation between the yields of crop rotation and soil PK content changes was not significant. This shows that the rates of mineral NPK fertilisers in a direct drilling system should be higher than in plough-based tillage.

CONCLUSIONS

1. The pre-established agro-technological measures had a similar effect on the character of P content changes in the arable layer of *fertile* soil: there was registered a regular decrease in P content. However, direct drilling led to a fast and great decrease in P content in the 0–10 cm soil arable layer compared to traditional and shallow ploughing tillage systems on an inherently fertile soil.

2. Different fertilisation rates in combination with direct drilling on *moderately fertile* soil resulted in a pronounced P content stratification in different soil layers: P increase in the 0–10 cm arable layer as compared with the 10–20 cm one.

3. Direct drilling in combination with different fertilisation rates on both fertile and moderately fertile soils led to K stratification in different soil layers: a marked increase in the 0–10 cm arable layer as compared with the 10–20 cm one.

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References

1. Andraski T. W., Bundy L. G., Kilian K. C. Manure history and long-term tillage effects on soil properties and phosphorus losses in runoff // Journal of Environmental Quality 2003. Vol. 32. P. 1782–1789.
2. Blake L., Hesketh N., Fortune S., Brookes P. C. Assessing phosphorus ‘Change-Points’ and leaching potential by isotopic exchange and sequential fractionation // Soil Use and Management. 2002. Vol. 18. P. 199–207.
3. Buah S. S. J., Polito T. A., Killorn R. No-tillage soybean response to banded and broadcast and direct and residual fertilizer phosphorus and potassium applications // Agronomy Journal. 2000. Vol. 92. P. 657–662.
4. Catt J. A., Johnston A. E., Quinton J. N. Phosphate losses in the Woburn Erosion Reference Experiment. In: Tunney H., Carlton O. T., Brookes P. C., Johnston A. E. (Eds.). Phosphorus Loss From Soil to Water. CAB International, Wallingford, UK, 1997. P. 374–377.
5. Crozier C., Naderman G., Tucker M. R., Sugg R. E.. Nutrient and pH stratification with conventional and no-till management // Communications in Soil Science and Plant Analysis. 1999. Vol. 30. P. 65–74.
6. Feiza V., Feiziene D., Riley H. C. F.. Soil available P and P offtake responses to different tillage and fertilisation systems in the hilly morainic landscape of western Lithuania // Soil and Tillage Research. 2003. Vol. 74. P. 3–14.
7. Gaston L. A., Drapcho C. M., Tapadar S., Kovar J. L. Phosphorus runoff relationships for Louisiana coastal plain soils amended with poultry litter // Journal of Environmental Quality. 2003. Vol. 31. P. 1422–1429.

8. Heathwaite A. L. Sources and pathways of phosphorus loss from agriculture. In: Tunney H., Carlton O. T., Brookes P. C., Johnston A. E. (Eds.). Phosphorus Loss from Soil to Water. CAB International, Wallingford, UK, 1997. P. 205–223.
9. Heckrath G., Brookes P. C., Poulton P. R., Goulding K. W. T. Phosphorus leaching from soils containing different phosphorus concentrations in the Broadbalk experiment // Journal of Environmental Quality. 1995. Vol. 24. P. 904–910.
10. Hesketh N., Brookes P. C. Development of an indicator for risk of phosphorus leaching // Journal of Environmental Quality. 2000. Vol. 29. P. 105–110.
11. Holanda F. S. R., Mengel D. B., Paula M. B., Carvado J. G., Bertoni J. C. Influence of crop rotations and tillage systems on phosphorus and potassium stratification and root distribution in soil profile // Communications in Soil Science and Plant Analysis. 1998. Vol. 29. P. 2383–2394.
12. Howard D. D., Essington M. E., Tyler D. D. Vertical phosphorus and potassium stratification in no-till cotton soils // Agronomy Journal. 1999. Vol. 91. P. 266–269.
13. Howse K. R., Catt J. A., Brockie D., Nicol R. A. C., Farina R., Harris G. L., Pepper T. J. Phosphorus leaching in the Brimstone Experiment, Oxfordshire. In: Tunney H., Carlton O. T., Brookes P. C., Johnston A. E. (Eds.). Phosphorus Loss From Soil to Water. CAB International, Wallingford, UK, 1997. P. 370–372.
14. Yin X. H., Vyn T. J. Residual effect of potassium placement for conservation-till corn on subsequent no-till soybean // Soil and Tillage Research. 2004. Vol. 75. P. 151–159.
15. Karathanasis A. D., Wells K. L. Conservation tillage effects on the potassium status of some Kentucky soils // Soil Science Society of America Journal. 1990. Vol. 54. P. 800–806.
16. Kleinman P. J. A., Sharpley A. N. Estimating soil phosphorus sorption saturation from Mehlich-3 data // Communications // Soil Science and Plant Analysis. 2002. Vol. 33. P. 1825–1839.
17. Mažvila J., Vaišvila Z. Fosforas. In: Mažvila J. (Ed.). Lietuvos dirvožemių agrocheminės savybės ir jų kaita. Kaunas: Petro ofsetas, 1998. P. 64–77.
18. Mažvila J., Vaišvila Z. Kalis. In: Mažvila J. (Ed.). Lietuvos dirvožemių agrocheminės savybės ir jų kaita. Kaunas: Petro ofsetas, 1998. P. 84–100.
19. Sharpley A. N., Rekolainen S. Phosphorus in agriculture and its environmental implications. In: Tunney H., Carlton O. T., Brookes P. C., Johnston A. E. (Eds.). Phosphorus Loss From Soil to Water. CAB International, Wallingford, UK, 1997. P. 1–54.
20. Sharpley A. N. Soil mixing to decrese surface stratification of phosphorus in manured soils // Journal of Environmental Quality. 2003. Vol. 32. P. 1375–1384.

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ŽEMĖS DIRBIMO IR TRĘŠIMO ĮTAKA JUDRIESIEMS PK SKIRTINGUOSE VIDURIO LIETUVOS DIRVOŽEMIUOSE

S a n t r a u k a

Lietuvos žemdirbystės institute 1999–2005 m. vykdyti du dvifaktoriniai bandymai. Dirvožemis (*Endocalcari-Epihypogleyic Cambisol*) – lengvo priemolio giliau karbonatingas sekliai glėjiškas rudžemis, maisto elementų turtingas (1 bandymas) ir vidutiniškai turtingas (2 bandymas). Žemės dirbimo ir tręšimo (pagal dirvožemio savybes ir planuojamą derlų) tyrimai 5 narių sėjomainos rotacijoje parodė, kad tręšimo normos negali būti vienodos skirtingose žemės dirbimo sistemose ir skirtingo našumo dirvožemiuose.

Augalų maisto medžiagų turtingame dirvožemyje naudotos agronominės priemonės turėjo panašią įtaką viso armens fosforingumo pokyčiams: nustatytas nuoseklus fosforingumo mažėjimas. Tačiau tiesioginė sėja lėmė ryškesnį P kiekio visame armenyje mažėjimą, palyginus su tradiciniu ar supaprastintu žemės dirbimu.

Nepriklausomai nuo tręšimo lygio, augalų maisto medžiagų turtingame ir vidutiniškai turtingame dirvožemiuose tiesioginės sėjos taikymas lėmė fosforo ir kalio pasiskirstymą skirtinguose sluoksniuose: labai ženklų šių elementų padaugėjimą 0–10 cm sluoksnyje, palyginus su 10–20 cm sluoksniu.

Raktažodžiai: žemės dirbimas, judrieji PK, tręšimas, dirvožemio našumas

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ВЛИЯНИЕ ОБРАБОТКИ ПОЧВЫ И УДОБРЕНИЙ НА СОДЕРЖАНИЕ ПОДВИЖНОГО ФОСФОРА И КАЛИЯ НА РАЗЛИЧНЫХ ПОЧВАХ ЦЕНТРАЛЬНОЙ ЛИТВЫ

Р е з ю м е

В Литовском институте земледелия в 1999–2005 гг. проводились два двухфакторных опыта. Почва (*Endocalcari-Epihypogleyic Cambisol*) дерново-глееватая легкосуглинистая, богатая питательными элементами (1-ый опыт) и среднеобеспеченная (2-ой опыт). Опыты по обработке почвы и применению удобрений (по свойствам почвы и планируемому урожаю) в пятипольном севообороте показали, что нормы удобрений не могут быть одинаковыми при применении различных систем обработки почвы и различной продуктивности почв.

На почвах высокой продуктивности применение различных систем обработки почвы одинаково влияли на изменение фосфорного обеспечения пахотного слоя: установлено последовательное снижение содержания подвижного фосфора. Однако прямой посев в стерню обеспечивал более заметное снижение содержания фосфора всего пахотного слоя по сравнению с традиционной и минимальной обработками почв.

Независимо от уровня удобрения на почвах, богатых питательными элементами, и среднеобеспеченных почвах применение прямого посева обеспечило распределение фосфора и калия в различных слоях пахотного горизонта: повышение содержания этих элементов было более заметно в слое 0–10 см, чем в слое 10–20 см.

Ключевые слова: обработка почвы, подвижные фосфор и калий, удобрение, продуктивность почвы