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THE EFFECT OF SOIL PH AND NUTRIENT CONTENT ON CROP YIELD AND WEED INFESTATION IN THE CROP ROTATION

Steponas ČIUBERKIS, Donatas KONČIUS

Lithuanian Institute of Agriculture
Vėžaičiai, Klaipėda district
E-mail: stepas@vezaiciai.lzi.lt

Abstract

The aim of the present study was to investigate the effect of different soil pH levels, nutrient content and its interaction on the crop productivity in a rotation and on crop weed infestation. During the period 1976-2005 after initial and periodical liming such average soil pH levels of the sixth rotation were formed (2000-2005): 4.1; 5.1; 5.4; 5.9; 6.2 and 6.6. The amount of mobile phosphorus / potassium in the sixth crop rotation was on average 70 / 130 mg kg^{-1} soil in unfertilized plots. After systematic crop fertilization with single, double, triple rates of mineral fertilizers the content of phosphorus / potassium increased to 120 / 210, 190 / 280 and 280 / 310 mg kg^{-1} soil respectively. A high grain yield of barley was produced in the plots with pH 6.6 and phosphorus / potassium content 280 / 310 mg kg^{-1} soil. Winter wheat grain yield increased with declining soil acidity to pH 5.4 and increasing P_2O_5 / K_2O to 190 / 280 mg kg^{-1} soil. A high yield of spring rape seed was obtained in the plots with pH 6.6 and 280 / 310 mg kg^{-1} P_2O_5 / K_2O in the soil. The highest content of metabolisable energy was accumulated in the soil plots with pH 5.9, and a high productivity was achieved in the plots with the content of phosphorus / potassium 280 / 310 mg kg^{-1} soil. With a reduction in soil pH from 4.1 to 6.6 weed infestation consistently declined in all crops (R = -0.71). Different nutrient content in the soil did not have any significant effect on cereal and spring rape weed infestation.

Key words: liming, pH, nutrients, crop rotation, fertility, weed infestation.

Introduction

Most of Lithuanian albeluvisols and luvisols are acid by nature. The experimental evidence obtained in Lithuania and other countries suggests that the major means for these soils taming are liming, organic and mineral fertilization /Plesevičius, 1995; Conyers et al., 2003/. Liming of acid soils resulted in significant changes in soil properties. Natural soil formation (pedogenic) processes are continuously occurring in nature, one of which is soil acidification. This process is promoted in agrosystems by abiotic and anthropogenic factors: acid precipitation, crop and soil management practices, application of physiologically acid mineral fertilizers, Ca, Mg and other elements leaching and removal with yield /Šilnikov et al., 1997; Čiuberkienė, Ežerinskas, 2000; Kurek, 2002/. The level of soil acidification in Poland's conditions, like in Lithuania, depends mainly on the mother rock, climate and biocenose /Kaczor, 2002/. This all results in a continual soil chemical and biological degradation /Douglas, 2000/. Consequently, in order to conserve soil productivity, periodical liming is indispensable

/Plesevičius, 1995; Čiuberkienė et al., 2003/. However, in recent years due to the shortage of funds only about 10 % of land area that needs liming has received lime, and albeluvisols have limited calcium reserves in the topsoil /Lietuvos dirvožemių savybės..., 1998/. As a result, the area of acid soils is increasing steadily, since topsoil loses 120-200 kg ha^{-1} of calcium annually /Mažvila et al., 2000/. Soil liming not only neutralises mobile aluminium, which is one of the most toxic elements to plants, but also causes changes in agrochemical properties, nutrient content and uptake, humus qualitative composition /Arlauskienė, 1996; Švedas, 2000/.

The relationship between phytocenosis productivity and soil acidity level is rather complex. Soil acidity affects the soil not so much directly as through nutrition links by changing mobility of macro and micro-elements, their sorption capacity and fertilizer efficacy /Švedas, 2000/. Therefore to achieve stable yields and competitive production it is important to know the optimum pH level necessary for various crops and crop rotations since different plants respond differently to acid soils and differently uptake the nutrients present in the soil.

Soil, its properties, agroclimatic conditions and fertilization exert many-sided effects on weed flora, weed population abundance in an agrophytocenosis /Salonen, 1993; Monstvilaitė, 1996; Forcella, 1998/. Some weed species can serve as indicators of soil properties. Some weeds tolerate well deficiency of Ca in the soil while others make a better use of fertilizers than cultivated crops. Still others are shade-intolerant and can be choked out by better-performing cultivated crops grown on a limed soil.

Based on the data from the long-term fixed trials, we sought to assess the effects of anthropogenic factors, i. e. various pH and different nutrient content on the productivity of agrocenosis, intensity of the processes occurring in the soil.

The aim of the present study was to establish the effects of different pH and nutrient contents in the soil, formed after primary and periodical liming, as well as the impact of fertilization on the long-term trial productivity of agrocenosis and weed infestation level in the crops.

Materials and Methods

The long-term trial was established at the Lithuanian Institute of Agriculture's Vėžaičiai Branch. The experiment was conducted on a *Dystric Albeluvisol* (ABd) light sandy loam soil. The topsoil before establishment of the experiment was acid pH_{KCl} 4.1-4.4, hydrolytic acidity 47-59 meq kg^{-1}, base saturation level 28-37 %, mobile aluminium 50-77 mg kg^{-1} soil. The soil was low in phosphorus and high in potassium: 95-104 and 255-267 mg kg^{-1} soil, respectively, humus content about 2 %. By liming we aimed to adjust very acid soil to such planned six levels pH_{KCl} (factor A): 1) < 4.7 (unlimed), 2) 4.7-5.2; 3) 5.2-5.7; 4) 5.7-6.2; 5) 6.2-6.7 and 6) > 6.7. Such soil acidity levels were achieved after incorporation of 2.0; 3.4; 6.9; 12.9; 44.1 t ha^{-1} pulverized limestone into the soil in 1976. Seeking to maintain the planned soil pH levels, experimental plots were additionally limed after each rotation in the autumn. During the period 1976-2005 such average soil pH_{KCl} levels were formed in the sixth rotation after periodical liming: 4.1; 5.1; 5.4; 5.9; 6.2 and 6.6.

The sixth five-course crop rotation was as follows: 1) spring rape 'Sponsor' (*Brassica napus annua* L.), 2) spring barley 'Ula' (*Hordeum vulgare* L.), 3) red clover

'Liepsna' (*Trifolium pratense* L.), 4) winter wheat 'Širvinta' (*Triticum aestivum* Host.), 5) spring barley 'Ula' (*Hordeum vulgare* L.). Mineral fertilizers – ammonium nitrate (NH_4NO_3), superphosphate ($Ca(H_2PO_4)_2 + 2CaSO_4$) and potassium chloride (KCl) in these experimental plots were used according to the following design (factor B): without fertilizers, single, double and triple rates of NPK. Single mineral fertilizer rate (N P_2O_5 K_2O or NPK for short) for spring rape was $N_{70}P_{60}K_{90}$, for spring barley and winter wheat $N_{45}P_{30}K_{45}$, for red clover $P_{45}K_{60}$. The amounts of mobile phosphorus and potassium increased in the plots after systematic fertilization by different rates of mineral fertilizes of crops during the period 1976-2005. The amount of mobile phosphorus / potassium in the sixth crop rotation (2001-2005) was on average: in unfertilized plots 70 / 130 mg kg^{-1} of soil (low content of nutrients), and after application of single, double, triple rates of mineral fertilizers increased to 120 / 210, 190 / 280, and 280 / 310 mg kg^{-1} of soil, respectively.

The initial plot size was: length 16 m, width 10 m, record plot 14×8 m.

Weed flora was assessed in 4 (0.5×0.5 m) quadrates per plot at the end of May – first ten-day of June, i. e. at tillering stage of cereals, in perennial grasses before the first cut. To determine the weed infestation in the crops, the assessed quadrates were covered with a polyethylene sheet before herbicide application.

Soil samples were taken by an auger from the 0-20 cm layer in 20 places per plot annually after harvesting. The soil samples were analysed using the following techniques: pH_{KCl} by electrometric method using a glass electrode, mobile aluminium by Sokolov, total absorbed bases by Kappen-Hilcovich, mobile phosphorus and potassium by A-L. The content of metabolisable energy (GJ) was calculated using the data presented in the references /Tamulis, 1986/.

Statistical data analysis was done using the software ANOVA for Excel vers. 4.0. The level of significance of differences between all treatments was estimated by the least significant difference (LSD) test. Regression analysis was applied to establish the relationship between weed flora and soil pH. The data of weed number were transformed by sqr (x+1) and ANOVA analysis was used. The data were back transformed for presentation.

Results and Discussion

Crop productivity. The soil acidity level and content of nutrients in the soil had a different effect on crop yield in a rotation. In unlimed, acid soil cereal grain yield was very low, and fertilization, especially for barley which required calcium-rich soil /Liu et al., 2004/ was ineffective (Table, interaction factors A×B). The highest grain yield of barley, which is a calciphilic crop, was produced in the plots with pH 6.6, the yield increased by 1.56 t ha^{-1} compared with unlimed soil (Table, factor A). In the soil with close to neutral acidity (pH 6.6) and P_2O_5 / K_2O content 280 / 310 mg kg^{-1} soil it was optimal to fertilize barley with $N_{135}P_{90}K_{135}$ in 2002, whereas in 2005 the same grain yield (2.35 t ha^{-1}) was obtained when barley had been fertilized with $N_{45}P_{30}K_{45}$. The highest yield of barley was obtained in the plots with P_2O_5 / K_2O content 280 / 310 mg kg^{-1} soil, or the yield increase made up 1.22 and 0.80 t ha^{-1} in 2002 and 2005, respectively, compared with unfertilized plots (Table, factor B). Winter wheat grain yield increased with declining soil acidity to pH 5.5 and was higher by 190 % and in the plots with 190 /

280 mg kg^{-1} soil P_2O_5 / K_2O was higher by 102 %, compared with unlimed and unfertilized soil. However, some authors maintain that winter wheat is more sensitive to soil acidity than oats or barley /Knašys, 1985; Jankauskas and Otabbong, 2004/. With a further increase in pH value the yield did not increase further and it was rational to fertilize winter wheat with $N_{90}P_{60}K_{90}$. In less acid soil with more intensive winter wheat fertilization the grain yield did not increase due to the lodging which occurred during the wet summer. Spring rape required a fertile soil and heavy mineral fertilization /Velička, 2002/. In our investigations the highest yield of spring rape was obtained in the soil with pH 6.6 and P_2O_5 / K_2O content 280 / 310 mg kg^{-1} soil, i. e. fertilizing by $N_{210}P_{180}K_{270}$ (Table, factors A and B). The rape yield increased by 45 and 57 %, respectively compared with unlimed and unfertilized plots.

The influence of pH_{KCl} and nutrient content (P_2O_5 / K_2O) in the soil on the crop yield of the rotation, t ha^{-1}

Sėjomainos augalų derlingumo t ha^{-1} priklausomumas nuo dirvožemio rūgštumo ir maisto medžiagų kiekio jame

Vėžaičiai, 2001-2005

Treatment *Variantas*		Spring rape, seed *Vasariniai rapsai, sėklos,* 2001	Spring barley, grain *Miežiai, grūdai,* 2002	Perennial grasses, DM *Daugiametės žolės, saus. medž.,* 2003	Winter wheat, grain *Žieminiai kviečiai, grūdai,* 2004	Spring barley, grain *Miežiai, grūdai,* 2005
pH_{KCl}	P_2O_5 / K_2O					
1	2	3	4	5	6	7
pH_{KCl} factor A / *pH_{KCl} A veiksnys*						
4.1		1.35	0.59	5.32	0.84	0.50
5.1		1.54	1.68	6.37	2.09	1.70
5.4		1.68	1.89	6.65	2.44	1.57
5.9		1.77	1.99	6.53	2.62	1.88
6.2		1.88	1.83	6.53	2.69	1.95
6.6		1.96	2.15	6.87	2.88	2.15
	LSD_{05} / *R_{05}*	0.101	0.279	0.462	0.258	0.120
Content of P_2O_5 / K_2O in soil – factor B / *P_2O_5 / K_2O kiekis dirvožemyje – B veiksnys*						
	70 / 130	1.29	1.03	5.85	1.34	1.06
	120 / 210	1.67	1.58	6.54	2.25	1.69
	190 / 280	1.79	1.89	6.40	2.71	1.88
	280 / 310	2.03	2.25	6.74	2.73	1.86
	LSD_{05} / *R_{05}*	0.082	0.228	0.377	0.010	0.098
Interaction of A×B factors / *A×B veiksnių sąveika*						
4.1	70 / 130	1.14	0.51	4.99	075	0.50
	120 / 210	1.36	0.72	5.20	0,94	0.52
	190 / 280	1.39	0.66	5.12	1.03	0.55
	280 / 310	1.50	0.47	5.96	0.62	0.42

Table continued
Lentelės tęsinys

1	2	3	4	5	6	7
5.1	70 / 130	1.22	0.93	5.73	1.25	1.07
	120 / 210	1.49	1.35	5.92	2.11	1.68
	190 / 280	1.59	2.33	6.79	2.72	2.06
	280 / 310	1.87	2.13	7.04	2.27	1.98
5.4	70 / 130	1.27	0.94	6.24	1.11	0.90
	120 / 210	1.68	1.87	7.38	2.45	1.51
	190 / 280	1.81	2.26	6.91	3.46	1.97
	280 / 310	1.95	2.47	6.07	2.73	1.90
5.9	70 / 130	1.32	1.37	5.85	1.38	0.95
	120 / 210	1.74	2.12	6.82	2.34	2.10
	190 / 280	1.85	1.81	5.67	3.29	2.35
	280 / 310	2.20	2.64	7.79	3.47	2.13
6.2	70 / 130	1.30	1.15	5.88	1.63	1.52
	120 / 210	1.85	1.46	7.04	2.49	1.98
	190 / 280	2.06	1.99	6.53	2.80	2.03
	280 / 310	2.29	2.72	6.68	3.82	2.26
6.6	70 / 130	1.46	1.27	6.42	1.91	1.45
	120 / 210	1.94	1.98	6.85	3.14	2.35
	190 / 280	2.04	2.28	7.35	2.98	2.33
	280 / 310	2.38	3.05	6.88	3.49	2.46
	LSD_{05} /R_{05}	0.202	0.559	0.924	0.515	0.239

The data averaged over 6 rotations showed that with declining soil acidity crop rotation productivity increased. The highest content of metabolisable energy 57.8 GJ was accumulated in the soil with pH 5.9 (Fig. 1). Annual yield increase amounted to 22.9 GJ ha^{-1}, or 58 %, compared with unlimed soil, and the highest productivity was achieved in the plots with phosphorus / potassium content 280 / 310 mg kg^{-1} soil, or average fertilization over rotation was $N_{135}P_{117}K_{171}$ (Fig. 1). With the highest reduction in soil acidity (pH > 6.1) resulting from liming, there was observed a trend of crop rotation productivity increasing.

Weed infestation of crops. Soil acidity and fertilization had one-to-many effects on weed infestation in the crops. With a reduction in soil pH from 4.1 to 6.6, the weed infestation consistently declined in all crops (Fig. 2, factor A). The number of weeds decreased by 32 % in spring barley (2002) in the plots with soil pH 5.1. There was established a nonlinear correlation between soil pH and the number of weeds (R = -0.71).

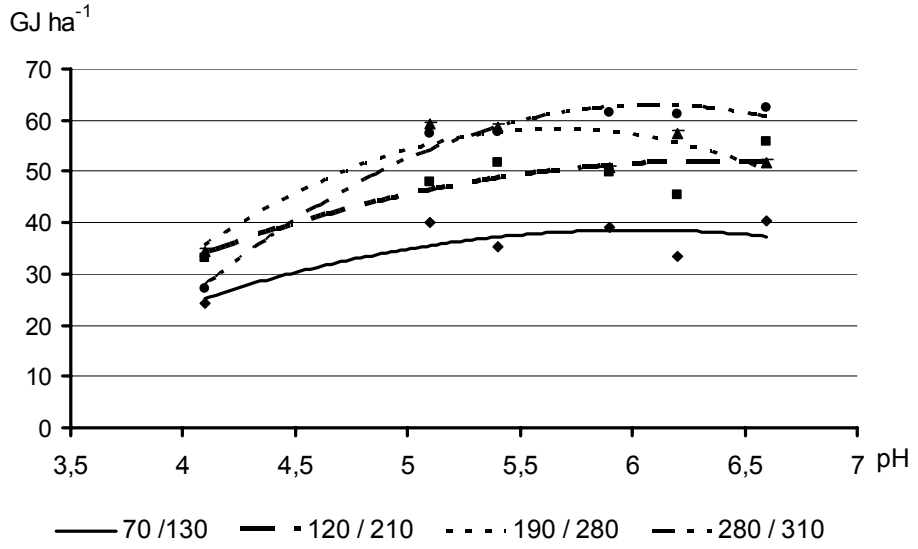
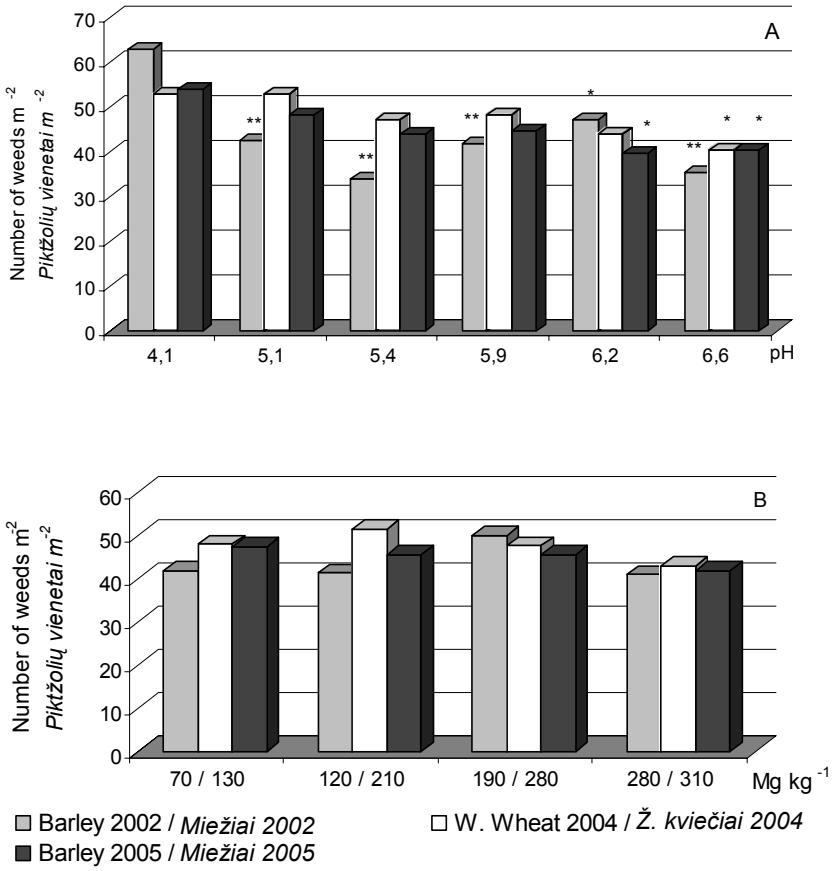


Figure 1. The relationship between metabolisable energy and soil pH and nutrient content (P_2O_5 / K_2O) in the soil

1 paveikslas. *Apykaitos energijos kiekio priklausomumas nuo dirvožemio pH_{KCl} ir maisto medžiagų (P_2O_5 / K_2O) kiekio jame*

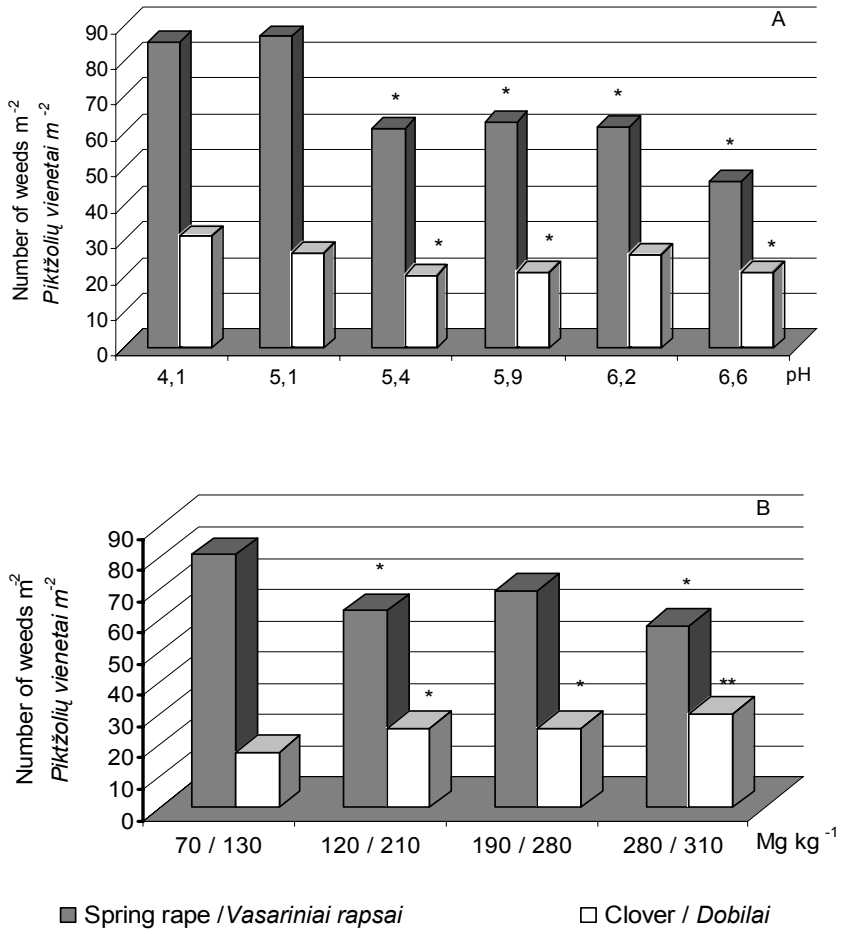
In spring barley grown in 2005 there was established a linear correlation between pH and the number of weeds (R = -0.96) and in the plots with pH 6.2-6.6 the number of weeds decreased by 25-27 % (Fig. 2, factor A). The greatest reduction in weed number under the effect of liming occurred in barley crop because improved soil agrochemical properties resulted in a dense stand and better competitive power. Winter wheat weed infestation decreased only in the plots with soil pH 6.6 (R = -0.90). Weed infestation of spring rape and red clover in the plots with pH 5.4 declined by 28 % and 35 % respectively, and yet reduction of soil pH to 6.6 did not result in a significant reduction in the number of weed compared with pH 5.4 plots (Fig. 3, factor A). Different content of nutrients in the soil did not have any significant effect on cereal weed infestation (Fig. 1, factor B). This may be explained by the conditions in spring and competitive power of cereals to weeds. In the plots with higher mobile phosphorus and potassium status the number of *Spergula arvensis* L. and *Scleranthus annuus* L. consistently decreased, while the number of *Chenopodium album* L.*, Tripleurospermum perforatum* (Merat) M. Lainz increased in the crop stands. The weed infestation of spring rape crop declined in the plots where the content of mobile phosphorus and potassium was 120 / 210 and 280 / 310 mg kg^{-1} soil (Fig. 3, factor B).



*,** Significant at the 0.05 and 0.01 levels, respectively
Patikimumo lygis atitinkamai 0,05 ir 0,01

Figure 2. The effect of soil pH_{KCl} (A) and nutrient content (P_2O_5 / K_2O, B) in the soil on weed infestation of cereals
2 paveikslas. *Javų pasėlių piktžolėtumo priklausomumas nuo dirvožemio rūgštumo ir maisto medžiagų kiekio jame*

Different weed species responded differently to the variation of soil acidity as affected by liming and fertilization. Under the effect of liming, with the variation of soil pH from 4.1 to 6.6 a consistent reduction in weed incidence occurred in the crop rotation. At soil pH 6.6, the number of weeds in the rotation was by on average 48 % lower compared with the crops in unlimed soil (pH 4.1). The number of *Scleranthus annuus* L. and *Spergula arvensis* L. declined by as much as 95 %, which determined the reduction in the total number of weeds. Improvement in plant growth ecological conditions resulted in an increase in the competitive power of cultivated crops after liming. However, with reducing soil acidity the number of *Chenopodium album* L, *Tripleurospermum perforatum* (Merat) M. Lainz almost consistently increased.



*,** Significant at the 0.05 and 0.01 levels, respectively
Patikimumo lygis atitinkamai 0,05 ir 0,01

Figure 3. The effect of soil pH_{KCl} (A) and nutrient content (B) in the soil on weed infestation in spring rape and red clover stands
Paveikslas 3. *Vasarinių rapsų ir raudonųjų dobilų pasėlių piktžolėtumo priklausomumas nuo dirvožemio pH_{KCl} (A) ir maisto medžiagų gausumo jame (B)*

When fertilizing the crops with $N_{82}P_{78}K_{114}$, $N_{135}P_{117}K_{171}$, the number of weeds significantly increased (by 12-16 %), including *Chenopodium album* L, *Tripleurospermum perforatum* (Merat) M. Lainz by 65-100 and 36-48 %, respectively, irrespective of the fact that the number of *Scleranthus annuus* L. and *Spergula arvensis* L. declined by 27-31 % (data not presented).

Conclusions

1. Initial (1976) and periodical liming after each rotation formed the following soil pH levels in the sixth rotation (2000-2005): 4.1; 5.1; 5.4; 5.9 and 6.6. The amount of mobile P_2O_5 / K_2O in unfertilized plots increased from 70 / 130 mg kg^{-1} soil after application of single, double and triple rates of mineral fertilizers to 120 / 210, 190 / 280 and 280 / 310 mg kg^{-1} soil, respectively.

2. A highest barley grain yield was produced in the plots with pH 6.6 and phosphorus / potassium content 280 / 310 mg kg^{-1} soil. Winter wheat grain yield increased with declining soil acidity to pH 5.4 and increasing P_2O_5 / K_2O to 190 / 280 mg kg^{-1} soil. A high spring rape seed yield was obtained in the plots with pH 6.6 and P_2O_5 / K_2O 280 / 310 mg kg^{-1} soil.

3. The highest content of metabolisable energy (61.60 GJ) was accumulated in the soil plots with pH 6.0 and a highest productivity was achieved in the plots with phosphorus / potassium content 280 / 310 mg kg^{-1} soil.

4. With a change in the soil pH from 4.1 to 6.6 the weed infestation declined in the rotation for all crops (R = -0.71). Different nutrient content in the soil did not exert any significant effect on the weed infestation in cereal and spring rape crops because the number of acidophilic weeds decreased and the number of nitrophilous weeds increased.

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SĖJOMAINOS AUGALŲ DERLIAUS IR PIKTŽOLĖTUMO PRIKLAUSOMUMAS NUO DIRVOŽEMIO RŪGŠTUMO IR GAUSUMO JAME MAISTO MEDŽIAGŲ

S. Čiuberkis, D. Končius

Santrauka

Tyrimų tikslas – ištirti skirtingo dirvožemio rūgštumo ir gausumo jame maisto medžiagų bei jų sąveikos įtaką sėjomainos augalų produktyvumui ir pasėlių piktžolėtumui. 1976-2005 m. po pagrindinio ir periodinio kalkinimo po kiekvienos rotacijos susiformavo šeštoje rotacijoje (2000-2005) tokie dirvožemio pH lygiai: 4,1; 5,1; 5,4; 5,9; 6,2 ir 6,6. Pasėlių netręšiant, šeštos rotacijos laukeliuose buvo 70 / 130 mg kg^{-1} dirvožemio P_2O_5 / K_2O. Sėjomainos augalus sistemingai tręšiant vienguba, dviguba ir triguba normomis NPK, dirvožemyje judriųjų fosforo ir kalio padaugėjo atitinkamai iki 120 / 210, 190 / 280 ir 280 / 310 mg kg^{-1} dirvožemio. Miežių grūdų didžiausias derlius buvo dirvožemyje, kurio pH 6,6 ir 280 / 310 mg kg^{-1} dirvožemio P_2O_5 / K_2O. Žieminių kviečių grūdų derlius didėjo mažėjant dirvožemio rūgštumui iki pH 5,4 ir didėjant P_2O_5 / K_2O kiekiui laukeliuose iki 190 / 280 mg kg^{-1} dirvožemio. Vasariniai rapsai geriausiai derėjo laukeliuose, kuriuose pH buvo 6,6 ir 208 / 310 mg kg^{-1} P_2O_5 / K_2O dirvožemio. Sėjomainos augalai apykaitos energijos daugiausiai (57,8 GJ) sukaupė, kurių pH 5,9 ir fosforo ir kalio buvo 280 ir 310 mg kg^{-1} dirvožemio. Mažėjant dirvožemio rūgštumui nuo pH 4,1 iki pH 6,6, mažėjo visų rotacijos augalų pasėlių piktžolėtumas (R = -0,71). Dirvožemyje esantis maisto medžiagų kiekis neturėjo esminės įtakos javų ir vasarinių rapsų pasėlių piktžolėtumui.

Reikšminiai žodžiai: kalkinimas, pH, maisto medžiagos, sėjomaina, derlingumas, piktžolėtumas.