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The effect of liming and organic fertilisation on the incidence of weeds in the crops of the rotation

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Abstract

To maintain the potential productivity of *Retisol* and produce stable yields of agricultural crops, one has to regularly lime and replenish soil reserves with organic matter. If the necessary amount of manure cannot be accumulated on farms, it is relevant to use other organic fertilisers. The current paper presents the results of long-term manuring experiment that was carried out at the Vėžaičiai Branch of Lithuanian Research Centre for Agriculture and Forestry under humid littoral climatic conditions during the 2015–2019 period. The objective of this study was to determine the influence of liming and organic fertilisation on the changes in weed incidence in the crops of the sustainable crop rotation. The experiment was carried out in the soils differing in acidity: unlimed soil with pH 4.13 and limed soil with pH 5.87. The organic fertilisation treatments were: 1) without organic fertilisers (control); 2) green manure; 3) farmyard manure 40 t ha^{-1}; 4) green manure, on the background of 40 t ha^{-1} farmyard manure; 5) farmyard manure 60 t ha^{-1}; 6) green manure, on the background of 60 t ha^{-1} farmyard manure.

The study found that at the beginning of crop growing season, i.e. during weed germination, soil acidity had significant influence on the total number of weeds, number of weed species as well as percentage of the annual dicotyledonous weeds and acidophilic weeds. The significant impact of interaction of soil acidity and organic fertilisation on weed incidence indices showed up at the maturity stage of crops of the rotation.

Key words: acidophilic weeds, annual weeds, soil pH, weed community dynamics, weed number and dry biomass.

Introduction

Weed community variation results from an interaction of different cropping and pedo-climatic aspects. The productivity of agricultural crops depends on geographical position, soil, level of agriculture and agroclimatic conditions (Čiuberkis, Vilkonis, 2013; Skuodienė et al., 2018). Weeds compete with crops for the resources; therefore, crop loss can reach up to 34% (Oerke, 2006; Mason et al., 2007). The environmental context of croplands is a major driver of weed composition with significant effects of geographic position, altitude and soil parameters: acidity (pH), texture, salt and humus content, $CaCO_3$, P_2O_5, K_2O, Na and Mg, as well as plot location (edge *vs* core position) and surrounding habitat types: arable field, road margin, meadow, fallow and ditch (Nagy et al., 2018).

Soil acidity neutralisation remains by far the most relevant problem and is the major factor affecting most of the agricultural plants all over the world (Rengel, 2015; Kunhikrishnan et al., 2016; Li et al., 2019). To maintain soil potential productivity and produce a stable yield, one has to regularly replenish soil reserves with organic matter and control the intensity of their synthesis and destruction processes (Schrumpf et al., 2013; Veremeenko, Furmanets, 2014; Jokubauskaite et al., 2016).

Manure is one of the most effective organic fertilisers maintaining soil fertility. It activates soil microorganisms (Vilkienė, 2017), enriches the soil with organic matter (Jokubauskaite et al., 2016) and improves soil structure (Repsiene, Karcauskiene, 2016). Manure contains calcium (Ca) and magnesium (Mg) which neutralise soil acidity; however, not in the way as liming does. These agricultural practices cannot interchange one another but supplement (Repsiene, Karcauskiene, 2016). It takes a long time for the influence of farmyard manure to stand out in the processes of soil fertility restoration. A long-term periodic liming in combination with manure application had a significant positive effect on the improvement of chemical properties and water stability of soil aggregates in moraine loam in both upper (Ah) and deeper (ElB) horizons (Repsiene, Karcauskiene, 2016). With an increase in soil pH_{KCl} index by 1 unit, the number of weeds decreased by 64.7 m^{-2} and their mass – by 46.0 g m^{-2} (Repšienė, Skuodienė, 2010).

Farmyard manure can be replaced by organic fertilisers such as green manure, straw or other plant residues which remain after the harvest period. According to Rainys and Rudokas (2003), the greatest amount of organic matter forms from perennial grasses compared

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with the annual grasses, winter and spring cereals. Annual weeds disappear quickly in well-established green manure stands, particularly if the canopy is regularly mown (Sjursen, 2001). Such full season grass-clover leys may increase yields through improved nitrogen (N) supply and through non-nutritional benefits such as improved soil structure, suppression of diseases and weeds, more earthworms and increased mycorrhizal activity (Cherr et al., 2006).

Many authors analyse perennial forage legumes as green manure in crops of the rotation (Talgre et al., 2012; Tamm et al., 2016). It has been documented that in the first year of the organic fertilisers' (manure) effect on winter wheat crops, the weed number strongly correlated with amounts of mobile aluminium (Al), hydrolytic acidity, Ca and Mg as well as pH_{KCl} index. Decreasing amounts of mobile Al, hydrolytic acidity, Ca and Mg and increasing pH_{KCl} index resulted in the decrease in the number of weeds (Repšienė, Skuodienė, 2010).

Fertilisation with farmyard manure, compared to other treatments (green manure), significantly (from 96.5% to 323.8%) increased the number of weeds in organic agricultural system. Farmyard manure application, compared with green manure (except for green manure of white mustard), significantly (from 55.1 to 118.4%) increased the number of weed seedlings in sustainable agricultural system (Bogužas et al., 2010). After inserting the farmyard manure, a minor tendency of the weediness increase remained even in the third year after fertilisation (Arlauskienė, Maikštėnienė, 2004).

According to the literature, the populations of charlock mustard (*Sinapis arvensis* L.), cleavers (*Galium aparine* L.), common chickweed (*Stellaria media* L.) and lamb's quarters (*Chenopodium album* L.) increased after fertilisation with solid cattle manure and green manure (Edesi et al., 2012). Acid soil liming changes weed species composition as well. As a result, this may have influence on crop productivity (Čiuberkis et al., 2006; Hanzlik, Gerowitt, 2011; Colbach et al., 2014; Nagy et al., 2018).

The main topsoil chemical and physical properties exerting a significant negative effect on crop productivity are the acid reaction (pH_{KCl} 4.0), high content (169.7 mg kg^{-1}) of mobile Al and unstable soil structure (Repsiene, Karcauskiene, 2016). The improvement of these characteristics is one of the most important challenges of modern agriculture science under changing climatic conditions. It was hypothesised that liming and organic fertilisation not only with farmyard manure but also with other alternative fertilisers will form favourable nutritional conditions for the agricultural crops; therefore, the number of weeds and their species composition will be decreased.

The aim of the study was to determine the influence of liming and organic fertilisation on the changes in weed incidence in the crops of the sustainable crop rotation.

Materials and methods

Site and soil description. The soil of the experimental site was *Bathygleyic Distric Glossic Retisol* (WRB, 2014) formed on medium-moraine loam. The trial was established in 2015 in a long-term experimental trial (since 1959) of farmyard manure rates. The five-course crop rotation consisted of perennial grasses: red clover cultivar 'Sadūnai' 80% and timothy cultivar 'Žolis' 20% (2015) → winter wheat cultivar 'Širvinta' 220 kg ha^{-1} (2016) → lupine cultivar 'Derliai' 70% and oats cultivar 'Migla' 30% mixture (2017) → winter rape cultivar 'Visby H' 8 kg ha^{-1} (2018) → spring barley cultivar 'Luokė' 200 kg ha^{-1} with undersown perennial grasses: red clover cultivar 'Liepsna' 80% and timothy cultivar 'Žolis' 20% (2019).

Trial factors and treatments. The net plot size was 8.5 × 3 m = 25.5 m^2. The harvested area amounted to 15 m^2 (6 × 2.5 m). The trial was replicated four times. Treatments in the replications were randomised.

Factor A. Soil acidity: 1) unlimed soil, 2) limed soil. Factor B. Organic fertilisation: 1) without organic fertilisers (C – control); 2) green manure (GM); 3) farmyard manure 40 t ha^{-1} (FYM 40); 4) green manure, on the background of 40 t ha^{-1} FYM (GM 40); 5) farmyard manure 60 t ha^{-1} (FYM 60); 6) green manure, on the background of 60 t ha^{-1} FYM (GM 60).

Before trial establishment in 2015, the unlimed soil without organic fertilisers was moderate in organic carbon (C_{org}) content (1.283%), high in mobile phosphorus (P_2O_5), potassium (K_2O) and aluminium (Al) content (233.0, 249.0 and 122.74 mg kg^{-1} soil, respectively), with pH 4.13; the limed soil without organic fertilisers was moderate in C_{org} content (1.373%), high in mobile P_2O_5 and K_2O content (194.7 and 180.3 mg kg^{-1} soil, respectively), with pH 5.87.

The soil was limed systematically: in 1959, the primary liming was done with slaked lime, and in 1964 liming with slaked lime was repeated. In the period of 1985–2005, the soil was limed periodically every 3–4 years in a seven-field rotation by incorporating powder limestone at 2 rates (15 t ha^{-1} $CaCO_3$) chosen according to the soil hydrolytic acidity. Since 2005, liming has been performed every five years (once in a rotation).

In a long-term field experiment starting from 1959 to 2005, 80 and 120 t ha^{-1} FYM were incorporated in two applications divided into equal parts for the seven-course crop rotation (for winter wheat and fodder beet). After the reconstruction of the trial in 2005, 40 and 60tha^{-1} of half-rotted FYM were incorporated in a single application (for winter wheat) in the five-course crop rotation.

The grasses were mown two times per year (2015) at the beginning of flowering of Fabaceae. The first harvest of grasses was used for forage. The following alternative organic fertilisers were employed: on the 12th of August in 2015 the aftermath of perennial grasses was cut at the beginning of flowering stage, disked in at 15 cm and after two weeks ploughed in at 20 cm depth. After wheat harvesting in 2016, two weeks later the straw was chopped, incorporated at 15 cm and due to the rainy weather only in the beginning of November was ploughed in at 20 cm depth. On the 19th of July in 2017, when lupine pods had reached the stage of ripening (BBCH 81), the green mass of lupine-oats mixture was cut, disked in at 15 cm and three weeks later ploughed in at 20 cm depth. In 2018, after oilseed rape harvesting, the stubble and straw were chopped, incorporated at 15 cm and due to the rainy weather only in the beginning of November was ploughed in at 20 cm depth. Green manure and straw were inserted in the 2nd, 4th and 6th treatments, and green manure and straw were removed from the 1st treatment.

In 2015, a single bar of the trial was limed using powder limestone to keep the optimal pH_{KCl} (5.8–6.0). In the plots of the third and the fifth treatments, 40 and 60 t ha^{-1} of FYM, respectively, were spread. Organic fertilisers were incorporated with a disc stubble cultivator (Gard SAS, France).

All treatments were equally fertilised with granular mineral fertilisers (background fertilisation). The rate of $N_{60}P_{60}K_{60}$ was applied for winter wheat and spring barley, $N_{30}P_{60}K_{60}$ – for lupine-oats mixture, $N_{60}P_{90}K_{120}$ – for winter rape. Conventional soil tillage was applied. Before sowing, the grains of winter wheat and spring barley were treated with Kinto (a.i. triticonazole + prochloraze) at a rate of 2 L t^{-1}. Plant protection products (pesticides) were used as well: in 2016, at BBCH 30–31 – Arrat (a.i. dicamba-sodio + tritosulfuron) 0.2 L ha^{-1}, at BBCH 33 – Fastac 50 EC (a.i. alpha-cypermethrin)

0.25 L ha^{-1} + Allegro Super (a.i. krezoksim-methil + epoxiconazol + fenpropimorph) 0.75 L ha^{-1}, at BBCH 71 – Fastac 50 EC (a.i. alpha-cypermethrin) 0.2 L ha^{-1} + Allegro Super (a.i. krezoksim-methil + epoxiconazol + fenpropimorph) 0.75 L ha^{-1}; in 2017, after winter rape sowing – Butisan 400 (a.i. metazachlor) 2.5 L ha^{-1}; in 2018, at BBCH 53 – Avaunt (a.i. indoxacarb) 0.17 L ha^{-1}, four weeks after winter rape harvesting – Barbarian Super 360 (a.i. glyphosate) 3 L ha^{-1}; in 2019, at BBCH 22 – Basagran 480 (a.i. bentazone) 2 L ha^{-1}. In perennial grass sward (2015) and in crops of lupine-oats mixture (2017) herbicides were not used at all.

Methods of analysis. Weed record was performed in stationary areas of 0.25 m^{-2} in size in four positions of every plot. During the growing season, two assessments of weed incidence were performed: the weed incidence in crops of winter wheat and spring barley was determined at the stages of tillering (1st) and wax maturity (2nd), in crops of winter rape – at the stages of shooting (1st) and wax maturity (2nd), while in the mixture of lupine-oats – at the stage of lupine inflorescence emergence (1st) and at the beginning of ripening (2nd). The weeds were counted before herbicide application. During the first assessment, weed species composition was determined; during the second assessment, the weed species composition as well as dry matter (DM) mass was determined. Weeds were cut at the soil surface, and their biomass was weighed by species after the samples had been dried. Weed number was recalculated to weeds m^{-2} and DM mass g m^{-2}. In acid soils dominating weeds: corn spurrey (*Spergula arvensis* L.), annual knawel (*Scleranthus annuus* L.) and red sorrel (*Rumex acetosella* L.), were attributed to the group of acidophilic weeds.

The DM yield of the perennial grasses of the 1st and 2nd cuts was determined by weighing. To determine the percentage of DM in the herbage, fresh grass samples of 0.5 kg were collected from each plot and dried at a temperature of 105°C.

Agrochemical characteristics of the soil were determined on the soil samples taken from the depth of 0–20 cm with a drill from each plot before establishing the experiment: soil acidity was measured by the potentiometric method in the extraction of 1 M KCl (pH_{KCl}) according to standard ISO 10390:2005 (Soil quality - Determination of pH). Mobile P_2O_5 and K_2O in the soil were determined using the Egner-Riehm-Domingo (A-L) method (LVP D-07:2016), mobile Al – according to standard ISO 14254:2018 (Soil quality - Determination of exchangeable acidity using barium chloride solution as extractant).

Agrometeorological conditions. In 2015, the amount of precipitation in spring reached 135%, in summer – 90%, in autumn – 79% of the standard climate normal (SCN). The weather in August was especially warm and dry, the recorded amount of precipitation was only 12.5 mm, or 13.0%, of the SCN; the mean monthly air temperature was 2.4°C higher than the SCN (Fig. 1).

In 2016, the amount of precipitation in spring reached 109%, in summer – 144%, in autumn – 64% of the SCN. Soil humidity conditions for the growth of agricultural plants were optimal during the whole growing season. In 2017, although the amount of precipitation per growing season reached 133% of the SCN, its distribution was uneven: in spring it was by 25% lower, in summer – by 18% lower and in autumn – by 117% higher than the SCN. In 2018, the amount of precipitation in spring reached 79%, in summer – 65%, in autumn – 90% of the SCN. During the growing season, the amount of precipitation was by 8% lower. Soil moisture at the 0–20cm depth on the 23rd of July was lower by 10.26–10.71% than the optimal moisture for plants. In 2019, the amount of precipitation in spring reached 116%, in

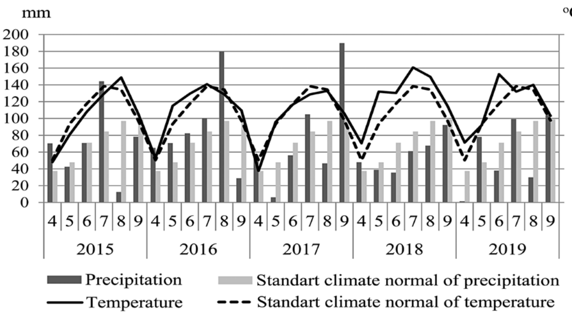


Figure 1. The amount of precipitation (mm) and mean air temperature (°C) during the experimental period (data from the Vėžaičiai Automatic Meteorological Station)

summer – 66%, in autumn – 109% of the SCN. During the growing season, the amount of precipitation was by 9% lower. The weather in June was especially warm and dry, the recorded amount of precipitation was only 37.9 mm, or 53%, of the SCN; the mean monthly air temperature was 4.4°C higher than the SCN.

Statistical analysis. Significance of the differences between the means was determined according to the Fisher's protected least significant difference (LSD) at 0.05 probability level. The data were processed using a two-factor analysis of variance (*ANOVA*) (Raudonius, 2017). Weed incidence data (weed number and DM mass) that did not correspond to the law of normal distribution were transformed before the statistical evaluation using the equation:

$$Y = \sqrt{x + 1},$$

where Y is transformed data of weed density and dry matter mass, x – the primary data; however, means on the original scales are reported.

Results and discussion

To maintain soil fertility and crop productivity, red clover-timothy sward was grown in the rotation (2015). The sustainability of an organic crop rotation frequently depends on the residual effects of legume pre-crops. However, the contribution of legumes varies considerably depending on their species as well as local soil and climatic conditions (Toleikienė et al., 2019).

In the first year of red clover-timothy sward growth, a long-term systematic liming and fertilisation with farmyard and green manure had a major impact on red clover-timothy sward growth and development (Table 1).

The greatest total DM yield of red clover-timothy sward was in limed soil. In unlimed soil without organic fertilisers the yield of red clover-timothy sward was lower by 46.6% compared to limed soil. The greater amount (on the average 42.1%) of clover in DM yield was estimated in limed soil compared to unlimed. Tomchuk (2018) has also indicated a positive liming effect on DM yield of clover-grass swards.

For the green manure, the yield of the red clover-timothy sward of the 2nd cut was used. It amounted to 36.5–77.2% and 46.2–59.6% of the annual yield, respectively, in unlimed and limed soil (Table 2).

The DM yield in limed soil distributed more equally among treatments than in unlimed soil. After the rarefaction of sown grasses, the weeds spread in two treatments of unlimed soil: without organic fertilisers and with green manure or plant residues. In these treatments, *Rumex acetosella* formed the greatest part of weeds: 37.5% and 35.6%, respectively.

In 2017, the lupine-oats mixture was grown to enrich the soil with organic matter and to make it more fertile. The highest DM yield (5.24 t ha^{-1}) of the lupine-oats mixture was in the soil fertilised with 40 t ha^{-1} FYM,

Table 1. Total dry matter (DM) yield of red clover-timothy sward, and the amount of red clover and weed in swards

Organic fertilisation (factor B)	Soil acidity (factor A)					
	unlimed soil			limed soil		
	DM yield t ha^{-1}	clovers %	weeds %	DM yield t ha^{-1}	clovers %	weeds %
Without organic fertilisers (control)	2.84	0.0	90.4	5.32**	92.7	0.4
Green manure	2.62	0.0	79.6	5.49**	92.0	1.1
Farmyard manure 40 t ha^{-1}	4.70**	78.6	0.8	4.08**	92.6	0.8
Green manure, bkgd of 40 t ha^{-1} FYM	4.97**	82.0	1.2	5.99**	91.8	1.0
Farmyard manure 60 t ha^{-1}	4.91**	82.0	1.6	4.47**	92.1	1.0
Green manure, bkgd of 60 t ha^{-1} FYM	4.08**	77.6	1.4	4.73**	91.8	0.2

Note. bkgd – the background of farmyard manure (FYM); ** – differences significant at $P < 0.01$, compared to the unlimed soil without organic fertilisers treatment.

and it was about 10% greater than the yield after insertion of 60 t ha^{-1} FYM (Table 2). The lowest DM yield (3.36 t ha^{-1}) of the lupine-oats mixture was in unlimed soil without organic fertilisers.

A long-term fertilisation with farmyard manure and organic fertilisers in moraine loam *Bathygleyic Distric Glossic Retisol* unequally affected the amount and DM mass of weeds in crops of the rotation. The

Table 2. Dry matter yield of plants used for the green manure

Organic fertilisation (factor B)	Soil acidity (factor A)			
	unlimed soil		limed soil	
	red clover-timothy sward	lupine-oats mixture	red clover-timothy sward	lupine-oats mixture
Without organic fertilisers (control)	1.24	3.36	1.88*	4.28
Green manure	1.06	3.52	1.74	4.41
Farmyard manure 40 t ha^{-1}	1.26	4.53*	1.51	5.24**
Green manure, bkgd of 40 t ha^{-1} FYM	2.06**	4.51*	1.86*	5.13**
Farmyard manure 60 t ha^{-1}	1.90*	4.53*	1.53	4.72*
Green manure, bkgd of 60 t ha^{-1} FYM	1.32	4.24	1.52	5.01**

Note. bkgd – the background of farmyard manure (FYM); * and ** – differences significant at $P < 0.05$ and $P < 0.01$, respectively, compared to the unlimed soil without organic fertilisers treatment.

data of the analysis showed that, according to *F*-test, soil acidity (factor A) had the significant impact on weediness of crops of the rotation (weed number and DM mass, number of weed species, percentage of annual and acidophilic weeds) throughout the growing season, except for the annual weeds at the shooting stage of crops of the rotation (Table 3).

Table 3. Significance of the effect of soil acidity and organic fertilisation for weed incidence according to *F*-test

Assessment	Indicators of weed incidence	Year	Action and interaction of factors		
			A	B	A × B
1st	Number of weeds m^{-2}	2016	**	ns	ns
		2017	**	ns	ns
		2018	*	ns	ns
		2019	**	ns	*
	Number of weed species m^{-2}	2016	*	ns	ns
		2017	**	ns	ns
		2018	ns	ns	ns
		2019	*	ns	ns
	Annual weeds %	2016	ns	ns	ns
		2017	ns	ns	ns
		2018	ns	ns	ns
		2019	ns	ns	ns
	Annual dicotyledonous weeds %	2016	*	ns	ns
		2017	ns	ns	ns
		2018	**	ns	ns
		2019	ns	ns	ns
	Acidophilic weeds %	2016	**	ns	*
		2017	**	*	ns
		2018	**	ns	ns
		2019	**	ns	ns
2nd	Number of weeds m^{-2}	2016	**	*	*
		2017	**	ns	ns
		2018	**	ns	*
		2019	**	**	**
	Dry matter mass of weeds g m^{-2}	2016	**	**	**
		2017	**	ns	ns
		2018	**	**	**
		2019	**	**	**
	Number of weed species m^{-2}	2016	**	ns	**
		2017	**	ns	ns
		2018	ns	ns	ns
		2019	**	**	*
	Annual weeds %	2016	**	**	**
		2017	**	ns	ns
		2018	ns	ns	*
		2019	*	ns	ns
	Annual dicotyledonous weeds %	2016	*	ns	ns
		2017	ns	ns	ns
		2018	**	ns	ns
		2019	ns	ns	ns
	Acidophilic weeds %	2016	**	**	**
		2017	**	**	ns
		2018	**	*	ns
		2019	**	**	**

* and ** – differences significant at $P < 0.05$ and $P < 0.01$, respectively; ns – not significant

The impact of interaction of investigated factors on weed number and DM mass, number of weed species and percentage of the acidophilic weeds in some cases showed up at the maturity stage of crops of the rotation.

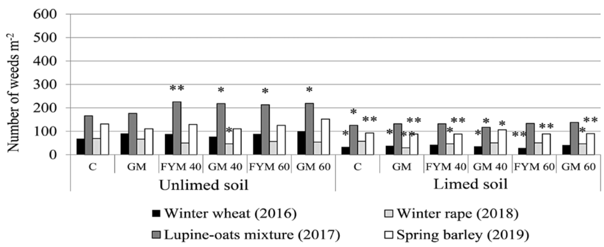
The impact of soil acidity and organic fertilisation on weeds germination. The number of weeds at the tillering or shooting stage of crops of the rotation was significantly lower (1.2–2.3 times) in limed soil compared to unlimed (Table 4, Fig. 2).

According to the average data, crops of winter wheat (2016) and winter rape (2018) were the least weedy both in limed and unlimed soil, while the mixture of lupine-oats (2017) was the weediest. The lupine plants are fond of moist or wet soil. The weeds that are present in crops not only reduce moisture in the soil (especially in the early development stages) but also compete for the other factors of growth. This is particularly evident in the drought period (Petrovienė, 2006).

Table 4. The impact of soil acidity on the number of weeds and dry matter mass

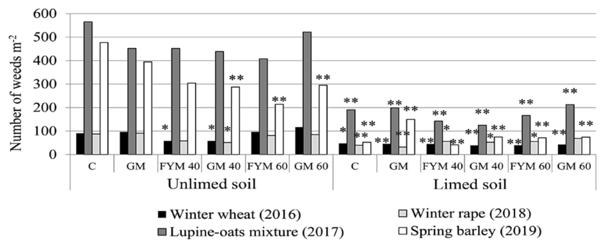
Soil acidity	Crop rotation			
	Winter wheat 2016	Lupine-oats mixture 2017	Winter rape 2018	Spring barley 2019
	Number of weeds at the tillering or shooting stage of crops m^{-2}			
Unlimed soil	85.7	203.2	57.2	126.6
Limed soil	36.7**	129.6**	46.9*	92.2**
	Number of weeds at the maturity stage of crops m^{-2}			
Unlimed soil	85.8	472.6	75.4	328.7
Limed soil	43.0**	172.6**	50.4**	77.1**
	Dry matter mass of weeds at the maturity stage of crops g m^{-2}			
Unlimed soil	74.0	92.2	87.5	141.3
Limed soil	14.1**	41.0**	19.8**	14.4**

Note. * and ** – differences significant at $P < 0.05$ and $P < 0.01$, respectively, between the unlimed and limed soil.



Note. C – without organic fertilisers, GM – green manure, FM 40 – 40 t ha^{-1} of farmyard manure (FYM), GM 40 – green manure, on the background of 40 t ha^{-1} FYM, FM 60 – 60 t ha^{-1} FYM, GM 60 – green manure, on the background of 60 t ha^{-1} FYM; * and ** – differences significant at $P < 0.05$ and $P < 0.01$, respectively, compared to the unlimed soil without organic fertilisers treatment.

Figure 2. The impact of soil acidity and organic fertilisation interaction on the number of weeds at the tillering or shooting stage of crops of the rotation



Explanations under Figure 2

Figure 3. The impact of soil acidity and organic fertilisation interaction on the number of weeds at the maturity stage of crops of the rotation

When comparing only the data of the organic fertilisation influence, it can be seen that the obtained differences were not significant in most cases. In the first (2016) and the second (2017) year of liming and organic fertilisation application, fertilising with different FYM rates or using the green manure on the background of different FYM rates the weed number was determined to be greater by 10.4–39.2% and 5.6–22.8%, respectively, compared to the soil without organic fertilisation. In the third year of the research (2018), soil without organic fertilisation was weedier by 15.2–24.2%. The number of weeds in the fourth year of the research (2019) was determined to be similar in all experimental plots.

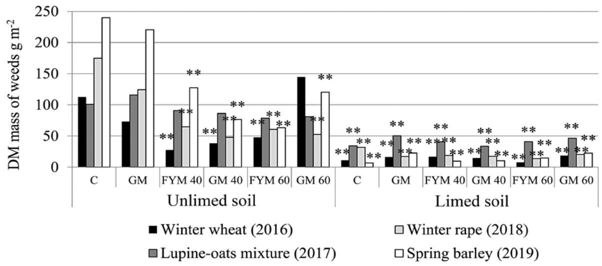
Weed number and DM mass at the maturity stage of crops of the rotation. Weed number was changing during the crop growing season. Crop weediness assessment data before the harvesting showed that different experimental year conditions determined the effect of investigated factors on weed number (Table 4). The number of weed at the maturity stage of crops of the rotation was significantly (1.5–4.3 times) lower in limed soil compared to unlimed.

During the growing season starting from shooting to maturity stages, the weed number persisted similar in the crops of winter wheat (2016) and winter rape (2018) (Fig. 3). The mixture of lupine-oats (2017) at the stage of maturity was the weediest crop of the rotation sequence. At the stages starting from shooting to maturity, herbicides were not applied, and the weed number in lupine-oats mixture increased by 2.3–1.3 times, respectively, in unlimed and limed soils.

Similar data was obtained in the previous crop rotation of this experiment (Skuodienė et al., 2017). It was observed that lupine, in contrast to other crops of the rotation, germinated longer; therefore, its leaves covered the soil surface later and weakly competed with weeds. However, in the months of May and June (2017) the amount of precipitation was by 87.2% and 21.2% lower than the SCN. In the crops of undersown spring barley (2019) at the shooting and maturity stages the weed number in limed soil decreased by 1.2 times. After the emergence of ecological niches in sparse crops of barley in unlimed soil, the weed number increased by 2.6 times. That was influenced by lower competition between the weeds and barley, as the crops of barley were short and rare in naturally acid soil. According to the literature, during the growing season from the complete weed emergence from cereal growth stage (BBCH 32–34) to cereal grain filling stage (BBCH 73), the total weed number decreased (Šarūnaitė et al., 2013). However, it has been reported that weed density was 50% higher at the wax maturity stage of wheat (BBCH 82–83) than at the tillering stage (BBCH 22–23) (Woźniak, 2018).

Due to the interaction of investigated factors in limed soil fertilised with organic fertilisers, the growth conditions of crops of the rotation improved. Better competitive ability in crops of the rotation determined a decrease in the total weed incidence. The weed number per square meter in the limed soil was significantly smaller, compared to the unlimed soil without organic fertilisers (Fig. 3). Organic fertilisers in unlimed soil also decreased crop weediness in many cases, especially in the crops of undersown barley. In the lupine-oats mixture the organic fertilisation effect was lower. The correlation analysis showed that the total number of weeds before the harvest depended on the number of weeds that germinated in spring ($r = 0.866$, $p < 0.01$).

At the maturity stage of crops of the rotation, the total mass of weeds was significantly (2.2–9.8 times) lower in the crops grown in limed soil compared to unlimed (Fig. 4).



Explanations under Table 2

Figure 4. The impact of soil acidity and organic fertilisation interaction on the dry matter (DM) mass of weeds at the maturity stage of crops of the rotation

Great differences of the weed DM mass were observed among organic fertilisation treatments in unlimed soil. During all experimental years, due to the interaction of investigated factors the total mass of weeds was determined to be significantly greatest in unlimed soil with poor nutrition conditions. There was a strong negative correlation ($r = -0.752$–-0.893, $p < 0.01$) between the total weed mass and yield of agricultural crops. Long-term liming changed chemical properties and morphological features of *Retisol* (Volungevicius et al., 2018); especially it was significant for soil acidity and reduction of all Al compounds in the solid phase (Kryževičius et al., 2019).

The data from all experimental period (2015–2019) suggest that the greatest amount of mobile Al (122.47 mg kg^{-1}) was determined in unlimed soil without organic fertilisers. A long-term systematic insertion of 40 and 60 t ha^{-1} FYM into unlimed soil significantly decreased the amount of mobile Al in different experimental years (2006–2009 and 2010–2014), compared to the soil without manure application (Repšienė, Skuodienė, 2010; Skuodienė et al., 2017). In limed soil, mobile Al was not detected at all – acid soil liming eliminated mobile Al from the topsoil layer. The literature indicates that a long-term systematic fertilisation only with the farmyard manure improves plant growth conditions, because manure contains Ca and Mg which connect the mobile Al (Fuentes et al., 2006). The smallest weed DM mass was estimated in the crops of winter wheat (2016) and spring barley (2019) in limed soil. Kandasamy (2017) has reported that increase in weed airy-dry mass is related to greater density of weeds.

While assessing the changes in weed incidence of all rotation it was determined that weed DM mass was influenced by the weed number ($r = 0.706$–0.960, $p < 0.01$) and the weed number depended on soil acidity ($r = 0.585$–0.971, $p < 0.01$).

Agrobiological indices of weeds. Changes of the ecological conditions for plant growth in the soil had a diverse effect on the agrobiological composition of weeds and their abundance in the crops grown in acid and limed soils. It was found that soil acidity changed agrobiological indices of weeds (Table 5). At the stages of shooting and maturity of crops of the rotation, the number of weed species was significantly (on average 33% and 40%, respectively) smaller while growing crops in limed soil compared to unlimed. The greatest number (6–12) of weed species was determined in the mixture of lupine-oats, and the smallest number (3–7) of weed species was found in the crops of winter wheat. During all experimental years (except for the third year of effect), soil acidity had a significant influence on the number of weed species in the crops of the rotation.

The interaction of investigated factors for the number of weed species showed up at the stage of maturity of crops. The number of weed species per square meter was significantly smaller in limed soil compared to unlimed (Table 5). Soil acidity had influence on weed germination in 2016 and 2017 ($r = -0.885$, $p < 0.01$ and $r = -0.828$, $p < 0.01$, respectively). Estimating the number of weed species before harvesting, the impact of soil acidity was determined in 2016, 2017 and 2019 ($r = -0.837$, $p < 0.01$; $r = -0.946$, $p < 0.01$ and $r = -0.908$, $p < 0.01$, respectively).

During all experimental years, annual weeds dominated in the crops at shooting and maturity stages: 96.4% and 85.1%, respectively (Table 5). The number of annual weeds in limed soil was determined to be slightly greater (3.2% and 1.3%, respectively) than in unlimed soil at shooting and maturity stages of crops.

The impact of organic fertilisation on the changes in weed populations during the crop growing season was also noticed. Irrespective of soil acidity in the first half of growing season, the number of annual weeds in the soil with organic fertilisers was greater by 1.5–3.2% and at crop maturity stage – by 10.1–14.0%

Table 5. Agrobiological indices of weeds in the crops of the rotations

Soil acidity	Crop rotation							
	winter wheat 2016		lupine-oats mixture 2017		winter rape 2018		spring barley 2019	
	Assessment							
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
	Number of weed species m^{-2}							
Unlimed soil	6.1	5.8	8.6	11.4	5.0	6.1	6.6	8.4
Limed soil	3.7**	4.1**	7.0**	8.3**	4.7	6.2	5.8*	4.1**
	Annual weeds %							
Unlimed soil	97.5	81.4	99.5	94.1	89.9	85.2	92.4	77.7
Limed soil	99.5	92.4**	99.8	99.3**	95.9	91.1	96.4	60.0*
	Annual dicotyledonous weeds %							
Unlimed soil	91.3	73.0	97.9	95.7	93.5	94.7	99.9	65.6
Limed soil	96.3*	82.4*	96.2	96.2	84.4**	73.8**	100.0	61.6
	Acidophilic weeds %							
Unlimed soil	27.7	13.0	23.7	32.2	33.3	33.3	22.1	7.1
Limed soil	4.2**	0.7**	5.5**	5.2**	4.6**	4.4**	6.4**	0.2**

Note. 1st – shooting (winter rape), tillering (winter wheat and spring barley) or inflorescence emergence (lupine-oats mixture) stage of crops of the rotation, 2nd – the maturity stage of crops of the rotation; * and ** – differences significant at $P < 0.05$ and $P < 0.01$, respectively, between the unlimed and limed soil.

compared to control treatment. Annual dicotyledonous weeds accounted for the largest part (65.6–99.9% and 61.6–100.0%, respectively), in unlimed and limed soil. The correlation analysis showed that the number of annual dicotyledonous weeds depended on the total number of annual weeds (r = 0.577, p < 0.01). Organic fertilisation did not have any significant influence on the spread of annual dicotyledonous weeds in the crop rotation during the growing season.

Weed communities, consisting predominantly of annual plants, show a much higher degree of temporal dynamics than other vegetation types (Lososová et al., 2003). Weed communities are also affected by crop type and sequence. Agricultural crops with different (winter or spring) growth cycles affect weed incidence, germination and growth (Andrade et al., 2017).

Soil acidity and diverse organic fertilisation had influence on the number of acidophilic weeds in crops of the rotation. The greatest number of acidophilic weeds was determined in unlimed soil without organic fertilisers. With increasing manure rates and inserting the green manure, the number of acidophilic weeds consistently decreased from 43.5% to 2.8% and from 49.2% to 2.0%, respectively, at shooting and maturity stages of crops. According to the average data, inverse linear correlation was determined between soil pH index (x) and the number of acidophilic weeds (y). With increasing soil pH index, at crop shooting and maturity stages the number of acidophilic weeds consistently decreased (r = −0.707, p < 0.01 and r = −0.439, p < 0.01, respectively), and a strong significant negative correlation was found between the acidophilic weed number and yield of agricultural crops (r = −0.639–−0.901, p < 0.01 and r = −0.737–−0.855, p < 0.01, respectively). Other authors (Čiuberkis et al., 2006; Ługowska et al., 2016) have documented similar trends. Vidotto et al. (2016) established some relationships between the number of weeds, number of weed species, number of dicotyledonous weeds and pedo-climatic parameters. Weed community variation seems to be result from the interaction of different cropping and pedo-climatic aspects.

Conclusions

1. Weed incidence, species composition and development depended on soil liming and organic fertilisation which created different nutrition conditions in the crops grown in the rotation. In the naturally acidic soil, the number of weeds was by 1.2–2.3 and 1.5–4.3 times greater than in the limed soil, respectively, at shooting and maturity stages of crops. Acidophilic weeds accounted for about one-third of the total weed number.

2. Organic fertilisation did not have any significant influence on weed number, weed species number, the percentage of annual weeds, annual dicotyledonous weeds and acidophilic weeds in the crop rotation in the first half of the growing season, except for the percentage of the acidophilic weeds in 2017.

3. Due to the interaction of liming and organic fertilisation at the plant maturity stage in the first year of the rotation (after the insertion of red clover-timothy sward and farmyard manure), significantly smaller weed number and dry matter (DM) mass, weed species number and the percentage of acidophilic weeds were determined in limed soil fertilised with organic fertilisers compared to unlimed soil. In the third and the fourth year of the rotation (after the insertion of lupine-oats mixture), the weed number and DM mass in limed soil fertilised with organic fertilisers were determined to be significantly smaller compared to unlimed soil.

4. The annual weeds dominated in the crops at shooting and maturity stages – on average 96.4% and 85.1%, respectively. The number of annual weeds in limed soil was determined to be slightly greater (3.2% and 1.3%, respectively) than in unlimed soil at shooting and maturity stages of crops. Annual dicotyledonous weeds accounted for more than two-thirds of the total number of weeds.

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Kalkinimo ir organinio tręšimo poveikis sėjomainos pasėlių piktžolėtumui

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Santrauka

Siekiant palaikyti balkšvažemio (*Retisol*) potencialų našumą ir gauti stabilius žemės ūkio augalų derlius, jį reikia kalkinti ir jo atsargas nuolat papildyti organinėmis medžiagomis. Ūkiuose nebesukaupiant reikiamo kiekio mėšlo, jį aktualu pakeisti kitomis organinėmis trąšomis. Tyrimas atliktas 2015–2019 m. Lietuvos agrarinių ir miškų mokslų centro Vėžaičių filiale. Eksperimento tikslas – nustatyti kalkinimo ir organinio tręšimo įtaką tausojamosios sėjomainos pasėlių piktžolių pokyčiams. Eksperimentas vykdytas skirtingo rūgštumo dirvožemyje: nekalkintame (pH 4,13) ir kalkintame (pH 5,87). Organinio tręšimo variantai: 1) be organinių trąšų (kontrolinis), 2) tręšta žaliąja trąša, 3) įterpta 40 t ha^{-1} mėšlo, 4) tręšta žaliąja trąša, 40 t ha^{-1} mėšlo fone, 5) įterpta 60 t ha^{-1} mėšlo ir 6) tręšta žaliąja trąša, 60 t ha^{-1} mėšlo fone.

Tyrimo duomenimis, piktžolių skaičiui, jų rūšių skaičiui ir trumpaamžėms dviskiltėms bei acidofilinėms piktžolėms dirvožemio rūgštumas esminės įtakos turėjo augalų vegetacijos pradžioje, t. y. piktžolių dygimo metu. Dirvožemio rūgštumo ir organinių trąšų sąveikos esminė įtaka piktžolėtumo rodikliams išryškėjo sėjomainos pasėlių brandos metu.

Reikšminiai žodžiai: acidofilinės piktžolės, dirvožemio pH, piktžolių bendrijos dinamika, piktžolių skaičius ir masė, trumpaamžės piktžolės.