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Changes in weed flora under the influence of long term application of liming and reduced soil tillage

Regina SKUODIENĖ¹, Danutė KARČAUSKIENĖ¹, Virginijus FEIZA², Dalia FEIZIENĖ², Regina REPŠIENĖ¹, Gintaras ŠIAUDINIS¹

¹Lithuanian Research Centre for Agriculture and Forestry, Vėžaičiai Branch
Gargždų 29, Vėžaičiai, Klaipėda distr., Lithuania
E-mail: regina.skuodiene@lammc.lt

²Lithuanian Research Centre for Agriculture and Forestry, Institute of Agriculture
Instituto 1, Akademija, Kėdainiai distr., Lithuania

Abstract

Many soil improvement practices are directly related to the reduction of weed infestation in crops. Sustainable use of the acid moraine loam *Bathygleyic Distric Glossic Retisol* prevailing in Western Lithuania is associated with the appropriate intensity of liming and tillage. Research was carried out at the Vėžaičiai Branch of Lithuanian Research Centre for Agriculture and Forestry during the period 2015–2018 in two long-term field experiments: liming (established in 1949) and soil tillage methods (established in 2003). The aim of the study was to establish the trends in weed infestation variation in the crop rotation after a long-term application of agronomic practices of different intensity (soil tillage and liming). Treatments of the soil tillage were as follows: conventional ploughing, shallow ploughing and shallow ploughless tillage. Treatments of liming were as follows: unlimed (pH_{KCl} 4.0–4.1) and limed (pH_{KCl} 6.2–6.8). The following weed infestation indicators were investigated: weed number and mass, weed species number, weed seed bank in the soil depths of 0–10, 10–20 and 20–30 cm.

Findings of the study suggest that the long-term liming had an impact on the disappearance of dominating acidophilic weeds from crop communities. In a limed soil (pH 6.4–6.8), the total number of weeds was 4.1 times lower compared to that in a naturally acid soil (pH 4.0–4.1). The contamination with weed seeds was 14.2 times greater in the naturally acid soil; however, irrespective of the soil acidity (pH), vertical seed distribution was determined to be similar in different depths of the soil. The long-term conventional ploughing reduced crop weediness in the soil of low acidity (5.1–5.3). The total weed number and mass were 1.6 and 1.4 times greater in the treatment of reduced tillage soil. The effect of long-term regular soil tillage tended to cause changes to the depth of soil loosening, affecting vertical weed seed distribution. Under reduced tillage conditions, the soil depth of 0–10 cm was the most contaminated with weed seeds.

Key words: acid soil, liming, primary soil tillage, seed bank, weed number and dry biomass.

Introduction

Weeds are a permanent component of agroecosystems and remain the most important factor causing yield reduction (Auškalnienė et al., 2011). Crop yield losses to weed competition have been estimated as 9% globally (Oerke, 2006). Weed specific composition mostly depends on the anthropogenic activity (Fried et al., 2008). Weed flora is affected by the changes in crop rotation (Hosseini et al., 2014), use of herbicides (Andreasen, Streibig, 2011), fertilization and liming (Ciuberkis et al., 2006; Karcauskiene et al., 2016) and management strategies (Deveikytė et al., 2006; Seehusen et al., 2017). Crop rotation is one of the factors to prevent the spread of weeds. It was established that cereals may account for 50% of a crop rotation, but if it is possible to effectively control weeds and pests, cereals may occupy 67% or 100%, when legumes are grown in a crop rotation (Auškalnienė et al., 2011).

European Community's agricultural policy has strongly encouraged conservation tillage practices, such as no-tillage and reduced tillage (European Union, 2000). Reduced tillage system involves, among others, a reduction in the number of tillage operations, shallower ploughing, replacing the plough by other implements, or the use of direct drilling. Low labour intensity of this system also makes it possible to grow crops in locations where it is a problem to maintain optimal sowing time (Gawęda et al., 2015). Although effects on cereal grain yield have not been consistent, conservation tillage can reduce soil erosion and improve soil fertility and soil water retention (Berner et al., 2008). Furthermore, desirable effects of conservation tillage may include the reduction of energy requirements for weed control, carbon sequestration and mitigation of greenhouse gas emissions (Meyer-Aurich et al., 2006), because

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consequences of this intensive agriculture are now well known with an important increase of atmospheric CO₂ concentrations, water pollution and biodiversity loss (Gaba et al., 2014).

Guinjuan et al. (2016) indicate that no-tillage has resulted in difficulties in controlling certain weed species. Decreasing tillage intensity increased the amounts of weeds, particularly of meadow grass (*Poa annua* L.) (Seehusen et al., 2017). In no-tillage, in addition to the fact that seeds stay close to the soil surface, greater crop residue also remains on the soil surface, suppressing weed emergence due to a mulch effect or allelopathy (Khan et al., 2000). Therefore, a modification of the size of the seedbank will result in changes of the emerging weed populations and *vice versa*. Furthermore, it is possible that weed seeds migrate into the plots from the surroundings of the farm or from deeper soil layers during ploughing (Riemens et al., 2007). As reported by Woźniak (2007), from 60% to 90% of the seed bank may be deposited in the topsoil. During mechanical cultivation, weed seeds with a short resting period are transferred from the topsoil into deeper soil layers, from where only few are capable of sprouting. It results in a depletion of the seed bank in the soil and, thus, in lesser crop infestation with weeds (Riemens et al., 2007; Gruber, Claupein, 2009).

Agricultural plants and weeds differently react to soil acidity, which determines plant nutrition, distribution and productivity. Liming of acid soils changes their characteristics as well as plant growth conditions (Skuodienė, Repšienė, 2009). The research conducted on a *Bathygleyic Dystric Glossic Retisol* showed that in the first year of organic fertilizer effect, i.e. in the stand of winter wheat, the weed number strongly correlated with soil agrochemical parameters tested: mobile aluminium (Al), hydrolytic acidity, calcium (Ca) and magnesium (Mg) content and pH_{KCl}.

Weed flora has markedly changed in the crops of Lithuania during the last decades (Auškalnienė et al., 2011). *Bathygleyic Dystric Glossic Retisols* prevailing in Western Lithuania are acid, low in organic matter and contain high level of toxic Al³⁺ (Repšienė, Karcauskiene, 2016; Volungevicius et al., 2018).

Based on these observations, we hypothesised that reduced soil tillage would increase the weed number and soil contamination with weed seeds, while the acid soil liming would affect the weed number and soil contamination with weed seeds in the opposite way.

The aim of the study was to establish the trends in weed infestation variation in the crops of the rotation after a long-term application of agronomic practices of different intensity (soil tillage and liming).

Materials and methods

Experimental site. Research into the effects of the soil tillage methods and liming on crop weediness was carried out during the period 2015–2018 in two long-term field experiments carried out at Vėžaičiai Branch of the Lithuanian Research Centre for Agriculture and Forestry in Klaipėda district. According to the content of clay particles, the soil profile is differentiated into alluvial and illuvial horizons whose diagnostic horizons: A (0–27 cm) – E1 (27–55 cm) – E1B (55–80 cm) – BtE1 (80–105 cm) – BCg (105–120 cm) (Kryzevicius et al., 2019). The soil is typical of the region of Western Lithuania.

Two experiments were carried out to achieve the aim of the research.

Experiment I – long-term liming impact on agrophytocenosis. A field experiment was established in 1949. Geographical location of the site: lat. 55°69' N,

long. 21°49' E. The soil was *Bathygleyic Dystric Glossic Retisol* (WRB, 2014) formed on medium-moraine loam with a texture of sandy loam (clay particles <0.002 mm – 13–15%).

Liming treatments: 1) unlimed (pH_{KCl} 4.0–4.1) and 2) limed at 2.0 rates every 3–4 years (pH_{KCl} 6.2–6.8). The unlimed soil was moderate in humus status (humus – 2.43%, organic carbon (C_{org}) – 1.41%), high in mobile phosphorus (P₂O₅) and potassium (K₂O) content (265 and 294 mg kg⁻¹ soil, respectively) and moderate in mobile aluminium (Al) content (73.3 mg kg⁻¹) with pH 4.08. The limed soil was moderate in humus status (humus – 2.17%, C_{org} – 1.26%) and high in mobile P₂O₅ and K₂O content (243 and 249 mg kg⁻¹ soil, respectively) with pH 6.3. The soil was limed systematically: in 1949, the primary liming was done with slaked lime, in 1964, liming with slaked lime was repeated, and in the period of 1985–2005, the soil was limed periodically every 3–4 years in a seven-field rotation incorporating powder limestone at 2.0 rates (15 t ha⁻¹ CaCO₃) chosen according to the soil hydrolytic acidity. Soil tillage was conventional ploughing.

The four-course crop rotation consisted of: in 2015 – spring rape (*Brassica napus* L. ssp. *oleifera* annua Metzger) cultivar 'Fenja', in 2016 – spring barley (*Hordeum vulgare* L.) cultivar 'Luokė' with undersown red clover (*Trifolium pratense* L.), in 2017 – red clover 'Liepsna' of the first year of use (2017), in 2018 – winter triticale (× *Triticosecale* Wittm.) cultivar 'Todant'. The crops were fertilised with mineral fertilisers. The rate for the spring rape was N₁₂₀ P₉₀ K₁₅₀, for the stand of barley with undersown perennial grasses – N₆₀ P₆₀ K₉₀, for the perennial grasses of the first year of use – P₉₀ K₉₀, for the winter triticale – N₉₀ P₆₀ K₁₀₀. Before sowing, the grains of winter triticale 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. In 2015 at BBCH 05, Butisan 400 a.i. (a.i. metazachlor) 2.5 L ha⁻¹, at BBCH 10 Fury (a.i. zeta-cypermethrin) 0.1 L ha⁻¹, at BBCH 51 Fury (a.i. zeta-cypermethrin) 0.1 L ha⁻¹. In 2016 at BBCH 13 Allegro Super (a.i. krezoksime-methyl + epoxiconazol + fenpropimorph) 0.75 L ha⁻¹, at BBCH 41–43 Fastac 50 EC (a.i. alpha-cypermethrin) 0.25 L ha⁻¹ + Allegro Super (a.i. krezoksime-methyl + epoxiconazol + fenpropimorph) 0.75 L ha⁻¹, at BBCH 60 Fastac 50 EC (a.i. alpha-cypermethrin) 0.25 L ha⁻¹ + Allegro Super (a.i. krezoksime-methyl + epoxiconazol + fenpropimorph) 0.75 L ha⁻¹. In 2018 at BBCH 23 Arrat (a.i. tritosulfuron + dicamba) 0.2 kg ha⁻¹, at BBCH 53 Allegro Super (a.i. krezoksime-methyl + epoxiconazol + fenpropimorph) 0.75 L ha⁻¹, at BBCH 69 Allegro Super (a.i. krezoksime-methyl + epoxiconazol + fenpropimorph) 0.75 L ha⁻¹.

The net plot size was 11.5 × 6.5 m = 74.75 m². A randomised complete block design with three replications was used. The treatments were assigned randomly.

Experiment II – different intensity soil tillage impact on agrophytocenosis. The trial was carried out in 2003 in the experimental crop rotation field. The geographical location of the site is lat. 55°72' N, long. 21°46' E. The soil was *Bathygleyic Dystric Glossic Retisol* (WRB, 2014) formed on medium-moraine loam with a texture of sandy loam (clay particles <0.002 mm – 13–15%), whose pH at the beginning of the trial was 5.1–5.3. The soil is moderate in humus status (humus – 2.43%, C_{org} – 1.41%), moderate in mobile P₂O₅ content and high in mobile K₂O (106 and 270 mg kg⁻¹ soil, respectively) (Skuodienė et al., 2018). Treatments of primary soil tillage: 1) conventional ploughing (22–5 cm), 2) shallow ploughing (12–15 cm) and 3) shallow ploughless tillage (7–10 cm).

Conventional and shallow ploughing was carried out with ploughs fitted with semi screw

mouldboards. Conventional and shallow ploughing was performed three weeks after scraping (at the depth of 6–8 cm). In the shallow ploughless tillage treatment as well as in ploughed treatments soil cultivation was done only after scraping. Pre-sowing tillage was the same in all treatments of the primary soil tillage: cultivation with a combined pre-sowing soil tillage cultivator.

The four-course crop rotation consisted of: in 2015 – red clover (*T. pratense* L.) cultivar ‘Sadūnai’ of the first year of use, in 2016 – winter wheat (*Triticum aestivum* L.) cultivar ‘Ada’, in 2017 – spring rape (*B. napus* L. ssp. *oleifera annua* Metzg) cultivar ‘Acheras’, in 2018 – spring barley (*H. vulgare* L.) cultivar ‘Luokė’ with undersown red clover. Crops were fertilised with mineral fertilisers. The rate for the stand of barley was $N_{60}P_{60}K_{90}$, for the perennial grasses – $P_{90}K_{90}$, for the winter wheat – $N_{90}P_{60}K_{90}$, for the spring rape – $N_{150}P_{90}K_{150}$. 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: in 2016 at BBCH 31 – Fastac 50 EC (a.i. alpha-cypermethrin) 0.25 L ha^{-1} + Allegro Super (a.i. krezoksimehtil + 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. krezoksimehtil + epoxiconazol + fenpropimorph) 0.75 L ha^{-1} ; in 2017 at BBCH 01 – Butisan 400 (a.i. metazachlor) 2.5 L ha^{-1} , at BBCH 12 – Fury (a.i. zeta-cypermethrin) 0.1 L ha^{-1} , at BBCH 16 – Galera (a.i. clopyralid + picloram) 0.3 L ha^{-1} , at BBCH 50–60 – Avaunt (a.i. indoxacarb) 0.17 L ha^{-1} . Due to the prolonged rainy period in the autumn of 2017, the primary soil tillage was not carried out. Therefore, before the soil tillage in the spring of 2018, Barbarian 2 (a.i. glyphosate) L ha^{-1} was applied; in 2018 at BBCH 32, MCPA Super (a.i. MCPA) 1.0 L ha^{-1} was used.

Annually, after harvesting of each crop of the rotation and before the primary soil tillage, 400 kg of CaCO_3 was spread to prevent soil acidification. After spreading the straw of winter wheat and rape, a rate of $10 \text{ kg nitrogen (N)}$ was distributed per each ton of straw. The net plot size was $10 \times 5 \text{ m} = 50 \text{ m}^2$. A randomised complete block design with four replications was used. The treatments were assigned randomly.

Analytical methods. Agrochemical characteristics of the soil were determined on the soil samples taken from 0–20 cm layer before establishing the experiment: soil pH_{KCl} was measured according to potentiometric method determined in 1 M KCl (soil and solution ratio 1:2.5) (ISO 10390:2005 - Soil quality - Determination of pH), mobile P_2O_5 and K_2O – using Egner-Riehm-Domingo (A-L) method (LVP D-07:2016). Mobile Al was determined after Sokolov method according to standards ISO11260 and ISO14254 (Soil quality - Determination of exchangeable acidity using barium chloride solution as extractant). Humus was determined according to Tiurin method (ISO 10694:1995 - Soil quality - Determination of organic and total carbon after dry combustion). Soil bulk density in 0–30 cm topsoil was determined every 5 cm using a metal cylinder (100 cm^3) by the Kachinsky method. Weeds were hand-harvested in stationary plots of 0.25 m^2 in six spots of each plot. Crop weediness in the stands of winter triticale, winter wheat and spring barley was determined during the periods of tillering and wax maturity before harvesting; in the stands of spring rape – during the periods of shooting and wax maturity before harvesting while in the sward of red clover – before cutting. During the first assessment, weed specific composition was determined, during the second assessment, the weeds were eradicated and their specific composition as well as dry matter mass was determined. Weed number was recalculated to weeds

m^2 and mass – dry matter (DM) mass, g m^{-2} . Weeds were cut at the soil surface and their biomass was weighed by species after the samples had been dried.

Soil contamination with weed seeds was investigated at the depths of 0–10, 10–20 and 20–30 cm. Soil samples were randomly taken from each plot using an agrochemical drill during crop maturity phase. The total number of samples was 360. The soil was dried out. Then, five samples of dry soil of each of 360 samples (100 g each) were weighed and wet-sieved through a 0.25 mm sieve until all contents of the soil were washed out. The remaining mineral part of the soil was separated from the organic part and weed seeds using the saturated salt solution. After completion of soil washing, the remaining contents were dried on filter paper. Weed seeds were counted and identified using binoculars with $8.75\times$ magnification. Weed seed number was recalculated to thousands of weeds m^{-2} using the following equation:

$$A = n \times h \times p \times 100,$$

where A is weed seed number per m^2 , n – seed number in a sample, h – soil depth (cm), p – soil density (Mg m^{-3}).

Meteorological conditions. In 2015, plant vegetation started on the 14th of April. The amount of precipitation in spring reached 135%, in summer – 90%, in autumn – 79% of the standard climate norm (SCN). The weather in August was especially warm and dry, the recorded amount of rainfall reached only 12.5 mm or 13.0% of the SCN; the mean monthly air temperature was 2.4°C higher than the SCN. Plant vegetation period ended on the 26th of November.

In 2016, the period of plant vegetation started on the 8th of April. The amount of precipitation through the year reached 113% of the SCN. The months of April and May were warm and humid and the average air temperature was by $0.2\text{--}2.4^\circ\text{C}$ higher than the SCN. The summer was relatively warm and humid: the average air temperature in June reached 16.3°C and exceeded the SCN by 1.8°C , and in July and August it was close to the SCN. The summer was slightly more humid than the norm – on the average 115% of the SCN. In September, the weather was warm and dry; however, starting from the second ten-day period of October it became cold, and the plant vegetation period ended on the 16th of October. Soil humidity conditions for agricultural plants to grow were optimal during the whole vegetation period.

In 2017, the period of plant vegetation started on the 5th of April. Although the amount of precipitation reached 140% of the SCN, its distribution was uneven: in spring it was by 25% lower, in summer – by 20% lower and in the autumn – by 117% higher than the SCN. The average temperature through the vegetation period was close to the norm and through the year it was 0.5°C higher than the SCN. The mean air temperature in November was by 1.8°C higher, so the period of vegetation ended only on the 23rd of November.

In 2018, the period of plant vegetation started on the 13th of April. The amount of precipitation through the year reached 84% of the SCN. During the vegetation period, the amount of precipitation was by 8% lower and in the summer time – by 35% lower compared to the SCN. Soil moisture at the 0–20 cm depth on the 23rd of July was lower (by 10.26–10.71%) than the optimal moisture for the plants. Plant vegetation ended on the 24th of November.

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 analysis of variance (ANOVA) (Raudonius, 2017). Weediness data (weed number and 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 x is the primary data, Y – transformed data of weed density and mass; however, means on the original scales are reported.

Results and discussion

Management factors change the biodiversity of agroecosystems. Crop rotation, liming and technologies applied are significant for the diversity of weed community (Ciuberkis et al., 2006; Andreasen, Streibig, 2011).

The impact of liming on weed germination.

Weeds exhibit a different response to soil acidity, which determines crop nutrition, distribution and yield. Improvement of crop nutrition through liming (reduction of mobile Al, which is harmful to plants) results in the changes in weed number and species composition in a crop (Ciuberkis et al., 2006; Skuodienė, Repšienė, 2009). The influence of liming on crop weediness during the period of shooting or tillering was determined in all experimental years (Table 1).

Table 1. Number of weed seedlings m^{-2}

Treatment	Spring barley + undersowing	Red clover	Winter triticale
	2016	2017	2018
Unlimed (pH 4.0–4.1)	134.0	104.0	64.0
Limed (pH 6.4–6.8)	28.7**	30.7*	14.7*

* – significant at $P \leq 0.05$, ** – at $P \leq 0.01$

Table 2. Number of weeds and dry biomass during the period of crop maturity

Treatment	Spring rape	Spring barley + undersowing	Red clover	Winter triticale
	2015	2016	2017	2018
	Weeds m^{-2}			
Unlimed (pH 4.0–4.1)	74.0	351.0	82.0	38.0
Limed (pH 6.4–6.8)	22.7**	88.0*	21.3*	23.3
	Weed dry biomass $g\ m^{-2}\ DM$			
Unlimed (pH 4.0–4.1)	–	141.0	105.9	71.4
Limed (pH 6.4–6.8)	–	9.4**	38.0	19.7*

DM – dry matter; * – significant at $P \leq 0.05$, ** – at $P \leq 0.01$

Table 3. Liming impact on weed species number in crops of the rotation, species m^{-2}

Crops	Development period of plants	Unlimed (pH 4.0–4.1)	Limed (pH 6.4–6.8)
Spring rape, 2015	shooting	–	–
	maturity	5	2*
Spring barley + undersowing, 2016	tillering	5	3*
	maturity	11	8
Red clover, 2017	beginning of flowering, 1 st cut	4	4
	beginning of flowering, 2 nd cut	4	3
Winter triticale, 2018	tillering	3	2*
	maturity	2	2

* – significant at $P \leq 0.05$, ** – at $P \leq 0.01$

growth and development. Irrespective of the soil pH, in normally dense red clover sward (2017) the number of weed species was not high (3–4 species). The lowest weed species diversity was determined in the stand of winter triticale (2018). This was influenced by dry weather in spring and summer; the amount of precipitation reached only 70% of the standard climate norm.

Liming of acid soils improves not only chemical soil characteristics and ecological plant growth conditions but also reduces crop weediness and changes the abundance of particular weed species (Ciuberkis, 2009). Acidophilic weeds tolerate the shortage of calcium and usually dominate in acid soils (Ciuberkis et al., 2006). In the present research, common spurrey (*Spergula arvensis* L.), annual knawel (*Scleranthus annuus* L.)

A greater competitive ability of crops of the rotation formed in the soil with pH 6.4–6.8 and led to a total decrease of crop weediness. The weed number per square meter was significantly lower in most of the cases compared to the unlimed soil. In the soil with pH 4.0–4.1, in one square meter of spring barley stand the number of weeds was on average 4.7 times, in red clover 3.4 times and in winter triticale 4.4 times greater than in the soil with pH 6.4–6.8.

Weed number and dry biomass during the period of crop maturity. During the period of crop maturity, weed number per square meter and dry biomass in the soil with pH 6.4–6.8 were significantly lower in most of the cases compared to the soil with pH 4.0–4.1 (Table 2).

In unlimed soil, in one square meter of spring rape stand the number of weeds was determined to be on average 3.3 times, in the stand of spring barley 4.0 times, in the sward of red clover 3.8 times and in the stand of winter triticale 1.6 times greater than in the soil with pH 6.4–6.8. A similar trend was found when analysing the weed biomass. In unlimed soil in the stand of spring barley, weed dry biomass was 15 times, in the sward of red clover 2.8 times, and in the stand of winter triticale 3.6 times greater compared to the limed plots.

Weed species diversity in the crops of the rotation during the plant vegetation period. In all crops of the rotation, the lowest weed species diversity was determined in the soil with pH 6.4–6.8 (Table 3). Irrespective of the soil pH, the greatest number of weed species (8–11 species) was estimated in 2016, when humid and warm weather during the period of vegetation was favourable not only for spring barley but also for weed

and sheep's sorrel (*Rumex acetosella* L.) spread more in the soil with pH 4.0–4.1, while fat hen (*Chenopodium album* L.), wild radish (*Raphanus raphanistrum* L.) and pale persicaria (*Persicaria lapathifolia* L.) spread more in limed soil. Other researchers indicate that together with decrease of the soil acidity after liming, the number of acidophilic weeds decreased as well (Ciuberkis et al., 2006), and the total weed number significantly depended on the amount of mobile Al in the soil (Skuodienė, Repšienė, 2009).

The total weed seed quantity through all experimental years was significantly lower in limed soil compared to unlimed soil. According to the mean data, 358.5–433.3 thousand of weed seeds m^{-2} were found in naturally acid soil seed bank (Table 4), while in the

Table 4. Contamination of naturally acid and limed soil with weed seeds, thousand seeds m⁻²

Treatment	Spring rape	Spring barley + undersowing	Red clover	Winter triticale
	2015	2016	2017	2018
	0–10 cm			
Unlimed (pH 4.0–4.1)	192.8	180.3	159.6	80.5
Limed (pH 6.4–6.8)	22.0**	7.3**	7.4**	10.8**
	10–20 cm			
Unlimed (pH 4.0–4.1)	183.9	143.6	139.6	169.7
Limed (pH 6.4–6.8)	16.2**	8.9**	10.7**	10.9**
	20–30 cm			
Unlimed (pH 4.0–4.1)	56.5	57.6	59.3	116.1
Limed (pH 6.4–6.8)	6.1**	5.0**	4.1**	5.8**

* – significant at $P \leq 0.05$, ** – at $P \leq 0.01$

soil with pH 6.4–6.8 there were 21.2–44.4 thousand of weed seeds m⁻² or on average 14.2 times less compared to unlimed soil. Soil liming created favourable conditions for the growth of agricultural plants, therefore they grew faster than in unlimed soil and smothered weeds in the crop rotation. As a result, weed seed production decreased.

Irrespective of the soil pH, vertical seed distribution was determined to be similar in different depths of the soil. The greatest number of weed seeds was found at the depths of 0–10 and 10–20 cm, respectively: 45.6% and 37.7% of the total number in unlimed soil and 39.1% and 41.6% of the total number in limed soil. The lowest (16.7–19.3%) seed number was found at a soil depth of 20–30 cm. Soil contamination with weed seeds depended on crop condition as well as application of agromeasures and corresponds to consistent patterns indicated in literature (Woźniak, Soroka, 2015; Auškalnienė et al., 2018; Skuodienė et al., 2018). The seed bank is an indicator of past and present weed populations.

The influence of primary soil tillage methods on weed germination. An interest in reduced soil tillage in Lithuania has been shown during the last 10–15 years. It was established that shallow ploughing did not exert any negative effect on soil agrochemical and physical properties, nonetheless, according to research evidence, abandonment of ploughing and using shallow loosening by a rotary cultivator in spring, compared with deep autumn ploughing, resulted in an increase in weed incidence in a barley crop by 2.3–10.3 times (Auškalnienė et al., 2011).

In high productivity *Cambisol* with pH 6.9–7.0, significant differences in the weed species composition

between the different tillage systems were recorded: no tillage system promoted infestation of some broadleaf weeds, particularly shepherd's purse (*Capsella bursa-pastoris* (L.) Med.). The lowest weed mass was determined for the conventional tillage plots compared to minimum tillage, and especially for no tillage plots (Auškalnienė et al., 2018). In low productivity *Retisol* with pH 5.1–5.3, primary soil tillage method had significant impact on the weediness of crop rotation in all experimental years. In shallow tillage soil, the number of weeds and dry mass were significantly greater as well as the diversity of weed species compared to conventional ploughing plots. Red clover sward was the least weedy crop (2015) of the rotation: the low weed number was influenced by a good density. However, in shallow ploughing plots of the red clover sward, the weed number was estimated to be significantly greater compared to conventional ploughing plots.

In spring, during the period of tillering in the crops of winter wheat (2016) the weed number was significantly greater (2.4 times) in the plots of shallow ploughless tillage. No significant differences between soil tillage systems were recorded for spring rape crops (2017) (Table 5). In shallow ploughing and shallow ploughless tillage plots, spring barley stand with undersown red clover (2018) was weedier compared to conventional ploughing plots, 2.2 and 1.7 times, respectively. Crop type had the most significant influence on species composition, although it had a low impact on species richness (Fried et al., 2008).

Table 5. Number of weed seedlings m⁻²

Soil tillage	Red clover	Winter wheat	Spring rape	Spring barley + undersowing
	2015	2016	2017	2018
Conventional ploughing	12.7	52.7	156.0	88.0
Shallow ploughing	42.7*	83.3	164.0	193.3
Shallow ploughless tillage	34.7	124.0*	165.3	153.3

* – significant at $P \leq 0.05$, ** – at $P \leq 0.01$

Weed number and dry biomass during the period of cereal and rape maturity. The influence of primary soil tillage on crop weediness remained during the period of crop maturity as well. According to Woźniak (2018), most of the weeds appeared in the second half of the vegetative season and underwent complete development cycle on the stubble field. Before harvesting, in the shallow ploughless tillage soil in the stand of winter wheat (2016), the weed number was by 1.4 times greater and in the plots of shallow ploughing and shallow ploughless tillage in the stand of spring rape (2017) it was by 1.7 and 1.2 times greater compared to the conventional ploughing plots (Table 6). A similar trend was determined in the spring barley stand (2018) as well: in the plots of shallow ploughing the number of weeds was estimated to be significantly or 3.0 times greater and in the plots of shallow ploughless tillage 1.9 times greater compared to conventional ploughing plots.

Different intensity soil cultivation methods had an ambiguous influence on weed dry biomass. In the shallow ploughing plots of spring rape and spring barley, the weed dry biomass was by 1.4 and 2.2 times greater compared to the conventional ploughing plots, and in the shallow ploughless tillage plots of winter wheat a significant difference was determined as well. Woźniak (2018) indicates that more weeds occurred in the winter wheat crop in the reduced tillage and herbicide treatment systems than in the conventional tillage system, although they produced higher biomass in the reduced tillage than in conventional tillage and herbicide treatment systems.

Weed species diversity in the crops of the rotation during plant vegetation period. The research results show that soil tillage methods change the diversity of weed species (Table 7).

In the third crop rotation of previous experimental years, the number of weed species was determined to

Table 6. Number of weeds and dry biomass during the period of cereal and rape maturity

Soil tillage	Winter wheat		Spring rape		Spring barley + undersowing	
	2016		2017		2018	
	weed m ²	weed dry biomass g m ⁻² DM	weed m ²	weed dry biomass g m ⁻² DM	weed m ²	weed dry biomass g m ⁻² DM
Conventional ploughing	62.7	11.1	156.0	130.6	88.0	40.6
Shallow ploughing	72.7	21.5	268.0	188.4	260.0*	87.4
Shallow ploughless tillage	87.3	61.9*	185.3	125.2	169.3	51.1

DM – dry matter; * – significant at $P \leq 0.05$, ** – at $P \leq 0.01$

Table 7. Primary soil tillage impact on weed species number in crops of the rotation, species m⁻²

Crops	Development period of plants	Conventional ploughing	Shallow ploughing	Shallow ploughless tillage
Red clover, 2015	flowering	2	5	4
Winter wheat, 2016	tillering	4	5	7*
	maturity	6	5	5
Spring rape, 2017	shooting	7	8	11*
	maturity	5	7	11**
Spring barley + undersowing, 2018	tillering	3	4	8*
	maturity	6	3*	5

* – significant at $P \leq 0.05$, ** – at $P \leq 0.01$

be 6–9 during the period of tillering and 3–6 during the period of maturity under the intensive soil tillage system, while in the plots of reduced tillage the number of weed species was by 13–44% greater (Skuodienė et al., 2016). Shallow ploughless tillage stimulated biological diversity of weeds. Applying conventional ploughing during the period of crop tillering of all experimental years, the number of weed species was found to be significantly lower compared to the shallow ploughless tillage plots. In the plots of shallow ploughing and shallow ploughless tillage, the number of weed species was found to be greater than in the conventional soil tillage plots, respectively: 1.1–1.3 and 1.6–2.7 times. Other researchers indicate that the number of weed species increases together with decrease of the soil tillage intensity (Hyvönen, Salonen, 2002; Edesi et al., 2012; Kolárová et al., 2013). Under direct drilling, most weed species were found to exhibit higher constancy compared to plough tillage plots (Gawęda et al., 2015).

Irrespective of the soil tillage methods, corn mayweed (*Tripleurospermum perforatum* (Merat.) M. Lainz), annual meadow grass (*Poa annua* L.) and common knotweed (*Polygonum aviculare* L.) were found in all plots of the red clover sward (2015). However, the greatest amount of these weeds was determined in the shallow ploughing plots. During the period of tillering, *Ch. album* and *P. aviculare* were spread in all plots of

the winter wheat stand (2016). *P. annua* was spread only in the shallow ploughing and shallow ploughless tillage plots. *Ch. album* and *C. bursa-pastoris* dominated in all plots of spring rape stand (2017). *S. arvensis* dominated only in the shallow ploughing and shallow ploughless tillage plots, while *Ch. album* was the dominant weed species in all plots of the spring barley stand (2018) as well. In the later vegetation period, i.e. during the period of plant maturity, the impact of soil tillage methods on weed species diversity was not determined. *P. annua* and *P. aviculare* dominated in the stand of winter wheat (2016), and *Ch. album* dominated in the stands of spring rape (2017) and spring barley (2018).

The weed seed bank is the main source of weeds in agricultural fields. Soil weed seed banks are reserves of viable seeds present on the surface and in the soil. The seed bank consists of new seeds recently shed by a weed plant as well as older seeds that have persisted in the soil for several years. Roger-Estrade et al. (2006) indicate that the depth and inversion tillage appear to be of major importance for weed biomass destruction and seed movement into the soil profile. Soil contamination with weed seeds depended on primary soil tillage method (Table 8). Applying shallow ploughing and shallow ploughless tillage, total weed seeds in the soil was estimated to be 1.7 and 1.5 times greater compared to conventional tillage plots (Table 8).

Table 8. Soil contamination with weed seeds in the soil of different tillage systems, thousand seeds m⁻²

Soil tillage	Red clover	Winter wheat	Spring rape	Spring barley + undersowing
	2015	2016	2017	2018
0–10 cm				
Conventional ploughing	26.7	18.2	10.7	8.5
Shallow ploughing	34.2**	23.5	26.2**	39.0**
Shallow ploughless tillage	49.3**	26.6	34.8**	53.8**
10–20 cm				
Conventional ploughing	14.4	12.1	7.1	13.1
Shallow ploughing	18.1	9.4	9.4	26.4**
Shallow ploughless tillage	13.1**	10.2	7.2	15.1
20–30 cm				
Conventional ploughing	10.6	3.9	6.9	10.2
Shallow ploughing	5.4*	3.5	4.8	4.1*
Shallow ploughless tillage	4.6**	4.1	4.0	2.9**

* – significant at $P \leq 0.05$, ** – at $P \leq 0.01$

When applying conventional ploughing, the number of weed seeds in the soil seed bank (0–30 cm layer) ranged from 24.7 to 51.6 thousand m⁻², when applying shallow ploughing the number ranged from 36.4 to 69.6 thousand m⁻², and under the shallow ploughless tillage the weed seed number ranged from 40.8 to 71.7 thousand m⁻².

Soil tillage methods had a significant influence on vertical weed seed distribution in the soil. When

evaluating particular arable soil layer's contamination with weeds, it can be seen that shallow ploughless tillage mostly influenced soil contamination in the 0–10 cm layer (72.3% of the total seed number). At the same depth 61.1% of weed seeds were found after the shallow ploughing application, and 43.7% of weed seeds of the total seed number were found after the use of annual conventional ploughing.

The least contaminated with weed seeds was the 20–30 cm soil layer when applying shallow tillage without ploughing, shallow ploughing and conventional ploughing, respectively: 7.4, 9.2 and 23.0 % of seeds of the total seed number. Literature indicates that seed bank traits clearly adapt to different types of arable farming. Seed longevity is favoured by frequent tillage, while seed mass is favoured by plant competition (Albrecht, Auerswald, 2009). It is possible to detect historical effects of past crops, sown in sequence, on weed seedbanks for up to three years (Bohan et al., 2011). Reduced tillage allows the bulk of the seed produced the previous year to remain in the most superficial layer of soil, leading to its extensive germination and emergence in subsequent years (Gruber, Claupein, 2009).

Conclusions

The sustainable use of acid moraine loam *Retisol* prevailing in Western Lithuania is related to appropriate intensity of liming and tillage.

1. In limed soil (pH 6.4–6.8), the total number of weeds was 4.1 times lower compared to naturally acid soil (pH 4.0–4.1). Acidophilic weeds, *Spergula arvensis* and *Scleranthus annuus*, dominated in the naturally acid soil during the maturity period of agricultural plants through all experimental years. The long-term liming had an impact on the disappearance of dominating acidophilic weeds from the crop communities.

2. In the soil with pH 6.4–6.8 there were 14.2 times less weed seeds compared to unlimed soil. Irrespective of the soil pH, vertical seed distribution was determined to be similar in different depths of the soil.

3. In the soil of low acidity (5.1–5.3), with the application of reduced soil tillage throughout the whole plant vegetation period, the total weed number and mass as well as weed diversity were significantly greater compared to conventional ploughing plots. In the early stages of plant development, when plants are especially sensitive to weed competition, the average total weed number in the plots of shallow ploughing and shallow ploughless tillage was 1.6–1.5 times greater compared to conventional ploughing. Weed number and dry matter mass during the period of cereal maturity were 2.0–1.4 and 1.6–1.3 times greater when applying reduced tillage than conventional ploughing.

4. Irrespective of the soil tillage methods, weed species diversity was determined by their ability to grow in particular crops: *Tripleurospermum perforatum* was found in all plots of the red clover sward, while the consistent components of crop communities: *Chenopodium album*, *Polygonum aviculare* and *Poa annua* were found in all plots of the cereal stand.

5. In reduced soil tillage treatments, the number of weed seeds was 1.6 times greater than in conventional ploughing plots. Type of tillage strongly influenced vertical seed placement in the soil. Annual application of the shallow ploughless tillage mostly influenced soil contamination with weed seeds (72.3% of the total seed number) at the depth of 0–10 cm. At the same depth 61.1% of weed seeds were found after the use of shallow ploughing, and 43.7% of weed seeds of the total seed number were found after the use of conventional ploughing.

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Piktžolėtumo kitimas taikant ilgalaikį kalkinimą ir supaprastintą žemės dirbimą

R. Skuodienė¹, D. Karčauskienė¹, V. Feiza², D. Feizienė², R. Repšienė¹, G. Šiaudinis¹

¹Lietuvos agrarinių ir miškų mokslų centro Vėžaičių filialas

²Lietuvos agrarinių ir miškų mokslų centro Žemdirbystės institutas

Santrauka

Daugelis dirvožemio gerinimo priemonių yra tiesiogiai susijusios su pasėlių piktžolėtumo mažinimu. Vakarų Lietuvoje vyraujančio rūgštaus moreninio priemolio nepasotintojo balkšvažemio tvarus naudojimas siejamas su tinkamo intensyvumo kalkinimu ir žemės dirbimu. Tyrimai atlikti 2015–2018 m. Lietuvos agrarinių ir miškų mokslų centro Vėžaičių filialo dviejuose ilgalaikiuose eksperimentuose: kalkinimo (įrengto 1949 m.) ir žemės dirbimo (įrengto 2003 m.). Tyrimo tikslas – nustatyti sėjomainos pasėlių piktžolėtumo kitimo tendencijas po ilgalaikio skirtingo intensyvumo agronominių priemonių (žemės dirbimo ir kalkinimo) taikymo. Žemės dirbimo variantai: gilus arimas (22–25 cm), sekus arimas (12–15 cm), sekus bearimis dirbimas (7–10 cm); kalkinimo variantai: nekalkinta (pH_{KCl} 4,0–4,1), kalkinta (pH_{KCl} 6,2–6,8). Tirti piktžolėtumo rodikliai: bendras piktžolių skaičius ir masė, piktžolių rūšių skaičius, sėklų bankas dirvožemio 0–10, 10–20 ir 20–30 cm sluoksniuose. Tyrimo rezultatai parodė, kad ilgalaikis kalkinimas turėjo įtakos vyraujančių acidofilinių piktžolių išnykimui pasėlių bendrijoje. Bendras piktžolių skaičius kalkintame dirvožemyje (pH 6,4–6,8) buvo 4,1 karto mažesnis, palyginus su natūraliai rūgščiu dirvožemiu (pH 4,0–4,1). Nors dirvožemio užterštumas piktžolių sėklomis buvo 14,2 karto didesnis natūraliai rūgščiam dirvožemyje, tačiau, nepriklausomai nuo dirvožemio rūgštumo (pH), jų pasiskirstymas vertikaliai dirvožemio sluoksniuose buvo panašus. Pasėlių piktžolėtumą mažo rūgštumo (pH 5,1–5,3) dirvožemiuose mažino ilgalaikis gilus arimas. Bendras piktžolių skaičius ir jų masė buvo 1,6 ir 1,4 karto didesni sekliai dirbtame dirvožemyje. Ilgalaikis žemės dirbimas turėjo įtakos dirvožemio supurenimo gyliui, lemiančiam vertikalų piktžolių sėklų pasiskirstymą. Dirbant sekliai, piktžolių sėklomis labiausiai užterštas buvo dirvožemio 0–10 cm sluoksnis.

Reikšminiai žodžiai: kalkinimas, piktžolių skaičius ir masė, rudeninis žemės dirbimas, rūgštūs dirvožemiai, sėklų bankas.