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Changes in weed seed bank and flora as affected by soil tillage systems

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Abstract

Tillage not only changes soil properties but also serves as a weed control means. Different soil tillage systems were investigated in a long-term field experiment conducted during 2003–2012 at Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry. The experiment was carried out in a cereal-based crop rotation. The experimental design included the following tillage treatments: 1) conventional tillage (CT): mouldboard ploughing at 22–24 cm depth; 2) minimum tillage (MT): stubble cultivation at 10–12 cm depth, non-selective herbicide (glyphosate) spray applied after harvesting; 3) no tillage (NT): direct drilling, non-selective herbicide spray applied after harvesting. This paper presents the data from the 2007–2012 experimental period. To determine weed seed bank, soil samples were taken in 2007 after spring barley harvesting and in 2012 after winter oilseed rape harvesting. Samples of weeds for the determination of fresh and dry mass were collected in 2011 and 2012 in winter wheat and winter oilseed rape crops during the growing period.

The weed seed bank in the soil significantly decreased over the five-year period. However, significantly the highest number of seeds in the soil was found in the no tillage plots. Significant differences in the weed species composition between the different tillage systems were recorded: no tillage system promoted infestation of some broadleaf weeds, particularly *Capsella bursa-pastoris*. The lowest weed mass was determined for the conventional tillage plots, compared to minimum tillage, and especially no tillage plots.

Key words: soil, species composition, tillage, weeds, weed mass, weed seed bank.

Introduction

Weeds are a major problem in most cropping systems, and their control is essential for successful crop production. The goal of weed control is not only to prevent crop yield loss, but also to minimize weed seed reserves in the soil, because the soil seed bank is the primary source of new infestations of annual weeds and represents the majority of the weed species composition. The majority of seeds entering the seed bank come from annual weeds growing in the fields. The size of the seed bank reflects past and present field management (Auffret, Cousins, 2011). Weed seed bank analysis provides knowledge on the effect of agricultural management practices on weed community dynamics. Such knowledge is difficult to acquire from short-term studies based on actual weed flora, whose composition is subjected to considerable variation in time and space (Birthisel et al., 2015). Weed communities are also affected by crop type and sequence. Agricultural crops with different growth cycles (winter or spring) affect weed spread, germination and growth (Andrade et al., 2017).

Tillage is an important aspect of farm management. Non-inversion or minimum tillage reduces energy usage, enables faster soil preparation and improves soil aggregation (Vakali et al., 2011; Bottineli et al., 2017), but deep-tillage implements that invert soil layers, bury weed seeds deep enough to prevent their germination and emergence (Farmer et al., 2017). In some cases, integrated use of mouldboard plough reduced the emergence of weeds by at least 95% over two growing seasons (Bagavathiannan, Norsworthy, 2012).

The magnitude of the effects of management practices on soil properties have been reported in the numerous studies (Feiza et al., 2011; Velykis et al., 2014; Munkholm et al., 2016; Nugis et al., 2016). However, changes in agricultural management practices encourage changes in weed seed bank characteristics, which often lead to the changes in the size and species composition of the weed flora (Nichols et al., 2015). Species composition of the flora may be more important than the total number of seeds (Jastrzębska et al., 2013).

Nevertheless, results of some investigations showed a close relationship between the emerged weed plants at the soil surface and the seedbank in the following year (Sjursen et al., 2008).

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The weed seed bank develops in two ways: it increases in amount from those weed seeds that mature weed plants spread by wind and running water into soil, and decreases by that amount which germinates or is lost due to activity of soil fauna. The number of weed seeds increased at sites with a low crop cover and a high density of weed plants at the soil surface. For example, winter cereals, sunflowers and lupines increased the weed seed bank by 30–40%. Grass-clover mixtures, however, reduced the seedbank by 39% (Albrecht, 2005). Analysis of the size and composition of the weed seedbank in the soil can provide information on the past and present weed populations and forecast any future weed problems (Auffret, Cousins, 2011). Changes in the soil weed seed reserves depend on soil tillage, crop rotation, and weed control (Auškalnienė, Auškalnis, 2009; Skuodienė et al., 2013). Weed community composition in the surface (0–15 cm) layer seems more influenced by tillage system than by crop rotation (Barberi, Lo Cascio, 2001). Researchers have been interested in the use of weed management control strategies aimed at the reduction of the soil weed seedbank to prevent large above ground weed communities and reduce weed management costs (Nichols et al., 2015). Some studies showed that the weed population emergence after cultivation was related to the size and composition of the weed seed bank (Hossain, Begum, 2015), nonetheless in other studies the relationship was found between weed seed bank and aboveground communities only for a small number of weed species (Gomaa, 2016). Albrecht (2005) found that the number of weed seeds increased at sites with low crop cover and high density of weed plants at the soil surface. Earlier harvesting of spring barley at the milky stage of maturity essentially decreased the reserves of the soil seed bank (Pilipavičius, 2013).

The interest in reduced soil tillage in Lithuania has increased over the last ten years. It was established that shallow ploughing and rototilling did not exert any negative effect on soil agrochemical and physical properties and grain mycoflora (Feiza et al., 2011; Supronienе et al., 2011), nonetheless abandonment of soil ploughing and use of shallow loosening by a rotary cultivator, compared with deep ploughing, resulted in an increase in weed incidence (Juchnevičienė et al., 2012).

The influence of tillage system on soil weed seed bank was investigated at the Institute of Agriculture in Lithuania. Previous studies showed that the highest number of weed seed species was found in the treatments with reduced and no tillage in the top soil layer (0–5 cm), in deeper soil layers no differences in species number of weed seeds were found (Auškalnienė, Auškalnis, 2009). Integration of preventive weed control measures with curative approaches should reduce weed management costs and the realization of its benefits for food security (Rao et al., 2017). Knowledge of associations between weed seed bank and management practices is an essential step towards development of alternative weed management strategies (Lal et al., 2016).

The aim of the present study was to evaluate the influence of different soil tillage intensities on the soil weed seed bank and weed flora.

Materials and methods

Long-term field experiments were conducted during 2003–2012 at the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, in Dotnuva (55°23′50″ N and 23°51′40″ E), Central Lithuania. The sequence of crops rotation was as follows: winter wheat (2003–2004, 2007–2008, 2010–2011), winter oilseed rape (2011–2012), spring wheat (2005), spring barley (2006, 2009) and field pea (2007, 2010). The soil was prepared according to the experimental design: 1) stubble cultivation to 10–12 cm depth, ploughing to 22–24 cm depth, tillage with a precision seedbed cultivator before sowing to 4–5 cm depth, sowing with a disc coulter drill – conventional tillage (CT); 2) stubble cultivation to 10–12 cm depth, sowing with a disc sowing aggregate non-selective herbicide (glyphosate) spray applied after harvesting – minimum tillage (MT); 3) direct drilling; non-selective herbicide (glyphosate) spray applied after harvesting – no tillage (NT). This paper presents the data from the 2007–2012 experimental period.

The field experiment was arranged as block design in four replicates. Gross plot size was 10 × 20 m and net harvested plot size 2.3 × 10 m. According to WRB (2014), the soil is classified as an *Endocalcari-Epigleyic Cambisol* (*CM-g.lp-can*), of a loam texture (Table 1).

Table 1. Physico-chemical properties of the experimental site (Dotnuva, Kėdainiai distr.)

Soil characteristics	Depth		
	0–10 cm	10–20 cm	20–30 cm
Texture	loam	loam	loam
pH	7.0	7.0	6.9
P_2O_5 mg kg^{-1}	256	201	206
K_2O mg kg^{-1}	272	228	216
Total N g kg^{-1}	1.52	1.46	1.39
Humus g kg^{-1}	22.1	21.1	20.1
Field capacity m^3 m^{-3}	0.31	0.30	0.28

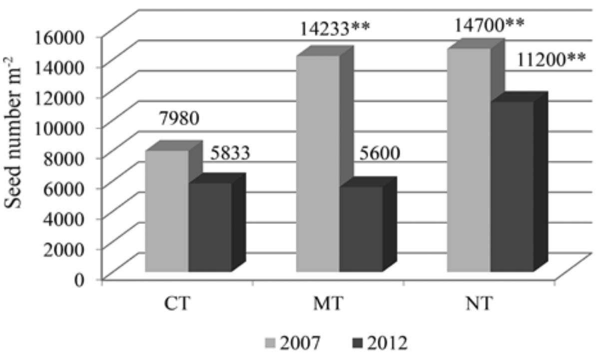
To determine soil weed seed bank, soil samples were taken in 2007 and 2012 after the harvesting of spring barley (2007) and winter oilseed rape (2012). Two soil cores from 0–10 cm depth were randomly taken from each plot, using a 5 cm diameter steel probe. The samples were stored at 4°C in the dark until processing (Barberi, Lo Cascio, 2001). The soil samples were placed into sieves (screen size 0.25 mm) and soaked in water for 10 minutes to soften. After soaking, the soil was placed under running tap water and hand manipulated to remove fine soil particles. After completion of soil washing, the remaining contents were dried on filter paper in glass Petri dishes. The dried samples were passed through sieves with a screen size ranging from 1.6 to 0.5 mm. After sieving, the contents of each sieve were analysed. Weed seeds were counted and identified using binoculars with 8$^{\times}$ magnification. Seed viability was determined by "destructive crushing" using forceps (Rahman et al., 1995). The above ground number and mass of weeds were established twice: in 2011 and 2012 in mid-summer in winter wheat (2011) and winter oilseed rape (2012) crops. Weeds were hand-harvested using 0.25 m^{-2} random quadrats for each plot with four replications (Rial-Lovera et al., 2016).

The data were subjected to the analysis of variance (*ANOVA*) from package *SELEKCIJA* (Raudonius, 2017). To achieve the homogeneity of variance, the data were (log + 2) transformed.

Results and discussion

It has been previously documented that long-term cultivation and different tillage systems produce important changes in the composition and density of soil seed banks (Cardina et al., 2002; Gulshan et al., 2013).

In our study, the soil weed seed bank varied in density depending on the tillage system (Fig. 1).



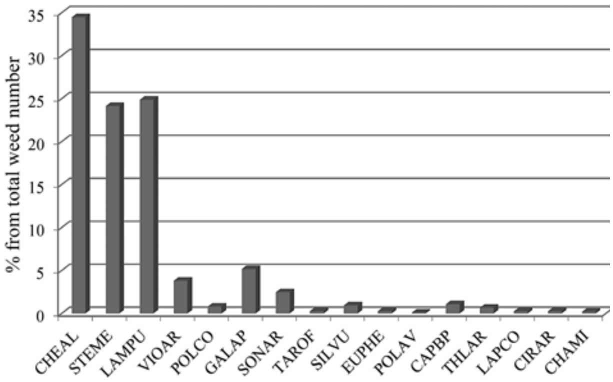
** – significant at $P < 0.01$ between treatments; CT – conventional tillage 20–22 cm depth, MT – minimum tillage 10–12 cm depth, NT – no tillage

Figure 1. Changes in the number of weed seeds in 0–10 cm soil layer as influenced by the different tillage systems (2007 and 2012)

As is seen from Figure 1, the highest number (14700) of weed seeds m^{-2} was extracted from the soil samples taken from the no tillage plots. Similar seed counts (14233) were found in the minimum tillage plots, while the seed counts in the conventional tillage plots were significantly lower (over a five-year period the soil weed seed bank significantly ($P > 0.01$) decreased). However, the differences between the tillage systems remained – in less disturbed soil there was a significantly higher weed seed number, compared to conventional tillage.

Sixteen weed species were found in the soil weed seed bank in the study area. The main weeds in weed seed bank were annual dicotyledonous: *Chenopodium album*, *Stellaria media* and *Lamium purpureum*, prevalent in 2007 (Fig. 2).

In 2007, weed species composition in all tillage systems was similar: *C. album* in all treatments composed 32.2–35.6%, *S. media* 21.7–26.6%, *L. purpureum* 19.3–29.8% of the total weed count (Table 2).



CHEAL – *Chenopodium album*, STEME – *Stellaria media*, LAMPU – *Lamium purpureum*, VIOAR – *Viola arvensis*, POLCO – *Fallopia convolvulus*, GALAP – *Galium aparine*, SONAR – *Sonchus arvensis*, TAROF – *Taraxacum officinale*, SILVU – *Silenia vulgaris*, EUPHE – *Euphorbia helioscopia*, POLAV – *Polygonum aviculare*, CAPBP – *Capsella bursa-pastoris*, THLAR – *Thlaspi arvense*, LAPCO – *Lapsana communis*, CIRAR – *Circium arvense*, CHAMI – *Chaenorhinum minus*

Figure 2. Weed species composition in the weed seed bank (in 2007)

Table 2. Weed seed species composition (%) in 0–10 cm soil layer in different tillage systems (in 2007)

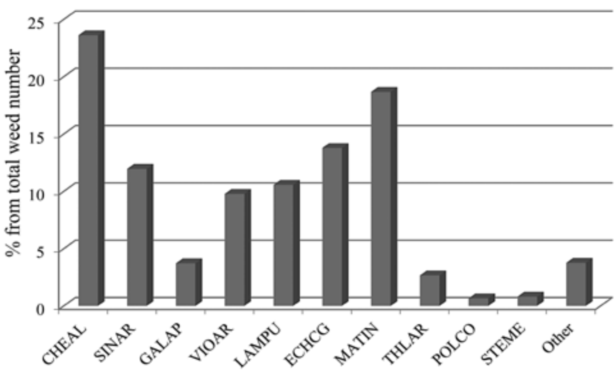
Weed species	Tillage system		
	CT	MT	NT
Chenopodium album L.	35.6	32.2	35.6
Stellaria media (L.) Vill.	24.1	21.7	26.6
Lamium purpureum L.	25.5	29.8	19.3
Viola arvensis Murray	3.9	3.8	3.7
Fallopia convolvulus (L.) À. Löve	0.8	0.8	0.8
Galium aparine L.	5.0	5.8	4.7
Sonchus arvensis L.	2.0	1.7	3.7
Taraxacum officinale F.H. Wigg	0.6	0.0	0.2
Silenia vulgaris (Moench) Garcke	0.3	1.9	0.6
Euphorbia helioscopia L.	0.6	0.2	0.0
Polygonum aviculare L.	0.3	0.0	0.0
Capsella bursa-pastoris (L.) Medik.	0.6	0.2	2.4
Thlaspi arvense L.	0.8	0.6	0.6
Veronica hederifolia L.	0.0	0.0	0.0
Lapsana communis L.	0.0	0.6	0.2
Cirsium arvense (L.) Scop.	0.0	0.6	0.2
Chaenorhinum minus (L.) Lange	0.0	0.2	0.4

CT – conventional tillage 20–22 cm depth, MT – minimum tillage 10–12 cm depth, NT – no tillage

All other weeds composed 8–26.8% of the total weed count. Species composition in the weed seed banks changed during the five years' period. The number of weed species slightly decreased from sixteen to twelve. Some species disappeared and new species emerged, especially high incidence was recorded for *Tripleurospermum inodorum* and annual monocotyledonous weeds, particularly *Echinochloa crus-galli* (Fig. 3).

Changes in weed species composition occurred in all tillage systems – in the minimum tillage and no tillage plots a significant increase in *T. inodorum* and a decrease in *C. album* were recorded. *E. crus-galli* were found in all tillage systems, with particularly high incidence recorded in minimum tillage treatment 22% from the total weed number present in the sample (Table 3).

This is in line with the findings of Barberi and Lo Cascio (2001) suggesting that different soil tillage systems produce important changes in density of soil seed bank and this difference takes short time to become evident (Feldman et al., 1997). The results of our investigations, suggesting that systems causing less soil disturbance allow the build-up of larger soil seed bank, agree with those of Feldman et al. (1997). The highest density of weed seeds in the no tillage system, as compared to the conventional system, has been reported by Cardina et al. (2002) as well. According to Feldman et al. (1994), this



CHEAL – *Chenopodium album*, SINAR – *Sinapis arvensis*, GALAP – *Galium aparine*, VIOAR – *Viola arvensis*, LAMPU – *Lamium purpureum*, ECHCG – *Echinochloa crus-galli*, MATIN – *Tripleurospermum inodorum*, THLAR – *Thlaspi arvense*, POLCO – *Fallopia convolvulus*, STEME – *Stellaria media*

Figure 3. Weed species composition in the weed seed bank (in 2012)

can be accounted for by the two factors: accumulation of crop residues on the surface, therefore more protection from predation and less movement of seeds along the soil profile, therefore less dormancy-breaking mechanisms and lower exposure of seeds to potential hazards. According to Ali et al. (2017), the highest number of seeds in no tillage system is related to the highest number of weed plants in the crops during the vegetation season.

The number of weed species found in our trials was comparatively low, while Barberi and Lo Cascio (2001) found more than 40 weed species in the soil seed bank. The differences could be explained by different crop management – conventional in our study and organic in the aforementioned authors' study. A common observation in the studies done in different countries was that weed species diversity increased when arable farming had been changed from conventional to organic management (Albrecht, 2005; Rial-Lovera et al., 2016). On the other hand, the use of herbicides led to a decrease of diversity – in our study the number of weed species decreased from 16 to 12. The composition of weed seed bank was similar to that reported by other authors – more than 90% of species were broadleaf weeds (Skuodienė et al., 2013, Ali et al., 2017).

Table 3. Weed species composition (%) in the weed seed bank in 0–10 cm soil layer after five years (in 2012)

Weed species	Tillage system		
	CT	MT	NT
Chenopodium album L.	33.3	18.0	19.5
Sinapis arvensis L.	28.6	0.0	7.3
Galium aparine L.	7.1	4.0	0.0
Viola arvensis Murray	7.1	10.0	12.2
Lamium purpureum L.	2.4	22.0	7.3
Echinochloa crus-galli (L.) P. Beauv.	7.1	22.0	12.2
Tripleurospermum inodorum (L.) Sch. Bip.	11.9	10.0	34.1
Thlaspi arvense L.	0.0	8.0	0.0
Fallopia convolvulus (L.) À. Löve	0.0	2.0	0.0
Stellaria media (L.) Vill.	0.0	0.0	2.4
Other	2.4	4.0	4.9

CT – conventional tillage 20–22 cm depth, MT – minimum tillage 10–12 cm depth, NT – no tillage

Weed communities are influenced by many factors including cropping systems and tillage practices (Kelton et al., 2011). Weed mass was examined twice in winter crops, in 2011 in winter wheat and in 2012 in winter oilseed rape at mid-summer. Significant differences between the tillage systems and years were recorded (Fig. 4).

The two-way analysis of variance (*ANOVA*) showed that the highest weed mass (P > 0.01) was recorded in no tillage system, whereas the lowest ($P > 0.01$) in conventional system. A higher weed mass was recorded in winter oilseed rape crop. This could be explained not only by the influence of meteorological conditions, but also growing technology and different competitiveness of crops.

According to the averaged data, *Capsella bursa-pastoris* was more prevalent in both years and accounted for more than 50% of the total weed number. Frequent weeds in winter wheat and winter oilseed rape crop were *T. inodorum*, *Viola arvensis* and other annual dicotyledonous weeds (Fig. 5).

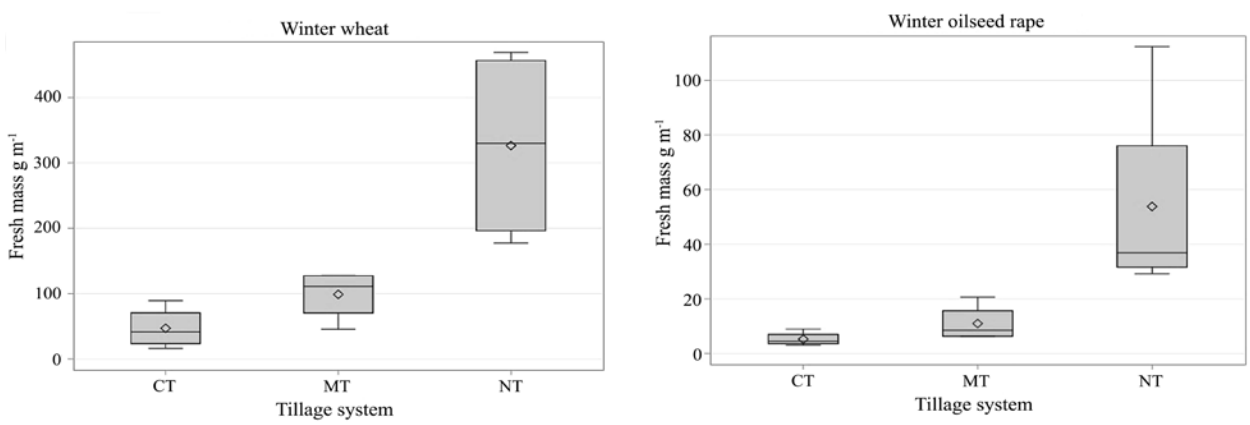
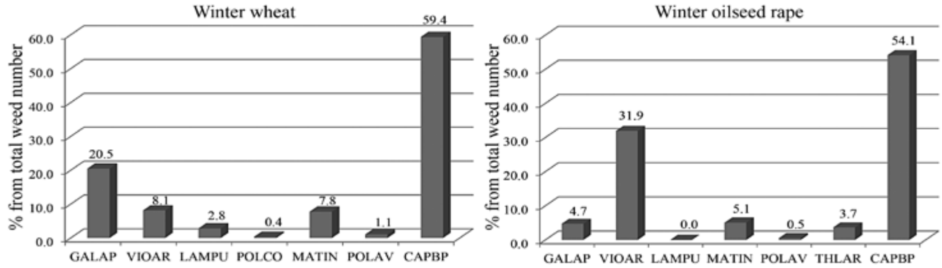


Figure 4. Weed fresh mass in different soil tillage systems in winter wheat (2011) and winter oilseed rape (2012) crops



Explanations of acronyms under Figures 2 and 3

Figure 5. Weed species composition in winter wheat (2011) and winter oilseed rape (2012) crops

Especially high number and mass of *C. bursa-pastoris* were recorded in the no tillage plots, where it composed more than 70%, whereas *V. arvensis* was more frequent in conventional tillage plots. Other researchers (Steckel et al., 2007) have documented different responses by individual species under varying tillage practices and over time.

Conclusions

1. Soil weed seed bank varied in density in response to the tillage system applied. The number of weed seeds in the soil was significantly higher in less disturbed soil, particularly in the minimum tillage (MT) treatment. No significant differences in the size of weed seed bank between the minimum tillage and no tillage (NT) treatments were found.

2. Over the five-year period, the weed seed bank significantly decreased, the number of weed species in the soil weed seed bank decreased as well.

3. Apparent differences were recorded in the weed species composition of weed flora in different tillage systems: no tillage promoted infestation of some broadleaf weed species, rapidly increasing the total weed biomass, particularly *Capsella bursa-pastoris*.

4. In the conventional tillage plots, weed mass was significantly lower compared to lower intensity soil tillage systems: minimum tillage and, especially, no tillage, irrespective of the year.

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Piktžolių sėklų banko ir floros pokyčiai priklausomai nuo žemės dirbimo

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Santrauka

Žemės dirbimas ne tik keičia dirvožemio savybes, bet ir yra piktžolių kontrolės priemonė. 2003–2012 m. Lietuvos agrarinių ir miškų mokslų centro Žemdirbystės institute buvo vykdytas stacionarus lauko eksperimentas, kuriame tirti įvairūs žemės dirbimo būdai: 1) klasikinis intensyvus dirbimas (skutimas 10–12 cm gyliu + arimas 22–24 cm gyliu): prieš sėją dirbta kombinuotu dirvos paruošimo agregatu 4–5 cm gyliu ir sėta diskine sėjamąja; 2) seklus neariminis pagrindinis (minimalus) žemės dirbimas 10–12 cm gyliu: prieš sėją dirbta kombinuotu dirvos paruošimo agregatu 4–5 cm gyliu, sėta diskine sėjamąja, po derliaus nuėmimo purkšta neatrankinio veikimo herbicidu (v. m. glifosatas); 3) žemė nedirbta – tiesioginė sėja: po derliaus nuėmimo purkšta neatrankinio veikimo herbicidu. Eksperimentas vykdytas javų pagrindu sudarytoje sėjomainos rotacijoje. Dirvožemio ėminiai piktžolių sėklų kiekiui ir pasiskirstymui nustatyti buvo paimti 2007 ir 2012 m. po vasarinių miežių (2007) ir žieminių rapsų (2012) derliaus nuėmimo. Piktžolių žalia masė nuimta 2011 ir 2012 m. žieminių kviečių ir žieminių rapsų pasėlyje intensyvaus augalų augimo metu. Per penkerių metų laikotarpį piktžolių sėklų kiekis dirvožemyje esmingai sumažėjo. Esmingai didžiausias piktžolių sėklų kiekis buvo tiesioginės sėjos laukeliuose. Piktžolių rūšinė sudėtis skyrėsi nevienodai įdirbtuose laukeliuose – tiesioginės sėjos laukeliuose itin išplito trikertė žvaginė (*Capsella bursa-pastoris* (L.) Medik.). Mažiausia piktžolių masė nustatyta taikant intensyvų žemės dirbimą, lyginant su minimalaus dirbimo ir ypač tiesioginės sėjos laukeliais.

Reikšminiai žodžiai: piktžolės, piktžolių masė, piktžolių sėklų bankas, žemės dirbimas.