Agronomy Research **14**(4), 1372–1379, 2016

Soil weed seed bank and factors influencing the number of weeds at the end of conversion period to organic production

J. Kuht*, V. Eremeev, L. Talgre, H. Madsen, M. Toom, E. Mäeorg and A. Luik

Estonian University of Life Sciences, Kreutzwaldi 1, EE51014 Tartu, Estonia
*Correspondence: jaan.kuht@emu.ee

Abstract. In 2008 an experiment was set up on the field in Eerika experimental station (Estonian University of Life Sciences) as a 5-field crop rotation: red clover, winter wheat, pea, potato and barley undersown with red clover. The objective of the study was to measure the content of weed seeds in the soil and to evaluate the diversity of the species at the end of the period of converting to organic production. In conventional farming systems without fertilizer (Conv I) and conventional farming with mineral fertilizer (Conv II) herbicides were used for weed control. All the crops in Conv II system received P 25 kg ha^{-1} and K 95 kg ha^{-1}, but the application rates of mineral nitrogen fertilizer differed. In organic systems (Org I – organic farming based on winter cover crop and Org II - organic farming based on winter cover crop and manure), the winter cover crops (ryegrass after winter wheat, winter oilseed rape after pea, winter rye after potato) were sown after the harvest and were ploughed into the soil as green manure in spring. The content of annual weed seeds was the lowest in red clover that had 17.7% less weed seeds in the soil of Org II system compared to control (Conv I). In winter wheat the content of winter annual weed seeds was 50–76% higher compared to other crops. By the end of 2009 the content of organic carbon (Corg %) in the soil had increased significantly in both organic systems which results in higher activity of organisms that decrease the viability of weed seeds.

Key words: organic farming, soil, weed seeds, seed bank, crop rotation, winter cover crops.

INTRODUCTION

The conversion to organic farming is related to several problems. During the conversion period many growers observe the decrease in crop yields as no synthetically produced pesticides and fertilizers are used anymore. On the contrary Carolyn et al. (2012) found that the yields of organically produced corn and soybean remained the same during the 3-year conversion period and even increased compared to the yields of conventional farming in the 4th year. The conversion period to organic production lasts at least two years in Estonia (Palts & Vetemaa, 2012). As chemical pest control products cannot be used, the most challenging task is to control the weeds and poor weed control is often cited as a major reason for lower yields in organic production (Gianessi & Reigner, 2005). Most weeds start to germinate from viable seeds which have been incorporated into the soil over time. Environmental conditions in soil, including temperature, water content, compaction, texture and air content can impact the timing of germination and the number of germinated seeds (Egley, 1995). With intensive cultivation and compaction especially in the conventional production systems the balance of soil air and water regime has been interrupted and its structure destroyed

(Verhulst et al., 2010). In conventional farming where agricultural machinery is intensively used (including fertilization and chemical pest control) the soil is more compact. It has been observed that after 6 times of wheeling the bulk density of soils increased by 0.15 Mg m^{-3} whereas soil penetration resistance increased by 3.0 MPa compared to the unmanaged soils (Reintam et al., 2009).

The soil weed seed bank consists of many different species and dominant species can account for up to 70–90% of the seed number in soil. The amount of weed seeds considerably varies depending on soil type, crops grown, crop rotation, cultivation methods and the use of herbicides (Grundy & Jones, 2002). Therefore each method that enables to reduce the soil weed seed bank in organic agriculture is of high value. Today, Estonian farmers usually apply herbicides to control weeds. After conversion to organic farming this tool is no longer available and weed control has to be accomplished by inversion tillage, mechanical weeding, weed suppressing crop rotations and other methods usually applied in organic agriculture. This research is valuable because organic farming may continue to gain importance in the future and there were no studies on the effects of organic crop production on weed seed bank in Estonia at the end of the period of converting to organic crop production.

The objective of the study was to determinate the content of weed seeds in the seed bank and to evaluate the diversity of the species at the end of the period of converting to organic production.

MATERIALS AND METHODS

In 2008 an experiment was set up in test site of the Estonian University of Life Sciences in Eerika (58°22′ N, 26°40′ E) as a 5-year rotation: red clover (*Trifolium pratense* L.), winter wheat (*Triticum aestivum* L.), pea (*Pisum sativum* L.), potato (*Solanum tuberosum* L.) and barley (*Hordeum vulgare* L.) undersown with red clover. First 5-year rotation ended in 2012. Samples for measuring the weed seedbank were collected in September 2010, at the end of conversion period (2008–2010) to organic production. The experiment was set up in four replications (80 plots), size of the plot was 60 m^2 in a systematic block design. Each plot was 6 meters wide and 10 m long. Organic and conventional plots were separated with an 18 m long section of mixed grasses to avoid contamination with synthetic pesticides, mineral fertilisers and winter cover crops. In systems Conv I (conventional farming without fertilizers (as control)) and Conv II (conventional farming with mineral fertilizers) the weed content was performed with herbicides. In conventional system Conv II all the crops received phosphorous (P 25 kg ha^{-1}) and potassium (K 95 kg ha^{-1}). The amount of nitrogen (N) varied depending on the crop: for pea N 20 kg ha^{-1}, for barley undersown with red clover N 120 kg ha^{-1}, for winter wheat and potato N 150 kg ha^{-1}. Plots with red clover did not receive any mineral fertilizers and chemical pest control. Two organic farming systems (Org I and Org II) were investigated. In both systems winter cover crops as green manure were used. Cover crops were sown right after the harvest: ryegrass (*Lolium perenne* L.) after winter wheat, winter oilseed rape (*Brassica napus* L., *var. oleifera, subvar. biennis*) after pea, winter rye (*Secale cereale* L.) after potato. Before sowing the subsequent crop all cover crops were ploughed into the soil as green mature. In the organic system Org II fully composted cattle manure was added in the autumn 2009 and in spring 2010 at a rate 40 t $ha^{-1}$and ploughed into soil. To analyse soil chemical parameters soil samples were collected at depths of 0–25 cm in spring 2008 and 2009. Organic C (Corg %) and total nitrogen content were measured by Dumas dry combustion method, by using the elemental analyser VarioMAX. Samples for measuring the weed seed bank were collected in September 2010, at the end of conversion period (2008–2010) to organic production. The weed seed bank samples were taken with soil borersafter crop harvest and before autumn ploughing. From each plot 16 soil samples were taken from the depth of 0–25 cm soil layer. Samples of each plot were mixed together in a bucket. The samples were air-dried and 500 g of each sample were sieved and washed through a 0.25 mm sieve. Weed seeds were separated from the soil by potassium carbonate (K_2CO_3) aqueous solution. For preparation of the solution 2.0 kg of potassium carbonate was dissolved in 1.8 l of water. A cone penetrometer (Eijkelkamp Penetrologger with 69 degree, 1 cm^2 cones) was used for measuring the penetration resistance of soil. The number of weed seeds in seed bank was calculated to an area of 1 m^2 using method described by Vipper (1989) with two different formula. We convert these into a joint formula as shown below (Eq. 1):

$$N = \frac{h \cdot D_b \cdot n \cdot 10}{S_p} \qquad (1)$$

where: N – number of viable seeds (n m^{-2}); h – depth of plough layer (cm); D_b – soil bulk density (g cm^{-3}); n – counted number of seeds in the soil sample; S_p – weight of dry soil sample (g).

The species composition of weed seed communities and the number of seeds of each species were used to assess the biodiversity.

The diversity indexes of weed seed species were calculated as Shannon-Wiener diversity index (Shannon, 1948) of weed species diversity H' (Eq. 2):

$$H' = -\sum_{i=1}^{s} pi \ln(pi) \qquad (2)$$

where the p_i's are the proportion of all observations in the i^{th} species category.
Simpsons' index (Simpson, 1949) of weed species domination (Eq. 3):

$$\lambda = \sum_{i=1}^{s} pi^2 \qquad (3)$$

where: p_i is the share of i^{th} species in the sample.
The formula to calculate Pielou evenness index (Pielou, 1966; Boyce, 2005) is (Eq. 4).

$$J' = \frac{H'}{H'max} \qquad (4)$$

where: H'_{max} = ln(S); S – number of species.

The results were analysed by using STATISTICA 7.0: ANOVA, Fisher (LSD) test (Statsoft Inc, 2005). Correlation analysis was used to study the correlation between different number of weed seeds and some indicators of soil physical properties. Linear correlation coefficients between variables were calculated, the significance of coefficients being $P < 0.001$, $P < 0.01$, $P < 0.05$.

RESULTS AND DISCUSSION

On average, the lowest content of weed seeds was observed in the Conv II system (Table 1). On average for the crop rotation there were 7,500 less seeds per m^2 than in Conv I. In Org II system where cover crops and manure were used there were 11.0% more weed seeds than in Conv II system, but 14.3% less weed seeds compared to control (Conv I). Within crops there were 2,800–9,100 less seeds per m^2 in red clover variants, while wheat variants had the highest number of weed seeds (Table 1). There were more than ten times less seeds of winter weeds compared to summer weeds and also these were more unevenly distributed, causing these results to be out of confidence limits. Only in winter wheat plots the significant (71.0%) decrease of the number of seeds of winter weeds was observed in Conv II system and 35–37% decrease in organic systems Org I and Org II compared to Conv I system (Table 1).

The lower abundance of seeds of summer weeds compared to Org I system was apparent for all the crops where manure had been applied in Org II system, where statistically significant decrease of weed seeds was observed: 14.0% for undersown barley, 17.0% for red clover, 26% for winter wheat and for pea (Table 1). In Org I system the number of seeds of summer weeds remained within the experimental deviation limits, only exception being potato where significant (28.0%) decrease of weed seeds was observed compared to control variant.

Table 1. Number of annual (summer, winter and total) weed seeds in the soil of the different crops in 2010

Crop and preceding crops	Weed seeds	Number of weed seeds, 1,000 seeds per m^2				
		Conv I	Conv II	Org I	Org II	Average
Barley, undersown	Summer annual	30.38[a*]	32.62[a]	34.72[a]	26.04[b]	30.94
1) potato	Winter annual	1.96[a]	0.70[a]	2.10[a]	1.82[a]	1.65
2) pea	Total	32.34[a]	33.32[a]	36.82[a]	27.86[b]	32.59
Red clover	Summer annual	29.40[a]	17.50[b]	32.48[a]	24.64[b]	25.95
1) barley, undersown	Winter annual	0.14[b]	1.12[ab]	0.84[ab]	2.80[a]	1.23
2) potato	Total	29.54[a]	18.60[b]	33.32[a]	27.44[b]	27.23
Winter wheat	Summer annual	37.24[a]	20.72[b]	42.84[a]	27.72[b]	32.13
1) red clover	Winter annual	6.86[a]	1.96[c]	4.34[b]	4.48[b]	4.41
2) barley, undersown	Total	44.10[a]	22.68[b]	41.18[a]	32.20[b]	35.04
Pea	Summer annual	28.28[a]	30.52[a]	38.08[a]	25.34[b]	30.56
1) winter wheat	Winter annual	0.98[ab]	2.94[a]	1.54[ab]	1.12[b]	1.65
2) red clover	Total	29.26[a]	33.46[a]	39.62[a]	26.46[b]	32.20
Potato	Summer annual	38.6[a]	26.26[b]	27.82[b]	38.09[a]	32.70
1) pea	Winter annual	0.91[a]	1.69[a]	0.91[a]	0.78[a]	1.07
2) winter wheat	Total	39.52[a]	27.95[b]	28.73[b]	38.87[a]	33.77
Average	Summer annual	32.78[a]	25.52[b]	35.19[a]	28.37[ab]	30.47
	Winter annual	2.17[a]	1.68[a]	1.95[a]	2.20[a]	2.00
	Total	34.95[a]	27.20[b]	37.14[a]	30.57[ab]	32.47

Note. Within the same row, values with different letters are significantly different (ANOVA, Fisher (LSD) test); 1) – preceding crops in 2009; 2) – preceding crops in 2008.

According to Lithuanian authors (Boguzas et al., 2004) there were 28% more weed seeds in plots where manure was applied at the start of conversion period to organic cultivation compared to conventional system, but during the 6th cultivation season the number of weed seeds was similar in both systems. In 7-year organic cultivation experiment in Germany it was concluded that the soil weed seed bank was reduced by 39.0% when grasses undersown with clover were used (Albrecht, 2005).

On average for the crops used in rotation (Table 1) the Shannon-Wiener diversity indexes (H') were similar in Conv I and Org II variants, while being higher by 0.12–0.14 compared to Conv II and Org I variants (Table 2). On the other hand, the Simpson's indexes of domination (λ) of Conv II and Org I variants were lower by 0.05–0.09 compared to Conv I and Org II variants. The effect of fertilization was observed for the Pielou evenness indexes (J'): it was the highest in unfertilized Conv I variant and differed by 0.07 in Conv II (mineral fertilizer), by 0.06 in Org II (manure and winter cover crops) and only by 0.12 in Org I variant (only winter cover crops were used).

Table 2. Species diversity (Shannon-Wiener), Simpson domination index and evenness index of the arable weed seed bank in different crops in 2010

Crops	Shannon-Wiener diversity index, *H'*				Simpson's domination index, λ				Pielou evenness index, *J'*			
	Con I*	Con II	Org I	Org II	ConI	Con II	Org I	Org II	ConI	Con II	Org I	Org II
Barley	0.76	0.53	0.56	0.66	0.65	0.77	0.78	0.68	0.47	0.27	0.29	0.38
R. clover	0.70	0.8	0.56	0.89	0.64	0.64	0.75	0.59	0.44	0.45	0.31	0.43
W. wheat	1.07	0.69	0.90	0.98	0.49	0.68	0.61	0.57	0.49	0.43	0.41	0.50
Potato	0.65	0.66	0.48	0.45	0.69	0.72	0.8	0.81	0.40	0.37	0.25	0.23
Pea	0.75	0.6	0.73	0.77	0.67	0.74	0.67	0.68	0.38	0.31	0.35	0.37
Average	0.79	0.66	0.65	0.78	0.63	0.71	0.72	0.66	0.44	0.37	0.32	0.38

* Con I (or II) = Conv I (or II).

In experiments by Edesi et al. (2012) it was observed that the land use intensity influenced the diversity of weed species. The average values of Shannon-Wiener diversity index were statistically higher in the organic (organic with green manure – 1.70, organic with cattle manure and green manure – 1.65) than in the conventional (1.06; $p < 0.05$) treatment.

According to Albrecht (2003) the activity of organisms detrimental to weed seeds may be increased due to large amounts of organic fertilizers and therefore the soil weed seed bank is reduced. The content of organic carbon (Corg) which formerly decreased due to lower organic matter input and frequent tilling remains the same or increases due to the application of organic fertilizers (Paustian et al., 1997; Blair, 2000). In the present experiment the highest amounts of organic matter were applied in the Org II system where winter cover crops and manure were additionally applied (Table 3). Due to this organic matter the Corg content in soil was significantly increased in both organic cultivation systems by the end of 2009. According to Kauer et al. (2015a; 2015b) the level of Corg in Org I and Org II systems remained higher than in conventional systems also during succeeding growing seasons.

There were 59 species of ground beetles in the present test area in 2010. The dominant species was *Harpalus rufipes*. Zhang et al. (Zhang, 1993; Zhang et al., 1994) found that this species is an important seed predator, whose larvae and adults both have seed predator qualities and according to Lalondea et al., (2012) it has great importance in areas where weed protection methods are limited. *Harpalus rufipes* damages the germination of the seeds of several annual weeds, including Common lambsquarters

(*Chenopodium album* L.), not only through direct consumption of seeds but also through burying activities of larvae and adult beetles to deeper soil layers where germination conditions are unfavourable (Hartke et al., 1998). Seed predators can damage up to 4,000 seeds per m^2 a day. As seed predators may significantly reduce the weed seed bank they may therefore be an important factor against weeds (Honek et al., 2003).

Table 3. Average C inputs (kg ha^{-1}) from main crops, winter cover crop (WCC), manure and weeds (based on the dry matter) in different farming systems per year

Farming system	Main crop	WCC	Weeds	Manure	Total
Conv I	3,226	0	0	0	3,226
Conv II	3,301	0	0	0	3,302
Org I	3,105	562	748	0	4,415
Org II	2,936	562	769	495	4,762

Our results indicated, that higher number of all species of ground beetles and lower number of weed seeds were found in areas where cover crops had been grown for green manure (Org I and Org II systems). The winter cover crops offer additional possibilities for overwintering of ground beetles.

In 2010 no significant differences in numbers of dominant species and other species of ground beetles were observed between variants. But according to Kruus et al. (2012) there was significantly higher number of ground beetles in organic variants of our experiment (especially in plots where pea was grown) in 2011. In 2010, the second most frequent seed predator was *Harphalus affinis* that was mostly abundant in plots where winter wheat was grown. *Harphalus affinis* prefers smaller seeds (Honek et al, 2003). The results of the multifactorial dispersion analysis indicated that the effect of management and the crop grown on the abundance of ground beetles was significant (F=1.765 ja F=2.109; $P \leq 0.001$).

The abundance and activity of many species of ground beetles is higher in no-tillage areas (Lalondea et al., 2012). For the seed predators to be able to damage the weed seeds in the soils of cultivated fields the physical properties of the soil have to be favourable (e.g. soil has to contain abundance of pores). Excessive compaction of soil affects nutrient uptake of cultivated plants and decreases their ability to compete with weeds (Reintam & Kuht, 2012).

In average the penetration resistance at the depth of up to 40 cm soil layer was lower in the crop rotation of conventional cultivation systems (Conv I and Conv II) compared to organic cultivation systems (Org I and Org II). But at the depth of 5 cm where it's easy for the seed predators to reach the seeds, the penetration resistance of the soil was 0.85–1.15 MPa. The correlative relationship between soil compaction and the number of weed seeds was observed (r = 0.59; P < 0.05). While at the time of sample collection the soil moisture content was ca 2% higher in organic variants (18.1%) than in conventional farming systems (16.3%), the soil could have lower penetration resistance. Therefore the different top soil conditions between variants could have contributed to the variation in activity of seed predators. According to Sanchez de Cima et al. (2012; 2015) the highest soil total porosity in 2011 was measured in organic system where manure had been applied (Org II, 44.7%) and the lowest in conventional system with no fertilization (Conv II, 40.9%). Hence the conditions for weed seed predators were more favourable in organic variants (especially in Org II) where manure had been applied compared to conventional farming system.

CONCLUSIONS

The unregularity of the number of weed seeds at the start of the conversion period to organic production changed to clear conformity where the variation in the abundance of weed seeds between variants became clearly apparent. Although the lowest number of weed seeds was measured in fertilized variant Conv II, significant reduction of the number of weed seeds in organic system was observed at the end of conversion period. In the soils of the organic cultivation system area where cover crops and manure had been used (Org II) the markedly lower content of weed seeds was observed compared to Org I system where only green manure had been applied. The decrease of the number of weed seeds in Org II system could have been due to the increase of content of soil organic carbon, higher number of species and the activity of seed predators in organic cultivation variants.

Hence the conditions for weed seed predators were more favourable in organic variants where manure had been applied compared to conventional farming system.

ACKNOWLEDGEMENTS. The authors gratefully acknowledge the financial support for this research provided by the ERA-NET CORE ORGANIC project FertilCrop and by Estonian University of Life Sciences project 8–2/P13001PKTM.

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