Quantitative and qualitative evaluation of weed seed bank in organic farming

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Abstract. The influence of organic farming on weed seed bank under two different crop rotations: with and without manure, was investigated in an organic farm of Kazliskiai over the period of 1997–2002. Proven by qualitative index, organic farming increases the diversity of weed species. Seeds of 10 weed species were found in one experimental field at the beginning of a transition period and, after 6-year organic farming, the diversity of weeds increased almost up to 16 species. In all years of the investigation, seeds of *Chenopodium album, Fallopia convolvulus* and *Stellaria media* were found in 0–25 cm soil layer. In the sixth year of organic farming there were found 26.3, 70.0 and 91.2% less seeds of the mentioned species, respectively, compared with the transition period. At the beginning of organic farming, the amount of weed seeds in the soil was 28.0% bigger in fields of crop rotation with manure, compared to crop rotation without manure but, in the sixth year of organic farming, the difference disappeared. All weeds were distributed into 3 biological and 4 ecophysiological groups and 3 types of dispersal. Most of seeds found in 0–25 cm soil layers were therophytes. Most of them germinate in summer, spread by water (barochory), because *Chenopodium album* dominates. Both in fields of the 1st and 2nd crop rotation and in all experimental years, the quantitative and qualitative distribution of weeds into biological, ecophysiological groups and types of dispersal was even, with the exception of ecophysiological groups in crop rotation with manure.

Key words: organic farming, weed seed bank, manure

INTRODUCTION

Organic farming has recently become of great interest in Lithuania. The main reason for this interest is the endeavour to conserve Lithuanian farming traditions, grow agricultural production without synthetic fertilisers and pesticides, conserve the environment, reduce production costs, and sell more production on foreign markets. So far 697 organic and transition period farms, with a total area 23,244 ha of land, have been certificated in Lithuania in 2003.

The resulting expansion of the organic farming area has been expected to enhance the biodiversity of agricultural habitats. Organic cropping practices can be hypothesised to support a higher number of weed species than conventional cropping and also to favour herbicide-susceptible and less nitrophilous species. According to Frieben (1996) and Hald (1999), the number of weed species is higher in organically than in conventionally cropped fields. An investigation by Becker and Hurle (1998) showed that long-term organic farming had not significant influence on the number of weed species in loam soil. However, soil coverage with weeds increased from 20% (over a transition period from conventional to organic farming) to 30% (in long-term organic farming).

Weeds are well adjusted to environmental conditions (Radosevich et al., 1997). Specific structure of fruits and seeds helps their spreading. Weeds mature, beyond comparison, more seeds than agricultural plants. For example, *Rumex crispus* L. plants mature 7,000 seeds; *Stellaria media* (L.) Vill – 15,000–25,000; *Chenopodium album* L. – up to 200,000; and *Amarantus retroflexus* L. even up to one million seeds. Using manure in organic farms increases the amount of weed seeds in soil. It has been indicated in literature that 60 Mg ha^{-1} manure brings 0.5–40 million viable weed seeds (Lazauskas, 1990).

The basic aim of weed control in organic farms is to eliminate weed seeds that already exist in the soil and restrict their substitution with new ones.

The aim of our investigation was to study the influence of organic farming on weed seed bank in 2 different crop rotations with and without manure.

MATERIALS AND METHODS

The investigation was carried out in an organic farm of Kazliskiai over the period of 1997–2002. The farm had gained the status of organic farm after a 3-year transition period. The farm is located in the southwestern part of Kaunas, in Lithuania, northern latitude – 54°53’, eastern longitude – 23°50’. Two crop rotations were established in the farm on arable land of 22 ha. The fields of the 1st crop rotation (5 fields) were fertilised with 50 Mg ha^{-1} manure in 1997. In the 2nd crop rotation (2 fields), the compound of vetch and oats was grown for grain with the purpose of increasing the amount of nitrogen in the soil. Crops and yields in both crop rotations have been marked in Table 1.

Table 1. Crops and yields in the 1st and 2nd crop rotation.

Year	Crop rotation I with manure		Crop rotation II without manure	
	Crop	Yield, Mg ha^{-1}	Crop	Yield, Mg ha^{-1}
1997	Grass-clover III year	5.60	Oats	3.90
1998	Winter wheat	4.60	Barley	3.45
1999	Barley	2.80	Compound of vetch and oats	1.83
2000	Grass–clover I year	7.90	Barley	3.06
2001	Grass–clover II year	6.40	Grass–clover I year	4.06
2002	Winter Wheat	4.00	Grass–clover II year	6.00

According to the new classification of soils 199(LTDK–99), systematic units that have been coordinated with FAO–UNESCO World soil map legends, predominant soils of the farm are *Endohypogleyi–Eutric Planosols –Ple –gln– w*, medium loam on light sandy loam. For soil sampling, stationary 100 m^{2} square plots of 10×10 m were arranged in each field. Each plot was split into 4 square shape replicates (5×5 m) of 25 m^{2}. Weed seed bank was investigated in all crop fields in autumn, using the small sample method (Stancevicius, 1980). Soil samples of the stationary 5×5 m squares have been taken in 15 replications by means of a 1.5 cm diameter soil borer from the 0–25 cm layer of each plot.

The preliminary two-way model (Y_{jl}) fitted to the data of the experiment had the form (Baltagi, 2001):

$$Y_{jl} = \alpha_j + \beta_l + \upsilon_{jl},$$

where α_j denotes the individual effect of rotation, β_l denotes unobservable time effect and υ_{jl} varies with individuals and time.

Statistical hypothesis:

$H_0 : p_{11} = p_{21}, p_{12} = p_{22} \dots p_{ni} = p_{nj}$

$H_1 : H_0$ wrong

Where $p_{11}, p_{12} \dots p_{ni}$ – a part of weed species or seed within the 1st crop rotation, $p_{21}, p_{22} \dots p_{nj}$ – a part of weed species or seeds within the 2nd crop rotation.

Hypothesis H_0 states that both in the soil of crop rotations and in survey years weeds were divided into biological and ecophysiological groups evenly according to the type of dispersal, H_1 – weeds spread into groups and types unevenly.

Statistical estimates:

$$\chi^2 = \sum_{i=1}\sum_{j=1} (O_{ij} - ((n_{i.} * n_{.j}) * n^{-1})) * ((n_{i.} * n_{.j}) * n^{-1})^{-1}$$

where χ^2 – Chi - Square; O_{ij} – i population part, in which the meaning of variable x passes to category j;

$\sum_{j=1}^{c} O_{ij}$ – number of initial members, in which the meaning of indication x is x_i;

$\sum_{i=1}^{r} O_{ij}$ - number of initial members, in which the meaning of indication y is y_j;

$n = \sum_{i=1}^{r} \sum_{j=1}^{c} O_{ij}$ - size of initial (Cekavicius & Murauskas, 2001).

Ecophysiological, biological and dispersal properties were subsequently attributed to each recorded species. The classification into ecophysiological and biological groups was made according to Monstvilaite and Ciuberkis (1978), Zanin et al. (1997). Only three dispersal modes were considered: by gravity, (barochory, B), by wind (anemochory, A), and by animals (zoochory, Z) (Grigas, 1986). Weed communities under 2 different crop rotations were compared by using “Sørenson’s Indices of Similarity” (Magurran, 1988) that allowed us to compare the stability of two different situations over time, high index values indicating strong similarity between the situations. The calculation was as follows:

Qualitative index = $[2C*(A + B)^{-1}]*100$

where C = number of species in common, A = total numbers of species in one of the two situations compared, and B = total number of species in the other situation;

Quantitative index = $[2N_t*(N_a + N_b)^{-1}]*100$

where N_t = sum of the lowest density values of the species common to the two situations compared, N_a = sum of the density values of all species in one situation, and N_b = sum of the density values of all the species in the other situation.

For each survey and crop rotation, the number of species and amount of seeds per m^{-2}, belonging to different weed categories, were counted and submitted to the independence test. Keeping survey years and crop rotation constant in turn, there were obtained contingency tables, to which the independence test was applied to detect any relationship between the size of each group and the rotation system, or between groups and survey years. The evaluation was performed by using the χ^2 test, the group of biennials being added to the hemicryptophyte plants.

RESULTS AND DISCUSSION

Floral analysis. In the years of the investigation, seeds of 34 weed species were found in the 0–25 cm soil layer of each field of an organic farm of Kazliskiai (20 annual, 1 biennial and 13 perennial species, Table 2). Weeds found belong to 12 families: *Asteraceae*, *Brassicaceae*, *Caryophyllaceae*, *Chenopodiaceae*, *Cyperaceae*, *Fabaceae*, *Juncaceae*, *Lamiaceae*, *Onagraceae*, *Poaceae*, *Polygonaceae*, and *Ranunculaceae*.

In all crop rotation fields, there were found more annual than perennial weeds (Table 3). In every year of the investigation, seeds of *Chennopodium album, Fallopia convolvulus* and *Stellaria media* were found in 0–25 cm soil layer. Compared to the starting of organic farming, more seeds of *Apera spica–venti, Galeopsis tetrahit*, *Juncus bufonius, Lamium purpureum, Rumex crispus, Sinapis arvensis* and *Viola arvensis* were found in the fifth and sixth year of organic farming.

The number of annual weed species increased in the sixth year of organic farming, compared to the first year, but the amount of seeds of these weeds decreased 2.3 and 1.7 times, respectively. At the same time, the number of perennial weed seeds in the soil had not changed significantly. According to Pupaliene (2004), the methods applied in an organic agricultural system created the most favourable conditions for the spreading of perennial weeds, especially *Cirsium arvense* and *Sonchus arvensis*.

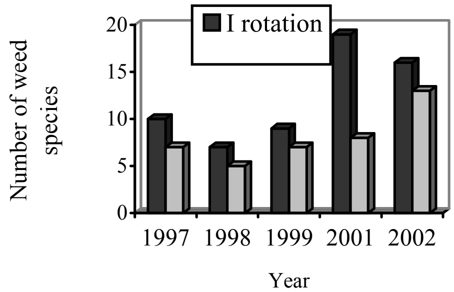
Total number of weed species found in soil over six years of organic farming increased 2.2 and 1.7 times, respectively (Fig. 1). According to Albrecht and Matteis (1996), the mean number of weed species in the organic system increased significantly, compared to conventional farming. Nevertheless, rare and endangered species scarcely showed and expanded neither in their population size nor in the distribution area. A lesser number of weed species in each experimental year was found in fields of the 2nd crop rotation, compared to fields of the 1st crop rotation, however, at the beginning of the transition period, the amount of weed seeds was bigger in fields of the 1st crop rotation (Fig. 2). In the sixth year of organic farming, the amount of weed seeds in fields of both crop rotations evened up. Investigations by Ciuberkis (2002) showed that fertilisation with manure increases crop weedness. On average 460 weed seeds were found in 1 kg of manure, mostly seeds of *Chenopodium album.*

Sørenson's indices of similarity. Smallest qualitative indices were ascertained between the fifth and first year of organic farming (Table 4). It proves that the composition of weed seed bank in the soil is changing. Quantitative indices in the fifth year of organic farming even increased, compared to the beginning of the transition period, however, in the sixth year they decreased again.

Table 2. Weed populations under crop rotation classified into biological groups (BG), ecophysiological groups (EG) and types of dispersal (D), 1997–2002.

Number	Species	BG	EG	D	Transition period						Organic farming			
					1997		1998		1999		2001		2002	
					I	II	I	II	I	II	I	II	I	II
1	*Achillea millefolium*	Hr	In	A							*			
2	*Alopecurus pratensis*	Hr	Au	B								*		
3	*Anthoxanthum odoratum*	Hr	Sp	B			*							
4	*Apera spica–venti*	Th	Au	B								*	*	*
5	*Artemisia vulgaris*	Hr	Sp	B							*			
6	*Capsella bursa pastoris*	Th	In	B	*				*	*				
7	*Carex sp.*	Hr	Sp	B								*		
8	*Cerastium arvense*	Hr	Sp	B	*									
9	*Chenopodium album*	Th	Su	B	*	*	*	*	*	*	*	*	*	*
10	*Chenopodium rubrum*	Th	Su	B						*				
11	*Cirsium arvense*	G	Sp	A							*		*	
12	*Convolvulus arvensis*	G	In	B			*							
13	*Epilobium montanum*	Hr	In	B								*		
14	*Euphorbia helioscopia*	Th	Sp	B				*						
15	*Fallopia convolvulus*	Th	Sp	B	*	*	*	*	*	*	*	*	*	*
16	*Galeopsis tetrahit*	Th	Sp	B							*		*	*
17	*Galium aparine*	Th	Au	Z	*								*	
18	*Juncus articulatus*	Th	Sp	B							*			
19	*Juncus bufonius*	Th	Sp	B						*			*	*
20	*Lamium purpureum*	Th	In	B					*		*		*	*
21	*Medicago lupulina*	Th	Sp	B							*			
22	*Melilotus albus*	H2	Sp	B					*		*			
23	*Myosurus minimus*	Th	Sp	A							*			
24	*Polygonum aviculare*	Th	Sp	B							*			
25	*Polygonum lapathifolium*	Th	Sp	B	*	*	*		*		*		*	
26	*Ranunculus scleratus*	Hr	Sp	B								*		
27	*Rumex crispus*	Hr	Su	A							*		*	*
28	*Sinapis arvensis*	Th	Sp	B		*		*			*		*	*
29	*Sonchus arvensis*	G	Sp	A							*			
30	*Stellaria media*	Th	In	B	*	*	*	*	*	*	*	*	*	*
31	*Taraxacum officinale*	Hr	In	A	*	*				*	*		*	*
32	*Thlaspi arvense*	Th	Sp	B	*		*		*		*		*	*
33	*Tripleurospermum perforatum*	Th	Au	B	*	*			*				*	*
34	*Viola arvensis*	Th	In	B									*	*

Note: I – rotation with manure; II – rotation without manure; Th – therophytes; H2 – biennial species; Hr – hemicryptophytes; G – geophytes; Sp, Su, Au – spring, summer, autumn germinating species; In – indifferent species (species germinating in any month); A – anemochory; B – barochory; Z – zoochory.



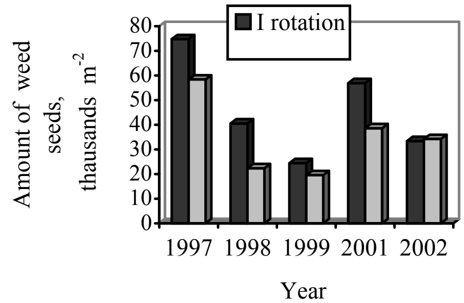


Fig. 1. Number of weed species, in the soil, the average of 1997–2002.

Fig. 2. Amount of weed seeds in the soil, the average of 1997–2002.

Table 3. Number of annual, biennial and perennial weed species and seeds in different years in different crop rotations, 1997–2002.

Exponentials	Transition period						Organic farming			
	1997		1998		1999		2001		2002	
	I	II	I	II	I	II	I	II	I	II
Number of weed species										
Annual	8	7	5	5	9	6	12	4	13	11
Biennial	0	0	0	0	0	0	1	0	0	0
Perennial	2	0	2	0	0	1	6	4	3	2
Number of weed seeds, m^{-2} thousands										
Annual	73.5	56.8	40.2	22.3	24.4	17.9	54.2	35.9	31.9	32.8
Biennial	0	0	0	0	0	0	0.10	0	0	0
Perennial	1.30	1.60	0.30	0	0	1.60	2.60	2.70	1.50	1.40

Table 4. Sørenson's qualitative and quantitative indices of similarity (in %) compared between all treatment combinations, 1997–2002.

Year	Crop rotation	Qualitative index									
		Transition period						Organic farming			
		1997		1998		1999		2001		2002	
		I	II	I	II	I	II	I	II	I	II
1997	I		71	59	40	74	59	41	33	62	52
	II	83		57	67	63	57	46	40	61	60
1998	I	70	43		50	63	43	38	40	43	40
	II	81	53	67		43	50	33	46	38	44
1999	I	47	38	67	49		50	50	35	56	55
	II	51	42	83	70	74		31	40	35	40
2001	I	81	63	83	90	56	62		22	69	33
	II	93	73	54	69	43	50	74		63	38
2002	I	56	45	75	62	81	79	69	74		90
	II	64	54	77	76	61	61	66	64	97	
									Quantitative index		

Note: I - crop rotation with manure; II - crop rotation without manure.

Table 5. Table of contingency between biological groups and crop rotation (within survey years) and between biological groups and survey years (within crop rotation), 1997–2002.

Analysis	Year	CR	Biological group			Within survey years	Within crop rotation	
			Th	Hr	G	$\chi^2/\chi^2_{0.05}$	CR	$\chi^2/\chi^2_{0.05}$
Qualitative	1997	I	8	2	0	0.09/3.84	I	6.39/15.5
		II	6	1	0			
	1998	I	5	1	1	1.73/5.99	II	6.20/9.49
		II	5	0	0			
	1999	I	9	0	0	1.36/3.84		
		II	6	1	0			
	2001	I	12	5	2	1.94/5.99		
		II	4	4	0			
	2002	I	13	2	1	0.87/5.99		
		II	11	2	0			
Quantitative	1997	I	73.5	1.30	0	0.16/3.84	I	3.72/15.5
		II	56.8	1.60	0			
	1998	I	40.2	0.15	0.15	0.15/5.99	II	2.79/9.49
		II	22.3	0	0			
	1999	I	24.4	0	0	2.09/3.84		
		II	17.9	1.60	0			
	2001	I	54.2	2.10	0.60	0.91/5.99		
		II	35.9	2.70	0			
	2002	I	31.9	0.90	0.6	0.70/5.99		
		II	32.8	1.40	0			

Note: I – rotation with manure; II – rotation without manure; Th - therophytes; Hr - hemicryptophytes; G - geophytes.

Independence test. The analysis of biological weed groups showed that in 0–25 cm soil layer the biggest number of weed species belonged to terophytes (Table 5). In the sixth year of organic farming, the number of terophytes in the soil increased but the amount of weed seeds decreased. Both in the crop rotations and survey years weeds distributed quantitatively and qualitatively similarly. The null hypothesis was accepted.

The results of the contingency of ecophysiological groups showed that weeds germinating in summer formed the highest amount of seeds in 0–25 cm soil layer (Table 6). The amount of these weed seeds in the sixth year of organic farming was lower than at the beginning of the transition period. Within crop rotation, the null hypothesis was rejected only in the 1st rotation under quantitative profile as a consequence of a difference in spring, autumn and indifferent germinating weed species.

According to the results of weed dispersal type, the biggest amounts of weed seeds spread by water (Table 7). In the sixth year of organic farming there was obtained a smaller amount of water spreading seeds than in the first year. Both in fields of the 1st and 2nd crop rotations and in survey years weeds distributed quantitatively and qualitatively similarly. The null hypothesis was accepted.

Table 6. Table of contingency between ecophysiological groups and crop rotation (within survey years) and between ecophysiological groups and survey years (within crop rotation), 1997–2002.

Analysis	Year	CR	Ecophysiological group				Within survey years	Within crop rotation	
			Sp	Su	Au	In	$\chi^2/\chi^2_{0.05}$	CR	$\chi^2/\chi^2_{0.05}$
Qualitative	1997	I	4	1	2	3	0.16/7.82	I	7.05/21.0
		II	3	1	1	2			
	1998	I	4	1	0	2	0.14/5.99	II	3.83/21.0
		II	3	1	0	1			
	1999	I	4	1	1	3	1.75/7.82		
		II	2	2	0	3			
	2001	I	13	2	0	4	5.75/7.82		
		II	3	1	2	2			
	2002	I	7	2	3	4	0.23/7.82		
		II	5	2	2	4			
Quantitative	1997	I	21.4	24.1	5.90	23.4	2.61/7.82	I	33.6/21.0
		II	11.3	26.0	4.90	16.2			
	1998	I	1.60	31.4	0	7.50	0.43/5.99	II	16.0/21.0
		II	1.60	17.5	0	3.20			
	1999	I	4.90	12.0	1.30	6.20	1.36/7.82		
		II	3.20	9.80	0	6.50			
	2001	I	5.20	34.8	0	16.9	3.70/7.82		
		II	3.10	28.4	0.90	6.20			
	2002	I	4.20	18.5	2.00	8.70	1.12/7.82		
		II	6.10	19.0	0.60	8.50			

Note: I – rotation with manure; II – rotation without manure; Sp, Su, Au - spring, summer, autumn germination species; In - indifferent species (species germinating in any month).

Table 7. Table of contingency between types of dispersal and crop rotation (within survey years) and between types of dispersal groups and survey years (within crop rotation), 1997–2002.

Analysis	Year	CR	Type of dispersal			Within survey years	Within crop rotation	
			A	B	Z	$\chi^2/\chi^2_{0.05}$	CR	$\chi^2/\chi^2_{0.05}$
Qualitative	1997	I	1	8	1	0.78/5.99	I	7.31/15.5
		II	1	6	0			
	1998	I	0	7	0	–	II	2.15/9.49
		II	0	5	0			
	1999	I	1	7	0	0.01/3.84		
		II	1	6	0			
	2001	I	6	13	0	3.25/3.84		
		II	0	8	0			
	2002	I	3	12	1	0.96/5.99		
		II	2	11	0			
Quantitative	1997	I	0.65	73.5	0.65	1.17/5.99	I	4.67/15.5
		II	1.60	56.8	0			
	1998	I	0	40.5	0	–	II	4.24/9.49
		II	0	22.3	0			
	1999	I	0.70	23.7	0	0.62/3.84		
		II	1.60	17.9	0			
	2001	I	2.60	54.3	0	1.81/3.84		
		II	0	38.6	0			
	2002	I	1.50	31.8	0.10	0.11/5.99		
		II	1.40	32.8	0			

Note: I – rotation with manure; II – rotation without manure; A - anemochory; B - barochory; Z - zoochory.

CONCLUSIONS

1. Organic farming increases the diversity of weed species. It is proven by the qualitative index. Seeds of 10 weed species were found in one experimental field at the beginning of a transition period. After 6-year organic farming, the diversity of weeds increased almost up to 16 species.

2. Weed seeds of *Chenopodium album, Fallopia convolvulus* and *Stellaria media* have been found in 0–25 cm soil layer in each year of the experiment. In the sixth year of organic farming, there were found 26.3, 70.0 and 91.2 % less seeds of the mentioned species, respectively, compared with the transition period.

3. The amount of weed seeds in the soil at the beginning of a transition period was bigger by 28.0 % when manure was used, compared to soil without manure. In the sixth year of organic farming there were observed no significant differences.

4. All weeds, found in the soil, distributed into 3 biological, 4 ecophysiological groups and 3 types of dispersal. Most of seeds found in 0–25 cm soil layers were therophytes. Most of them germinate in summer, spreading by water (barochory), because *Chenopodium album* dominates. Both in fields of the 1st and 2nd crop rotation

and in all experimental years, the quantitative and qualitative distribution of weeds into biological, ecophysiological groups and type of dispersal were similar, with the exception of ecophysiological groups in crop rotation with manure.

5. After transition to organic farming and refusal of herbicides, weed infestation can be stabilised and even reduced by appropriate cropping and crop rotations.

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