Chapter 4

Weed Control by Soil Tillage and Living Mulch

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Additional information is available at the end of the chapter

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1. Introduction

Reduced soil tillage can be classified as minimum, sustainable, conservation, ploughless or zero tillage. For example, in the United Kingdom, such tillage systems are commonly referred to as non-inversion tillage. These different types of non-reversible soil tillage methods maintain at least 30% residue coverage on the soil surface [1]. In reduced soil tillage practices, residue coverage leads to lower moisture evapotranspiration, higher soil water content and soil structural stability, and more effective prevention of soil erosion [2-4]. Compared to conventional annual deep soil ploughing, reduced tillage may decrease technological production costs and improve the economic effectiveness of agricultural practices [5]. However, weed control in such soil tillage systems is more complex. Reduced soil tillage leads to different weed seed bank distributions in the soil and occasionally lower herbicide effectiveness, which delays the time of weed seed germination because of crop residue coverage [6] and other indices.

How much do different soil tillage systems influence the weed infestation of crops? First, weed stand density depends on the competition ability of the crop. Cereals generally have higher competitiveness than do cultivated crops (beet, maize, and potato). For example, Vakali et al. [7] showed that in deeply cultivated plots, the barley crop weed shoot biomass was 65–88% higher than that in reversibly tilled plots, but in rye no clear influence was found. Ozpinar and Ozpinar [8] established that shallow soil rototilling (compared with mouldboard ploughing) increased the total weed density by 72 and 58% in maize and vetch crops, while the differences in wheat were low. Similar results were found by Mashingaidze et al. [9]. In crop rotations with maize, the highest weed stand differences were obtained between mouldboard ploughing and no tillage technologies. Occasionally, no tillage resulted in up to 20 times more weed infestation [10]. The spread of perennial weeds was typically more evident [11]. However, Streit et al. [12] showed that for no tillage technologies without herbicides, the weed density was lower than that in conventional or minimum tillage.

Different soil tillage intensities may slightly change the diversity of weed species in crops. In a 23-year experiment by Plaza et al. [13], in minimally tilled plots there were more weed species than in not tilled or traditionally ploughed plots. In a 14-year experiment by Carter and Ivany [14], the weed species diversity was slightly lower in ploughed soil than in shallowly or not tilled soil. In addition, high weed infestation resulted in substantial reductions in maize yield [15].

Worldwide experiments of reduced soil tillage have been widely and well documented, but investigations with maize crops (especially using the no-tillage system) are quite new in lands with low level of herbicide practice.

In chemicalless (ecological, organic, biological or similar) farming systems common problem is high risk of weed infestation. Weeds rival with crops for space, light, water and nutrients. Lazauskas [16] formulated the law of crop productivity, "...crop performance, expressed by the total mass of crops and weeds, is relatively constant and may be defined by the equation: $Y = A - bx$; Y – crop yield, A – maximum crop productivity, x – weed mass and b – yield depression coefficient". According to this law, the crop yield is inversely proportional to the crop weed mass. Rusu et al. [17] found similar results and concluded that maize green mass production losses could be considered equal to the mass of green weeds.

Living mulches (additional component of agrocenosis) can be useful for effective weed control [18]. According to the Lazauskas law, interseeded living mulch occupies part of total bio-production and may decrease weed infestation. Nakamoto and Tsukamoto [19] found that "living mulches are cover crops that are maintained as a living ground cover throughout the growing season of the main crop". The winter rye (*Secale cereale* L.), ryegrasses (*Lolium* spp.) and subterranean clover (*Trifolium subterraneum* L.) might be used to suppres weeds in corn crop (*Zea mays* L.) [20]. However, living mulches can compete for nutrients and water with the main crop and yields of crop could decrease [21, 22]. As a result, living mulch plants often must be mechanically or chemically controlled [23, 24].

2. Impact of different primary soil tillage methods on weed infestation

Soil tillage is the main method to control weeds. The most valuable is primary soil tillage. For answer how effective primary soil tillage methods are, the long-term stationary field experiment is being conducted at Aleksandras Stulginskis University's (up to 2011 Lithuanian University of Agriculture) Experimental Station. The field experiment was set up in 1988 in the then Lithuanian Academy of Agriculture's Experimental Station. The soil of the experimental field is *Endohypogleyic-Eutric Planosol – PLe-gln-w*. The thickness of the soil ploughlayer is 23–27 cm. Soil texture – loam on heavy loam. The upper part of the ploughlayer (0–15 cm) contained: pH_{KCL} – 6.6–7.0, available phosphorus – 131.1–206.7 mg kg^{-1}, available potassium – 72.0–126.9 mg kg^{-1}. Primary tillage methods investigated: 1. Conventional ploughing at 23–

25 cm depth (CP) (control treatment); 2. Shallow ploughing at 12–15 cm depth (SP); 3. Deep cultivation at 23–25 cm depth (DC); 4. Shallow cultivation at 12–15 cm depth (SC); 5. Not tilled soil (direct sowing) (NT). Crop rotation in the experiment: 1) spring rape; 2) winter wheat; 3) maize; 4) spring barley. The experiment involved 4 replications. Each crop was cultivated in 20 plots. The initial size of plots was 126 m^2 (14 x 9 m), and the size of record plots was 70 m^2 (10 x 7 m). The plots of the experimental treatments were laid out in a randomised order. The protection band of the plot was of 1 m width and that between replications of 9 m width. After crop harvesting, all experimental plots (except for treatment 5) were cultivated by a disc stubble cultivator Väderstad CARRIER 300 at the 12–15 cm depth. JOHN DEERE 6620 tractor was used in the experiment. According to the experimental design, primary tillage was performed in August–September (for winter wheat) or in October (for spring crops). The soil was ploughed with a conventional plough Gamega PP-3-43 with semi-helical mouldboards at the 23–25 cm depth (treatment 1) or at the 12–15 cm depth (treatment 2). Deep cultivation was carried out by a ploughlayer's cultivator (chisel) KRG-3.6 at the 23–25 cm depth (treatment 3). The plots of treatment 4 were additionally cultivated by a disc stubble cultivator Väderstad CARRIER 300 at the 12–15 cm depth. The plots of treatment 5 were not tilled.

In spring, after the soil had reached maturity stage, it was shallow-cultivated by a cultivator Laumetris KLG-3.6 (except for the plots of treatment 5), fertilizers were applied by a fertilizer spreader AMAZONE-ZA-M-1201. Pre-sowing, the soil was cultivated at a seed placement depth. The crops were sown by the following sowing machines: Väderstad Super Rapid 400C in 2010, Väderstad Rapid 300C Super XL in 2011 and in 2012. Herbicides and insecticides were sprayed by a sprayer AMAZONE UF-901. Spring rape and winter wheat plots were harvested by a small plot combine harvester "Sampo-500'' in 2010 and 2011 and by "Wintersteiger Delta'' in 2012. Spring barley was harvested by a small plot combine harvester "Sampo-500'' in 2010 and by "Wintersteiger Delta'' in 2011 and 2012.

Spring rape. Cultivars 'Hunter' in 2010, 'SW Landmark' in 2011 and 'Fenja' in 2012 were sown at a rate of 2–2.3 million seeds ha^{-1} at the 2–3 cm depth. Fertilizers were incorporated at the 2.5 cm depth. Sowing was performed by a continuous-row method with 12.5 cm wide inter-rows.

Winter wheat. Cultivar 'Ada' in 2010–2012 was sown at a seed rate of 4.5–5 million seeds ha^{-1} at the 4–5 cm depth. Fertilizers were incorporated at the 6 cm depth. Sowing was performed by a continuous-row method with 12.5 cm wide inter-rows.

Maize. Hybrids 'Pioneer P 8000 (x6T584)' in 2010, 'Pioneer P 8000 (x027)' in 2011 and 'Es capris' in 2012 were sown at a seed rate of 100 thousand seeds ha^{-1} at the 6 cm depth. Fertilizers were incorporated at the 6.5 cm depth. Sowing was performed by a continuous band wide-row method with 50 cm wide inter-rows (between bands), 12.5 cm wide inter-rows between rows.

Spring barley. Cultivars 'Simba' in 2010 and 2012, 'Tokada' in 2011 were sown at a seed rate of 5–6 million seeds ha^{-1} at the 3.5 cm depth. Fertilizers were applied by placement method at the 4–4.5 cm depth. Sowing was performed by a continuous-row method with 12.5 cm wide inter-rows.

Weed seed bank in the soil was determined in treatments 0–5 (1 and 5 treatments) at the 0–15, 15–25 cm depths after primary tillage in 20 spots of a record plot in 2010 and 2012. The samples were taken with an auger, and a composite sample was formed. Sampling at the 0–5 cm depth was done to compare the weed seed bank in the upper ploughlayer of the conventionally tilled and not tilled plots. A 100 g dry soil sample was placed on a sieve with 0.25 mm mesh diameter and washed with running water until small soil particles washed out. Weed seeds and the remaining mineral soil fraction were separated from the organic soil fraction using saturated salt (or potash) solution [25].

Crop weed incidence was assessed by identifying weed species composition, weed number at the beginning of vegetation or at resumption of vegetation (winter wheat) during intensive weed growth. Dry weed weight was determined at the end of crops vegetation. Weed incidence was assessed in 10 spots of a record plot in 0.06 m^2 area. At the beginning of vegetation, weed seedlings were counted (weed seedlings m^{-2}), and at the end of vegetation weed number (weeds m^{-2}) and dry matter weight (g m^{-2}) were established. The weeds were pulled out, dried to air-dry weight, and analysis of their botanical species composition was conducted [26].

The research data were statistically processed by the analysis of variance and correlation-regression analysis methods. Software ANOVA was used when estimating the least significant difference LSD_{05} and LSD_{01}. The correlation-regression analysis of the research data was conducted using software STAT and SIGMA PLOT. In the case of significant difference between the specific treatment and the control (reference treatment), the probability level was marked as:

* – differences significant at 95 % probability level;

** – differences significant at 99 % probability level.

2.1. Weed seed-bank in the soil

The effectiveness of weed control mainly depends on the ability to sweep out weed seed-bank and to prevent the addition with newer ones [27].

Analysis of the data on the effects of different primary tillage on weed seed bank in the soil revealed that nearly in all cases both in not tilled plots and conventionally deep-ploughed plots weed seed bank in the upper ploughlayer (0–5 cm depth) did not differ significantly (data are not presented). In deeper layer (0–15 cm depth) weed seed bank in reduced tillage treatments generally increased, except for not tilled plots, where weed seed bank was less abundant. Only single significant differences were established (Tables 1-4). In the samples taken from the 15–25 cm depth, the weed seed bank was generally smaller. The seeds of annual weeds prevailed in the soil. In many cases, having reduced tillage, the ploughlayer differentiated into upper layer characterized by more abundant weed seed bank (60.1 % of the total weed seed bank) and bottom layer characterized by less abundant weed seed bank (39.9 %). Weed seeds found in conventionally ploughed soil, at the 0–15 cm depth, in different crops accounted for 51.3 to 52.9 % of the total weed seed bank, and in the 15–25 cm depth – from 47.1 to 48.5 %, in shallow-ploughed soil – 55.9–68.6 and 31.4–44.1 %, respectively, in deep-cultivated soil – 50.0–75.9 and 24.1–50.0 %, in shallow-cultivated soil – 50.0–70.8 and 29.2–50.0 %, in not tilled soil – 56.0-64.3 and 35.7–44.0 %.

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The most widespread were annual weed's seeds: Chenopodium album, *Polygonum lapathifolia*, *Echinochloa crus-galli* and *Sinapis arvensis* L.

Soil tillage method	**Years**	**Sampling depth cm**	
		0–15	15–25
Conventional ploughing	2010	22	23
	2012	12	9
Shallow ploughing	2010	30	23
	2012	16	5
Deep cultivation	2010	34*	20
	2012	12	5
Shallow cultivation	2010	29	24
	2012	16	10
No-tillage	2010	20	10*
	2012	10	8

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 1. The impact of different primary tillage on the number of weed seeds per 100 g of soil in spring oilseed-rape cultivation

Soil tillage method	**Years**	**Sampling depth cm**	
		0–15	15–25
Conventional ploughing	2010	25	16
	2012	16	22
Shallow ploughing	2010	32	16
	2012	17	6**
Deep cultivation	2010	16	7
	2012	24	8**
Shallow cultivation	2010	12	9**
	2012	16	19
No-tillage	2010	14	8
	2012	13	14*

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 2. The impact of different primary tillage on the number of weed seeds per 100 g of soil in winter wheat cultivation

Soil tillage method	Years	Sampling depth cm	
		0–15	15–25
Conventional ploughing	2010	30	26
	2012	13	15
Shallow ploughing	2010	49	25
	2012	14	16
Deep cultivation	2010	71*	15
	2012	17	12
Shallow cultivation	2010	52	17
	2012	15	12
No-tillage	2010	21	12
	2012	13	12

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 3. The impact of different primary tillage on the number of weed seeds per 100 g of soil in maize cultivation

Soil tillage method	Years	Sampling depth cm	
		0–15	15–25
Conventional ploughing	2010	23	13
	2012	14	20
Shallow ploughing	2010	26	15
	2012	12	15
Deep cultivation	2010	27	28*
	2012	14	12
Shallow cultivation	2010	24	14
	2012	19	9
No-tillage	2010	20	8
	2012	17	11

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 4. The impact of different primary tillage on the number of weed seeds per 100 g of soil in spring barley cultivation

According to the K. S. Torresen et al. [28] investigations, in top layer of minimally tilled soil there was found higher number of weed seeds than in 10-20 cm depth. Our investigations partlyš comfirms that findings, arable layer devited into upper one with higher number of weed seeds (60.1 % of total number) and deeper layer with less quantity of seeds (Table 5).

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Soil tillage method	Sampling depth cm	Crops			
		spring oilseed-rape	winter wheat	maize	spring barley
CP	0–15	51.5	51.3	52.4	52.9
	15–25	48.5	48.7	47.6	47.1
SP	0–15	62.2	68.6	61.5	55.9
	15–25	37.8	31.4	38.5	44.1
DC	0–15	65.7	71.4	75.9	50.0
	15–25	34.3	28.6	24.1	50.0
SC	0–15	56.4	50.0	70.8	64.7
	15–25	43.6	50.0	29.2	35.3
NT	0–15	62.5	56.0	58.6	64.3
	15–25	37.5	44.0	41.4	35.7

Table 5. The impact of different primary tillage on quantity of weed seeds after primary soil tillage, %, data averaged over 2010 and 2012.

2.2. Weed spread

Analysis of the data on the effect of different primary tillage on the weed incidence in the crops at the beginning of vegetation revealed that almost in all the cases of reduced tillage or direct drilling into not tilled plots, the number of weeds increased; however, significant difference was estimated only for not tilled winter wheat plots (Tables 6-9). In conventional ploughing treatment, the spread of annual weeds was more intensive. Having replaced conventional ploughing by shallow ploughing, deep and shallow cultivation and direct drilling, the number of annual weeds tended to decrease, while that of perennial weeds tended to increase.

Soil tillage methods	Years	Groups of weeds		
		annual	perennial	total
CP	2010	41.3	17.5	58.8
	2011	264.6	23.4	288.0
	2012	529.7	15.8	545.5
SP	2010	33.4	20.4	53.8
	2011	203.8	49.6	253.4
	2012	533.4	50.8	584.2
DC	2010	31.7	14.6	46.3
	2011	166.3	268.3**	434.6
	2012	675.5	28.3	703.8
SC	2010	17.2	20.8	38.0*
	2011	190.5	91.2	281.7

Soil tillage methods	Years	Groups of weeds		
		annual	perennial	total
	2012	523.3	42.5	565.8
NT	2010	29.2	12.5	41.7
	2011	147.9	124.6	272.5
	2012	320.4	225.8*	546.2

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 6. The impact of different primary tillage on weed spread (number m^{-2}) at the beginning of spring oilseed rape vegetation

Soil tillage methods	Years	Groups of weeds		
		annual	perennial	total
CP	2010	113.3	3.8	117.1
	2011	109.2	0.0	109.2
SP	2010	108.8	5.4	114.2
	2011	106.3	3.7	110.0
DC	2010	317.5**	6.7	324.2**
	2011	99.6	15.4*	115.0
SC	2010	201.2	6.7	207.9
	2011	102.5	17.5**	120.0
NT	2010	123.8	1.7	125.5
	2011	47.1*	0.8	47.9*

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 7. The impact of different primary tillage on weed spread (number m^{-2}) at the beginning of winter wheat vegetation

Soil tillage methods	Years	Groups of weeds		
		annual	perennial	total
CP	2010	445.9	18.4	464.3
	2011	305.4	13.4	318.8
	2012	188.4	47.9	236.3
SP	2010	616.3	24.2	640.5*
	2011	395.4	11.3	406.7

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Soil tillage methods	Years	Groups of weeds		
		annual	perennial	total
	2012	193.7	115.0	308.7
DP	2010	625.8	65.4	691.2*
	2011	314.6	40.0*	354.6
	2012	165.0	90.0	255.0
SP	2010	520.8	83.8*	604.6
	2011	286.7	35.8*	322.5
	2012	152.1	155.4**	307.5
NT	2010	515.5	35.9	551.4
	2011	167.9	22.1	190.0
	2012	107.2	82.9	190.1

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 8. The impact of different primary tillage on weed spread (number m^{-2}) at the beginning of maize vegetation

Soil tillage methods	Years	Groups of weeds		
		annual	perennial	total
IA	2010	262.8	16.7	279.5
	2011	205.8	29.6	235.4
	2012	198.3	10.4	208.7
SA	2010	243.7	8.8	252.5
	2011	307.1	10.4	317.5
	2012	234.6	25.8	260.4
GP	2010	428.8	11.2	440.0
	2011	299.6	12.1	311.7
	2012	214.1	39.2*	253.3
SP	2010	327.5	26.7	354.2
	2011	359.6*	22.1	381.7*
	2012	265.4	34.6	300.0
ND	2010	516.3*	38.3*	554.6*
	2011	281.3	21.6	302.9
	2012	135.9	11.3	147.2

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 9. The impact of different primary tillage on weed spread (number m^{-2}) at the beginning of spring barley vegetation

At the end of vegetation, the weed incidence in reduced-tillage or not tilled plots increased in all cases compared with the control; however, the difference was not significant. Reduced tillage and direct drilling generally tended to increase the number of both annual and perennial weeds (Tables 10-13).

Soil tillage methods	Years	Groups of weeds: annual number m^{-2}	annual mass g m^{-2}	perenial number m^{-2}	perenial mass g m^{-2}	total number m^{-2}	total mass g m^{-2}
CP	2010	80.4	77.2	9.6	6.6	90.0	83.8
	2011	172.9	139.8	15.4	45.6	188.3	185.4
	2012	483.4	335.7	11.6	5.5	495.0	241.2
SP	2010	125.0	127.8	13.3	21.4	138.3	149.2
	2011	140.8	110.3	19.6	32.2	160.4	142.5
	2012	487.9	355.9	19.2	19.4	507.1	375.3
DC	2010	256.2**	123.3	18.8	21.6	275.0**	144.9
	2011	210.8	76.5	40.4*	167.7*	251.2	244.2
	2012	552.1	227.8	22.5	42.7	574.6	270.5
SC	2010	219.5*	157.4*	13.8	48.2*	233.3**	205.6*
	2011	190.8	93.8	38.3	91.0	229.1	184.8
	2012	605.0	340.2	20.0	12.3	625.0	352.5
NT	2010	304.6**	54.6	15.8	8.0	320.4**	62.6
	2011	275.0	106.1	6.2	4.6	281.2	110.7
	2012	408.8	215.7	40.0*	16.9	448.8	232.6

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 10. The impact of different primary tillage on weed spread at the end of spring oilseed-rape vegetation

Soil tillage methods	Years	Groups of weeds: annual number m^{-2}	annual mass g m^{-2}	perenial number m^{-2}	perenial mass g m^{-2}	total number m^{-2}	total mass g m^{-2}
CP	2010	33.8	2.9	21.2	2.3	55.0	5.2
	2011	57.9	3.6	15.8	10.8	73.7	14.4
	2012	81.7	20.6	60.8	100.2	142.5	120.8
SP	2010	32.5	3.2	20.8	2.2	53.3	5.4
	2011	90.0	3.5	25.8	44.9*	115.8	48.4*
	2012	43.7	9.6	73.8	292.2*	117.5	301.8

Soil tillage methods	Years	Groups of weeds					
		annual		perenial		total	
		number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}
DP	2010	47.1	3.0	19.2	3.4	66.3	6.4
	2011	167.1	5.8	30.8*	42.5*	197.9	48.3*
	2012	34.2	3.3	129.1*	267.1*	163.3	270.4
SP	2010	66.2*	6.3	15.4	1.6	81.6	7.9
	2011	41.7	1.4	39.6**	44.6*	81.3	46.0*
	2012	132.5	226.1	124.6*	193.5	257.1	419.6*
NT	2010	69.6*	8.9*	27.1	6.6	96.7**	15.5*
	2011	249.2*	4.7	17.9	0.6	267.1*	5.3
	2012	87.9	13.8	31.7	16.3	119.6	30.1

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 11. The impact of different primary tillage on weed spread at the end of winter wheat vegetation

Soil tillage methods	Years	Groups of weeds					
		annual		perenial		total	
		number m^{-2}	mass g m^{-2}	number m^{-2}	number m^{-2}	mass g m^{-2}	number m^{-2}
CP	2010	304.6	199.9	16.6	8.6	321.2	208.5
	2011	40.8	93.0	6.7	16.7	47.5	109.7
	2012	109.9	193.7	33.4	70.3	143.3	264.0
SP	2010	467.9*	283.2	15.4	11.4	483.3*	294.6*
	2011	48.3	119.0	18.3	66.9	66.6	185.9
	2012	150.0	165.2	47.1	111.1	197.1	276.3
DC	2010	396.3	304.6*	42.5	31.7	438.8	336.3**
	2011	51.2	122.3	23.8	79.3	75.0	201.6*
	2012	168.7	105.7	34.6	66.1	203.3	171.8
SC	2010	367.9	317.7*	59.2	42.8	427.1	360.5**
	2011	49.6	103.9	12.1	13.3	61.7	117.2
	2012	122.1	111.8	55.8	206.8*	177.9	318.6
NT	2010	272.1	260.2	75.8*	52.4*	347.9	312.6*
	2011	43.3	104.5	21.3	10.1	64.6	114.6
	2012	145.4	198.7	34.6	57.3	180.0	256.0

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 12. The impact of different primary tillage on weed spread at the end of maize vegetation

Soil tillage methods	Years	Groups of weeds					
		annual		perenial		total	
		number m-2	mass g m-2	number m-2	number m-2	mass g m-2	number m-2
CP	2010	231. 6	109.6	16.7	5.2	248.3	114.8
	2011	167.1	11.4	8.3	4.9	175.4	16.3
	2012	31.6	7.3	21.7	13.8	53.3	21.1
SP	2010	386.7	135.0	17.1	6.3	403.8	141.3
	2011	263.8	23.9	13.3	15.0	277.1	38.9
	2012	37.5	2.9	22.5	7.2	60.0	10.1
DC	2010	785.0*	173.2	23.8	26.8	808.8*	200.0
	2011	289.6	34.6*	5.4	2.0	295.0	36.6
	2012	71.2	9.2	39.6	17.9	110.8	27.1
SC	2010	384.6	110.5	16.7	13.4	401.3	123.9
	2011	371.2	30.4	10.0	5.6	381.2	36.0
	2012	184.6**	20.1*	40.0	30.2	224.6**	50.3*
NT	2010	778.3*	156.5	10.0	6.4	788.3*	162.9
	2011	193.3	27.8	31.7*	80.0*	225.0	107.8**
	2012	35.0	9.1	24.2	3.0	59.2	12.1

Note: * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 13. The impact of different primary tillage on weed spread at the end of spring barley vegetation

There were found 21-22 species of weeds in experiment. The most widespread were: *Chenopodium album* L., *Echinochloa crus-galli* L., *Polygonum lapathifolia* L., *Sonchus arvensis* L., *Cirsium arvense* L. Scop. and *Elytrigia repens* L. Nevski.

The correlation-regression analysis of the experimental data revealed that the spread of weeds partly depended on the soil structure and its stability, penetration resistance of deeper soil layers (35–50 cm), moisture content in the upper ploughlayer, soil phosphorus and potassium status, pH, crop stand density, amount of plant residues in the soil surface and weed seed bank in the ploughlayer.

3. Impact of living mulch on weed infestation

Numerous research and observations have been conducted aiming to establish weed spread methods and reasons and weed-crop competition peculiarities. Enhancement of the competitive ability of agricultural crops is one of the principal tools to increase the productivity of agricultural crops. Sowing living mulches between the rows of a main crop is a weed control method that does not employ herbicide application. Living mulches result in reduced field weed infestation and an increase in crop yield. From the ecological viewpoint, this technology is promising and beneficial. The study was aimed to establish the competitive peculiarities of the multi-component agrocenosis (maize, living mulches, weeds) and its effects on soil properties under sustainable farming conditions. Experimental object – different species of living mulch plants and maize monocrop. Research was conducted during 2009–2011 at the Lithuanian University of Agriculture (since 2011 Aleksandras Stulginskis University), Experimental Station. The soil of the experimental field was *Calc(ar)i-Epihypogleyic Luvisol LVg-p-w-cc* [29] with a texture of silty light loam on heavy loam. The soil pH_{KCl} measured 7.1, available phosphorus 134.83 mg kg^{-1}, available potassium 74.66 mg kg^{-1}. The soil in this territory has formed on a bottom morain or bottom glacial formations, covered by glacial lacustrine sedimentary rock and is a continuation of the Lithuanian Middle Plain. The layer of the sedimentary rock is of different thickness.

A one-factor, stationary field experiment was conducted. Different living mulches inter-seeded in maize inter-rows were tested.

1. Without a living mulch (control – reference treatment);
2. Spring rape (*Brassica napus* L.);
3. White mustard (*Sinapis alba* L.);
4. Spring barley (*Hordeum vulgare* L.);
5. Italian ryegrass (*Lolium multiflorum* Lam.);
6. Black medic (*Medicago lupulina* L.);
7. Persian clover (*Trifolium resupinatum* L.);
8. Red clover (*Trifolium pratense* L.).

In all experimental years, the same living mulches were inter-seeded in the inter-rows of maize monocrop. The plots of the control treatment were weeded out twice. The experiment was replicated four times. The plots were laid out in a randomised design. The total area of an experimental plot was 24 m^2, and the area of a record plot was 20 m^2. In 2009, black fallow preceded maize and in 2010–2011 maize was monocropped.

Maize monocrop inter-seeded with living mulches was grown without chemical pest control under arable agriculture conditions. In spring, when the soil had reached physical maturity, complex NPK 16:16:16 fertilizer at a rate of 300 kg ha^{-1} was applied, and later the soil was loosened at 4–5 cm depth. Maize was sown by a pneumatic-mechanical drill Köngskilde PRECI – SEM with 50 cm-wide inter-rows and 16–17 cm distance between seeds. Post-emergence of maize, inter-rows were loosened and living mulches were sown with a 7-row manually-operated greenhouse seeder. The marginal rows of the inter-seeded living mulches were at 1–2 cm distance from maize. In each experimental year, living mulches were inter-seeded in the plots in the same places. Living mulches were cut and chopped 2–3 times at maize growth stages BBCH 15–16, 31–32 and 63–65. BBCH 15–16 is leaf development stage when average maize height is 10–12 cm (Photo 1). BBCH 31–32 is stem elongation stage when 1–2 nodes are visible and maize height is 56–63 cm. BBCH 63–65 is maize flowering stage when the plant height is 70–215 cm. At flowering stage, the living mulch was cut only in 2009.

Photo 1. After first cut of living mulch. 2009.

Later the practice was abandoned since tractor-hitched implement would not be able to do this. Mulches were cut with a hand-operated brush cutter "Stihl" FS – 550, using a designed and manufactured trolley, reducing the operator's load, with a protection hood, which evenly spreads the mulch in the inter-row and protects the crop from mechanical damage. Living mulches were cut after they had reached a height of up to 20–25 cm. Green mass of the living mulches was spread in maize inter-rows. At stem elongation stage (BBCH 31–32), the maize crop was additionally fertilized with nitrogen (N_{60}). When fertilizing at 250 kg N ha^{-1} rate, no significant differences were observed between maize cultivation systems. The objective of our experiment was to determine the competition among living mulches, maize and weeds; therefore the total nitrogen rate selected was as low as 108 kg N ha^{-1}. Maize samples for the determination of productivity were hand-cut at the end of September – middle of October (BBCH 87–88) at maize physiological maturity stage. After harvesting, the remaining plant residues were ploughed in by a reversible plough with semi-helical mouldboards at the 20–22 cm depth.

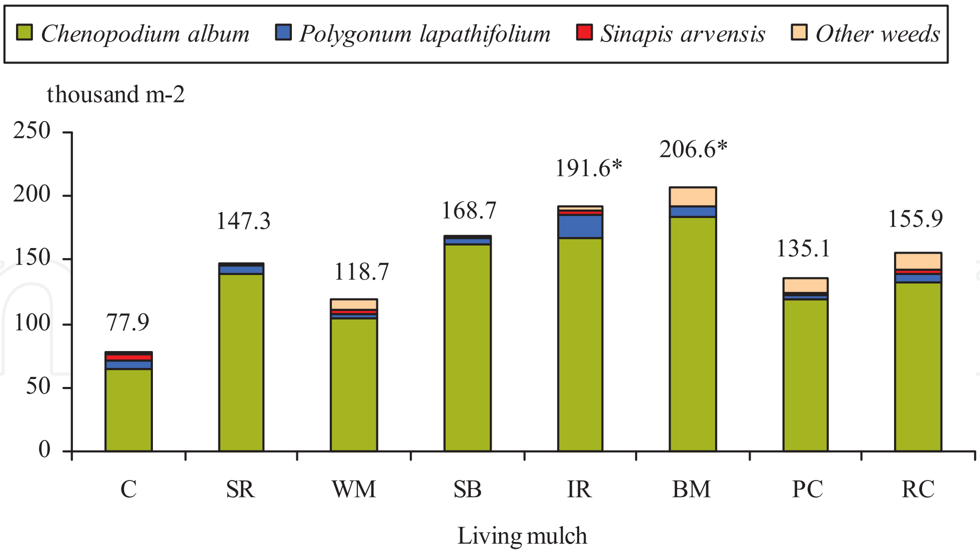
A hybrid maize cultivar 'Silvestre' was used in our experiment. Gul et al. [30] have reported that a denser maize crop increased competition between maize and weeds. As a result, the seed rate of maize in our experiment was 130–138 thousand seeds ha^{-1} or (20–23 kg ha^{-1}). Spring rape (cv. 'Sponsor'), white mustard (cv. 'Braco'), Italian ryegrass (cv. 'Avance'), black medic (cv. 'Arka'), Persian clover (cv. 'Gorby'), red clover (cv. 'Nemuniai') (Photo 2) were sown at a seed rate of 10 kg ha^{-1}, and spring barley (cv. 'Simba') was sown at a rate of 200 kg ha^{-1}.

The first assessment of weed infestation in maize crop was made post emergence of crop and weeds. Weeds were counted in 5 randomly selected record plots 0.06 m^2 in size, analysis of weed botanical composition was done, the weeds were dried up to a dry weight and weighed [26]. Weed number was re-calculated into weeds m^{-2}, dry matter weight into g m^{-2}. Such assessment was conducted before each cut of living mulches and before maize harvesting. Soil contamination with weed seeds was estimated after maize harvesting. Soil samples were taken with a sampling auger in 10 places of the record plot from the 0–20 cm depth of the ploughlayer. The number of weed seeds found was re-calculated into thousand seeds m^{-2} [25]. The tests were done in 2009 and 2011.

Photo 2. Inter-seeded red clover.

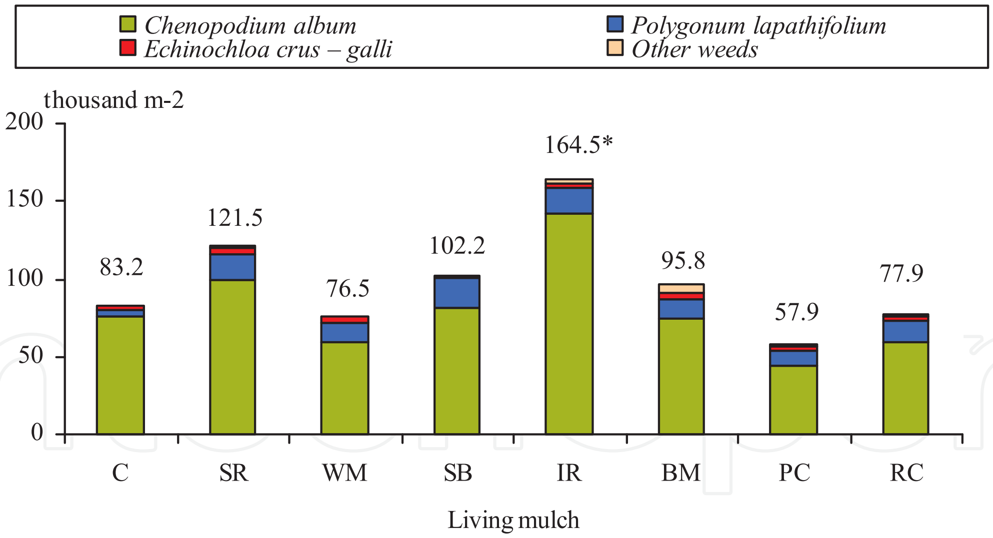
3.1. Weed seed-bank in the soil

Weed seed bank in the ploughlayer was established at the beginning of the experiment in 2009 and at the end in 2011 (Fig. 1-2). The seeds of *Chenopodium album* L. accounted for the largest share in the total weed seed bank. Analysis of the change in weed seed bank over the three experimental years suggested that living mulches reduced weed seed bank in the ploughlayer by 14.1 to 57.1 %. In 2011, compared with the control treatment, the lowest number of weeds was established when growing white mustard (8.0 %) and Persian clover (30.4 %) living mulches. Although weed suppressive capacity of Italian ryegrass was high, contrary to expectations, it gave only a small reduction in weed seed bank and the weeds were significantly, nearly twice as big as those in maize crop without living mulch.



Notes: C – control treatment (without living mulch), SR – spring rape, WM – white mustard, SB – spring barley, IR – Italian ryegrass, BM – black medic, PC – Persian clover, RC – red clover; differences significant at: * – 95 % probability level, ** – 99 % probability level. Control – reference treatment when analyzing mass of living mulches – red clover living mulch.

Figure 1. The impact of living mulch on weed seed-bank in the soil, 2009



Notes: C – control treatment (without living mulch), SR – spring rape, WM – white mustard, SB – spring barley, IR – Italian ryegrass, BM – black medic, PC – Persian clover, RC – red clover; differences significant at: * – 95 % probability level, ** – 99 % probability level. Control – reference treatment when analyzing mass of living mulches – red clover living mulch.

Figure 2. The impact of living mulch on weed seed-bank in the soil, 2011

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3.2. The abundance of weeds and living mulch

At early development stages of maize, more intensive growth was exhibited by spring rape, barley and white mustard living mulches (Table 14). However, living mulches of Italian ryegrass, black medic, Persian and red clover up to the first cut (maize BBCH 15–16) were only at seedling stage and therefore competed weakly with weeds. An especially rapid growth rate was shown by white mustard and until the first cut its dry mass was the highest. However, spring rape, barley and white mustard intercrops were sensitive to mulching and their re-growth after cut was poor, and in the second half of the summer they completely rotted away, the cut mass rapidly decomposed, therefore at later development stages of maize weed number and mass increased. Irrespective of this, these living mulches served their major purpose – competed with weeds at the time when maize competitive ability was low. The *Fabaceae* living mulches grown in maize inter-rows developed slowly; however, in the second half of the summer their growth rate increased and after cutting continued until the end of maize growing season. Moreover, they produced the largest mass. Compared with other *Fabaceae* family plants, black medic exhibited a slower development rate. Its mass was lower than that of other *Fabaceae* plants and it suppressed weeds more poorly; however, better than spring rape, barley and white mustard living mulches that had rotted away by the end of the summer. Italian ryegrass living mulch also produced large mass and exhibited a good weed suppressive ability. Its vegetation also continued until maize harvesting.

Living mulch	**Weeds**						**Living mulch g m^{-2}**
	annual		**perennial**		**total**		
	number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}	
			2009				
C	859.4	202.5	11.5	1.74	870.9	204.2	–
SR	984.3	327.6*	24.0	5.64	1008.3	332.4	104.4
WM	1015.5	297.5	20.9	4.82	1036.4	302.3*	52.2*
SB	951.4	256.9	30.2*	8.31*	981.6	265.2	126.2
IR	535.4*	95.7*	8.3	0.97	543.7*	96.6*	473.2*
BM	915.7	260.1	11.5	1.24	927.2	261.3	131.0
PC	477.0*	135.6	1.1*	0.10*	478.1*	135.7	451.6*
RC	691.6	158.6	1.0*	0.01*	692.6	158.6	236.2
			2010				
C	381.0	136.2	13.6	10.4	394.6	146.6	–
SR	571.7*	258.3	51.7*	18.8	623.4*	277.1	6.0*
WM	548.9	245.8	31.3*	12.0	580.0*	257.8	43.5*
SB	495.0	261.3*	33.3*	60.9*	528.3*	322.2*	3.0*
IR	549.2*	195.7	16.6	9.9	511.3	205.6	193.1
BM	552.1*	325.9*	24.0	8.8	596.0*	334.7*	120.6
PC	459.2	226.4	12.4	3.9	471.6	230.3	213.4

Living mulch	Weeds						Living mulch g m^{-2}
	annual		perennial		total		
	number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}	number m^{-2}	mass g m^{-2}	
RC	409.5	174.3	6.2	4.0	415.7	178.3	272.2
2011							
C	579.3	109.7	18.8	8.7	598.1	118.4	–
SR	567.1	238.6*	21.9	20.3*	589.0	258.9	37.9*
WM	654.2	266.0*	42.8*	37.6*	697.0*	303.6*	41.1*
SB	597.9	248.3*	27.1	29.8*	625.0	278.1*	37.6
IR	437.6*	126.0	9.4	2.2	447.0	148.2	220.9
BM	578.2	195.7	17.7	8.0	595.9	203.7	78.1*
PC	483.3	155.8	10.4	12.0	493.7	167.8	226.0
RC	443.3	203.3	2.1*	0.9*	445.4*	204.2	166.8

Notes: C – control treatment (without living mulch), SR – spring rape, WM – white mustard, SB – spring barley, IR – Italian ryegrass, BM – black medic, PC – Persian clover, RC – red clover; differences significant at: * – 95 % probability level, ** – 99 % probability level. Control – reference treatment when analyzing mass of living mulches – red clover living mulch.

Table 14. The abundance of weeds and living mulch plants over the whole growing season of maize, 2009–2011

The correlation-regression analysis of the data from 2009 revealed statistically significant relationships between dry mass of living mulches and weed number and dry mass (Table 15).

Growing season	Weeds, Y					
	annual		perennial		total	
	number m^{-2}	g m^{-2}	number m^{-2}	g m^{-2}	number m^{-2}	g m^{-2}
2009	0.916**	–0.797*	n	n	–0.908**	–0.796*
2010	–0.762*	–0.948**	–0.909**	–0.850**	–0.820*	–0.956**
2011	–0.802*	–0.778*	–0.949**	–0.731*	–0.802*	–0.726*

Note: n–non-significant or weak relationship. * – significant differences from control treatment (conventional ploughing) at 95 % probability level, ** – at 99 % probability level.

Table 15. The relationships between dry mass of living mulches (*x*) and weed number and dry mass (*Y*) over the whole growing season of maize 2009–2011

4. Conclusions

1. In most cases, different tillage did not have significant impact on weed seed bank in the ploughlayer and weed abundance in the agricultural crops tested. The ploughlayer differentiated into the upper layer with a greater weed seed bank (60.1 % of the total weed seed bank) and bottom layer with a less abundant weed seed bank (39.9 %). In spring

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crops, weed mass in shallow-ploughed plots was by on average 28.6 %, in deep-cultivated plots by 41.5 %, in shallow-cultivated plots by 39.9 % and in not tilled crops by 16.1 % higher than that in conventionally ploughed plots, and in winter wheat crop by respectively 2.5; 2.3; 3.4 times higher, and in not tilled plots by 2.8 times lower.

2. Non-regrowing living mulches (white mustard, spring barley and rape) competed with weeds at early development stages when maize competitive ability was poor. Living mulches whose vegetation was longer exhibited better weed suppressive ability and produced more biomass; however, they competed more for nutrients with maize. The correlation regression analysis of the experimental data indicated that at more advanced growth stages of maize, the number and mass of weeds mostly depended on the biomass of living mulches. Living mulches reduced weed seed bank in the ploughlayer by 14.1 to 57.1 %. The greatest change was established when growing Persian clover (57.1 %) and black medic (53.6 %).

3. Most of the *Poaceae and Brassicaceae* living mulches competed more with weeds for space at the beginning of maize vegetation, while *Fabaceae* plants and Italian ryegrass – already after the first mulching of the inter-rows. In most cases, a strong correlation was determined between the surface area covered by weeds and living mulches.

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