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Interaction of maize and living mulch. Crop weediness and productivity

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Abstract

In 2009–2010, a field experiment was carried out at the Experimental Station of the Lithuanian University of Agriculture (LUA) (54º52′ N, 23º49′ E) on a silty loam, *Calc(ar)i-Epihypogleyic Luvisol*, *LVg-p-w-cc(sc)* in the conditions of transitional maritime-continental climate. The study was aimed to establish the interaction between maize and living mulch and its influence on maize crop weediness and productivity. Maize crop inter-rows were sown with spring oilseed rape (*Brassica napus* L.), white mustard (*Sinapis alba* L.), spring barley (*Hordeum vulgare* L.), Italian ryegrass (*Lolium multiflorum* Lamk.), black medic (*Medicago lupulina* L.), Persian clover (*Trifolium resupinatum* L.) and red clover (*Trifolium pratense* L.) plants as living mulch.

Experimental data showed a strong negative linear relationship between living mulch (x, %) and weed coverage (Y, %) (r_{2009} = −0.90**, r_{2010} = −0.98**), coverage of living mulch (x, %) and irradiance (Y, %) (r_{2009} = −0.899**, r_{2010} = −0.860*), total air-dry mass of living mulch plants (x, g m^2) and air-dry mass of annual, perennial and total (Y, g m^2) weeds: r_{2009} = −0.93** and r_{2010} = −0.615, r_{2009} = −0.639 and r_{2010} = −0.666, $r_{(2009)}$ = −0.93** and r_{2010} = −0.753).

Living mulches competed with the maize crop and decreased its yield and other growth parameters. Living mulch exerted the highest negative significant influence on the height (r_{2009} = −0.795*, r_{2010} = −0.844*) and dry biomass of stems and leaves (r_{2009} = −0.74, r_{2010} = −0.689) of maize. Italian ryegrass mostly decreased maize shoot dry biomass due to rapid re-growth after each cutting. Because of their long vegetation and high biomass production rates, legumes (black medic, Persian and red clover) decreased maize productivity. Spring oilseed rape, white mustard and spring barley living mulches effectively suppressed weeds at first stages of development and had the least negative impact on maize productivity, therefore they might be suggested to be sown in maize crop inter-rows.

Key words: maize crop, living mulch, weeds, interaction, productivity.

Introduction

In non-chemical (organic, biological, ecological) farming systems the most serious problem is high crop and weed competition. Weeds compete with crops for space, light, water and nutrients. According to Lazauskas (1990), "…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. Similarly, Rusu et al. (2010) concluded that maize production losses in terms of green mass per hectare could be considered equal to the weight of green weeds.

Living mulches (as a component of agrocenosis) can be important for use as an ecological strategy to control weeds (Liedgens et al., 2004 a). As per Lazauskas law, living mulch plants take part in the total bio production and decrease role of weeds. Nakamoto and Tsukamoto (2006) specified 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.) can be used to control weeds in sweet corn (*Zea mays* L.) (De Gregorio, Ashley, 1986). However, living mulches compete for nutrients and water with the main crop and this can reduce yields (Echtenkamp, Moomaw, 1989; Uchino et al., 2009). As a result, they may eventually need to be mechanically or chemically killed (Brandsaeter et al., 1998; Tharp, Kells, 2001).

The interaction between living mulches and weeds in maize crop is well documented by other authors but still not comprehensively investigated in Lithuania. We have no experience of growing maize with living mulches under the conditions of non-chemical agricultural system. Therefore, the aim of our experiment was to find the interactions among the main crop, living mulches and weeds; and to choose species of living mulch plants, which would strongly compete with weeds and have little negative influence on maize productivity.

Materials and methods

Site, soil and experiment description. The stationary field experiment was carried out at the Experimental Station of the Lithuanian University of Agriculture (LUA) (54º52′ N, 23º49′ E) (Pilipavičius et al., 2011) during 2009–2010. The Lithuanian climate lies between maritime and continental, with wet winters and moderate summers. Winter temperatures are usually below freezing. Rainfall is distributed throughout the year, but more rain tends to fall on the coast of the Baltic Sea. Summer is the wettest season. The average annual precipitation is 720 millimetres on the coast and 490 millimetres in the eastern part of the country.

The soil of the experimental site is clay loam over moraine clay on a silty loam, *Calc(ar)i-Epihypogleyic Luvisol*, *LVg-p-w-cc(sc)* (IUSS Working Group WRB, 2007). Soil chemical properties are presented in Table 1.

Table 1. Soil chemical properties
LUA Experimental Station, 2009–2010

Index	Amount of elements	Evaluation
pH	6.9/7.1	neutral
humus g kg^{-1}	26.0/24.1	average
P_2O_5 mg kg^{-1}	153.2/100.0	sufficient/average
K_2O mg kg^{-1}	96.3/67.4	low
Ca mg kg^{-1}	2140.1/2800.0	very high

The experiment was established according to the scheme: 1) hand weeding (control treatment), 2) spring oilseed rape (*Brassica napus* L.) living mulch, 3) white mustard (*Sinapis alba* L.) living mulch, 4) spring barley (*Hordeum vulgare* L.) living mulch, 5) Italian ryegrass (*Lolium multiflorum* Lam.) living mulch, 6) black medic (*Medicago lupulina* L.) living mulch, 7) Persian clover (*Trifolium resupinatum* L.) living mulch, 8) red clover (*Trifolium pratense* L.) living mulch.

The number of replications was four, plot distribution was randomized. The initial size of plot was 24 m^2. In 2009, the pre-crop of maize was black fallow, in 2010 maize. In October, the soil was ploughed with a mouldboard plough at 20–22 cm depth. In April, before pre-sowing tillage complex fertilizer NPK 16:16:16 300 kg ha^{-1} was applied. The soil of the plots was tilled by a cultivator at 4–5 cm depth before sowing. Maize inter-rows were 50 cm wide. Maize seeds were sown by a pneumatic drill with wedge-type coulters at the end of April. Distance between seeds was 16–17 cm (130–138 thousand seeds per ha). Based on their field experiment, Gul et al. (2009) reported that a denser maize crop should increase the competition between maize and weeds. We sowed maize hybrids PR39K13 (2009) and 'Silvestre' (2010). Before sowing of living mulch plants, the soil was shallowly harrowed. Similarly as in Abdin et al. (2000) investigations, in our experiment plants of living mulch were sown into spaces between rows after maize germination. Living mulch (inter-row) plants were sown with a 7-row hand seeder (equipment for greenhouses). The distance between maize and living mulch plant last rows was 1–2 cm. Seed rate of black medic (variety 'Arka'), white mustard (variety 'Braco'), spring oilseed rape (variety 'Sponsor'), clovers (varieties: red clover 'Nemuniai', Persian clover 'Gorby') and Italian ryegrass (variety 'Avance') was 10 kg ha^{-1}, spring barley (variety 'Simba') 200 kg ha^{-1}. Such seed rates warrant higher density and competitiveness of living mulch crops. Chemical pest control was not used.

According to Grubinger and Minotti (1990), to avoid interference which reduces main crop yield, the living mulch requires management techniques which minimize resource utilization during the critical period of crop development without killing the mulch outright. For this reason, in our field experiment living mulch was cut and chopped 2–3 times at maize growth stages BBCH 15–16, 31–32, 63–65 with a "Stihl" brush cutter FS 550 (imitation of tractor aggregate). BBCH 15–16 – leaf development stage, 6 leaves unfolded, average maize height – 10–12 cm. BBCH 31–32 – stem elongation stage, 1–2 nodes detectable, maize height from 56 to 63 cm. BBCH 63–65 – flowering, maize height from 70 to 215 cm. The time of living mulch cutting depended on plant height. The most qualitative cutting was when living mulch plants were not higher than 20–25 cm. If cut above this height, the plants were damaged. In 2009, hand weeding was done once during the first cutting of living mulch. In 2010, because of the weather conditions favourable for weed development, maize crop was weeded twice. Green mass of living mulch was laid into the spaces between maize rows. Maize crop was fertilized additionally with ammonium nitrate (N_{60}) at the stage of stem elongation. In Garibay et al. (1997) investigations the conventional maize cropping system (maize was sown into the bare, autumn-ploughed soil) with 110 kg N ha^{-1} fertilization rate was much more productive than the systems with ryegrass living mulch. When 250 kg N ha^{-1} was applied, there were no significant variations among the cropping systems. However, the aim of our experiment was to highlight the competition among living mulch, weeds and maize. Therefore, the total amount of nitrogen was only 108 kg N ha^{-1}. Maize was harvested by hand at the end of September up to the middle of October (BBCH 87–88 – ripening stage, physiological maturity, kernels have about 60% of dry matter).

Methods. Maize growth stages were evaluated according to the BBCH scale (Meier, 2001). Maize inter-row coverage was estimated with a frame 30 × 20 cm, which was segmented into 6 parts. The air-dry mass of weeds and living mulch plants was established by weighing. Samples were taken from each experimental plot in no less than 10 places by a frame 30 × 20 cm (the area was 600 cm^2) before each cut and hand weeding. The same frames were used for counting seedlings and re-emerged weeds and living mulch. Density of weeds was determined by the quantitative method (Dospechov et al., 1977). The results of crop weediness were recalculated into square meters. Latin names of weeds were presented according to Jankevičienė (1998).

Before cutting of living mulch, photosynthetic active radiation (PAR) was measured with a radiometer HD 9021 RAD/PAR (PAR E m^{-2}, 400–700 nm) at different heights – on the surface of soil, at the ¼, ½, ¾ height of maize and background radiation. Irradiance data were recalculated into percentage difference from background radiation.

Samples for evaluation of maize crop density, morphometric and productivity parameters were taken in 10 randomized places of each plot of the field experiment. The total sampling area was 5 m^2 per plot.

The data of the experiment were analyzed by *ANOVA*. The treatment effect was tested by the least significant differences LSD_{05} and *P* tests by *SigmaStat* software. The trial data were also evaluated using correlation and regression analysis by *SigmaPlot* software. Abbreviations of correlation coefficients: * – $P < 0.01$, ** – $P < 0.05$.

The weather conditions. The weather conditions during maize vegetation period are presented in Table 2.

In 2009, maize germination period was dry and air temperature was higher than normal. In such conditions the germination of weeds was slow. Therefore, maize crop harrowing before sowing of living mulch plants was not a very effective weed control method. The most favourable time for weed germination, development and competition with maize was in June because of high amount of rainfall and lower air temperature. Since

Table 2. Average air temperatures and rainfall during maize vegetation
Kaunas Meteorological Station, 2009–2010

Index	Month					
	April	May	June	July	August	September
Temperature ºC	8.9 7.4	12.7 13.7	14.8 16.5	18.4 21.9	16.9 19.7	13.8 12.0
Long-term average	6.7	12.6	15.6	17.6	17.1	12.2
Rainfall mm	8.6 58.5	42.0 94.8	107.4 127.0	83.8 101.7	87.5 112.5	28.3 63.3
Long-term average	38.1	47.2	66.7	83.0	73.2	53.8

maize is a short-day plant, its rapid development begins at the end of July under Lithuania's conditions. July and August conditions were favourable for maize and corresponded with the weather conditions of many years. In the autumn, the distribution of precipitation was not even. In September, the amount of precipitation was about 50% less than usual. High amount of precipitation resulted in lower quality of grain production.

In 2010, all vegetation season of maize was wetter than average of many years. Seed germination and development conditions were favourable for maize and weeds but not for living mulch plants. The germination of living mulch plants was poor and late, especially of spring barley, oilseed rape and white mustard. Wet conditions during the summer and higher temperatures than usual resulted in higher productivity of maize than in 2009.

Generally, in Lithuania meteorological conditions mostly are uneven, for example, variation of monthly precipitation sometimes reaches 50–60%.

Results and discussion

Weeds and crops strongly compete for space. In our field experiment coverage of maize inter-row depended on weeds and living mulch plants' germination and development rate. Lehoczky et al. (2004) observed stronger weed competition 7 weeks after maize seeding. In 2009, in our experiment in early stage of maize growth (BBCH 15–16) (6–7 weeks after maize seeding) before the first weeding and cutting significantly lowest rate of development was of red clover and black medic plants (Table 3). Plants of other living mulch species successfully competed with weeds for space. In 2010, wet soil conditions exerted a positive effect on the development of legumes; however, oilseed rape and spring barley crops were poor.

After the first cutting of living mulch plants, research data showed significantly lower re-growth of spring oilseed rape, white mustard and spring barley plants.

Table 3. Coverage of maize inter-row at different growth stages
LUA Experimental Station, 2009–2010

Weed control treatment	Coverage component %		
	soil	weeds	living mulch plants
BBCH 15–16 (before the first cut/weeding)			
Hand weeding	47.8/55.0	52.2/45.0	–/–
Spring oilseed rape living mulch	24.1*/50.4	32.3*/43.5	43.8**/6.1**
White mustard living mulch	27.2*/55.1	17.2**/31.2	55.6**/13.7
Spring barley living mulch	34.7/53.3	38.4/44.1	26.9**/2.6**
Italian ryegrass living mulch	30.6/45.4	26.6**/44.7	42.8**/9.8*
Black medic living mulch	27.2*/41.5	64.5/51.6	8.3*/6.9**
Persian clover living mulch	37.2/37.5	24.4**/41.2	38.4*/21.3
Red clover living mulch	54.4/48.1	23.6**/34.1	22.0/17.8
LSD_{05}	20.54/18.80	18.59/20.38	12.28/7.64
LSD_{01}	27.96/25.60	25.32/27.7	16.83/10.47
BBCH 31–32 (before the second cut/weeding)			
Hand weeding	84.5/80.4	15.5/19.6	–/–
Spring oilseed rape living mulch	23.2**/40.0**	54.1**/55.7**	22.8*/4.3**
White mustard living mulch	33.1**/45.8**	48.8**/44.6**	18.1**/9.6**
Spring barley living mulch	21.9**/46.4**	44.1**/49.6**	36.0/4.0**
Italian ryegrass living mulch	7.4**/26.3**	9.4/23.4	83.2**/50.3**
Black medic living mulch	18.5**/36.8**	47.5**/31.3	34.0/31.9**
Persian clover living mulch	6.8**/15.6**	14.7/13.0	78.6**/71.4
Red clover living mulch	16.9**/13.9**	40.6**/18.7	42.5/67.4
LSD_{05}	14.44/13.72	14.60/14.24	14.65/7.59
LSD_{01}	19.66/18.68	19.88/19.39	20.07/10.40
BBCH 63–65 (before the third cut, 2009), BBCH 87–88 (before maize harvesting, 2010)			
Hand weeding	64.1/76.9	35.9/23.1	–/–
Spring oilseed rape living mulch	39.4**/39.4**	59.7**/60.6**	0.9**/0.0**
White mustard living mulch	44.7*/43.8**	55.3**/56.2**	0.1**/0.0**
Spring barley living mulch	40.6**/53.5**	57.8**46.5**	1.6**/0.0**
Italian ryegrass living mulch	19.1**/29.7**	17.8*/9.7	65.9/60.6*
Black medic living mulch	20.0**/29.9**	24.4/24.2	55.6*/45.9**
Persian clover living mulch	18.8**/33.1**	15.3**/34.1	65.9/32.8**
Red clover living mulch	17.6**/19.1**	16.9*/7.0*	65.6/73.9
LSD_{05}	14.48/15.78	14.2115.06	9.08/10.04
LSD_{01}	19.72/21.49	19.3520.50	12.45/13.76

* – significant differences from the control treatment (hand weeding – for soil and weeds, red clover mulch – for living mulch) at 95% probability level; ** – at 99% probability level

After the second cutting the above-mentioned species almost did not re-grow. Re-growth of Italian ryegrass and Persian clover was rapid during all vegetation season of maize. Therefore, maize inter-rows not covered by living mulch were mostly occupied by weeds. Correlation and regression data analysis showed a strong negative linear relationship between living mulch (x, %) and weed coverage (Y, %) ($r_{2009} = -0.90^{**}$, $Y_{2009} = 58.861 - 0.622x$; $r_{2010} = -0.98^{**}$, $Y_{2010} = 54.572 - 0.674x$).

Living mulch or cover crops can decrease the infestation of weeds by competition for light (Teasdale, Mohler, 2000). In 2009, in early stage of growth (BBCH 15–16, maize height 10–12 cm) the competitiveness of maize crop, living mulch plants and weeds for light was poor (Table 4). The irradiance on soil surface reached up to 89.9% from background irradiance. In 2010, development of maize, living mulch plants and weeds was faster than in 2009. Therefore, they intercepted light more effectively – up to 55%.

Table 4. Maize crop irradiance (PAR, %) conditions during vegetation
LUA Experimental Station, 2009–2010

Weed control treatment	Measuring altitude in maize crop			
	soil surface	¼	½	¾
BBCH 15–16				
Hand weeding	68.2/55.0	–/–	98.5/78.3	–/–
Spring oilseed rape living mulch	69.1/42.1	–/–	100.0/88.0	–/–
White mustard living mulch	44.1/45.4	–/–	100.0/89.1	–/–
Spring barley living mulch	69.5/41.0	–/–	98.6/79.6	–/–
Italian ryegrass living mulch	65.7/55.4	–/–	98.3/81.4	–/–
Black medic living mulch	56.8/43.8	–/–	97.6/85.0	–/–
Persian clover living mulch	89.9/44.4	–/–	97.8/85.1	–/–
Red clover living mulch	88.8/46.5	–/–	97.2/87.3	–/–
LSD_{05}	31.62/14.46		8.27/16.34	
LSD_{01}	43.05/19.69		11.25/22.24	
BBCH 31–32				
Hand weeding	48.5/23.8	–/35.8	69.9/64.0	–/89.1
Spring oilseed rape living mulch	13.3**/14.8**	–/33.0	41.2*/65.1	–/93.2
White mustard living mulch	20.8**/13.4**	–/28.0	65.2/45.4	–/86.0
Spring barley living mulch	11.4**/16.8**	–/35.0	41.6*/66.0	–/91.4
Italian ryegrass living mulch	5.8**/12.8**	–/42.2	39.8*/77.8	–/100.0
Black medic living mulch	14.4**13.4**	–/25.8	46.8/53.3	–/85.8
Persian clover living mulch	2.5**/11.9**	–/30.8	29.2**/61.2	–/86.8
Red clover living mulch	9.3**10.4**	–/33.0	58.1/61.3	–/90.8
LSD_{05}	11.77/5.95	–/14.49	24.05/23.34	–/13.91
LSD_{01}	16.03/8.10	–/1973	32.74/31.78	–/18.94
BBCH 63–65 (before the third cut, 2009), BBCH 87–88 (before maize harvesting, 2010)				
Hand weeding	3.5/15.2	7.14/20.8	15.7/43.4	46.5/82.1
Spring oilseed rape living mulch	4.7/11.1	7.4/17.2	16.5/41.4	63.8/81.5
White mustard living mulch	12.9*/14.7	16.7*/26.0	32.1/44.7	74.3*/84.0
Spring barley living mulch	7.8/18.2	11.6/29.3	21.6/53.4	62.2/85.9
Italian ryegrass living mulch	6.1/15.5	15.9/28.2	38.6**/48.3	78.9*/82.0
Black medic living mulch	4.6/13.7	11.6/29.2	20.5/46.4	72.5/87.5
Persian clover living mulch	4.2/20.1	12.2/35.9	24.4/60.2	54.0/88.0
Red clover living mulch	4.1/7.0	11.7/21.7	29.3/43.7	65.0/81.8
LSD_{05}	7.86/7.53	8.87/15.27	16.58/19.80	26.01/11.40
LSD_{01}	10.70/10.26	12.07/20.79	22.57/26.35	35.42/15.52

Notes. Data present percentage expression of particular crop irradiance, if background irradiance (over plants) equals 100%. * – significant differences from the control treatment (hand weeding) at 95% probability level, ** – at 99% probability level.

At maize stem elongation stage (BBCH 31–32, maize height 56–63 cm) the influence of living mulch on soil surface irradiance increased. The correlation and regression analysis showed a strong relationship between coverage of living mulch (x, %) and irradiance (Y, %) ($r_{2009} = -0.899^{**}$, $Y_{2009} = 20.449-0.208x$; $r_{2010} = -0.860^{*}$, $Y_{2010} = 15.404-0.06x$). The highest light interception was established in Persian clover, Italian ryegrass and red clover living mulches.

At later stages of maize development (maize height from 70 to 215 cm), the influence of weeds and living mulch on irradiance conditions became lower ($r = -0.4$–0.6) because of higher competiveness of maize.

In our field experiment, the most widespread annual weeds were *Chenopodium album* L., *Stellaria media* (L.) Vill., *Sinapis arvensis* L., *Polygonum lapathifolium* L., *Poa annua* L., *Capsella bursa-pastoris* (L.) Medik., perennial – *Taraxacum officinale* F.H.Wigg., *Plantago major* L., *Sonchus arvensis* L.

How much did shoot biomass of living mulch influence weed mass and number? In our previous field investigations, in conditions of intensive soil tillage, the highest choking of weeds in sugar beet crop was observed in Italian ryegrass and white mustard living mulches (Romaneckas et al., 2009). In early stage of maize growth (BBCH 15–16), living mulches mostly had no significant influence on the number and mass of annual and perennial weeds (Table 5). In 2009, significantly lowest mean air-dry mass of all weeds was established in white mustard and red clover living mulches. In 2010, hand weeding was a more effective method of weed control. Inter-rows with living mulch plants had more weeds than the control treatment.

Table 5. The number and air-dry mass of weeds and living mulch plants at different growth stages of maize
LUA Experimental Station, 2009–2010

Weed control treatment	Weeds						Living mulch mass 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}	
1	2	3	4	5	6	7	8
BBCH 15–16							
Hand weeding	532.3 / 252.2	110.6 / 85.6	2.1 / 3.1	0.04 / 1.7	534.4 / 262.3	110.6 / 87.3	– / –
Spring oilseed rape living mulch	507.3 / 386.9	74.7 / 127.3	4.2 / 7.7	0.54 / 3.6	511.5 / 394.6	75.2 / 130.9	38.4 / 5.6
White mustard living mulch	488.3 / 375.3	40.2 / 90.8	2.1 / 1.0	0.02 / 0.03	490.4 / 376.3	40.2** / 90.8	50.9 / 22.8
Spring barley living mulch	519.8 / 288.8	84.7 / 106.8	1.0 / 3.1	0.01 / 0.9	520.8 / 291.9	84.7 / 107.7	24.9 / 0.0
Italian ryegrass living mulch	462.5 / 423.1	74.3 / 121.0	2.1 / 6.2	0.05 / 0.4	464.6 / 429.3	74.4 / 121.4	29.6 / 0.0
Black medic living mulch	594.8 / 370.6	126.2 / 82.5	2.1 / 4.2	0.04 / 0.4	596.9 / 374.8	126.2 / 82.9	0.0 / 0.0
Persian clover living mulch	406.2 / 391.6	78.8 / 172.1*	0.0 / 3.1	0.00 / 0.6	406.2 / 394.7	78.8 / 172.7*	0.0 / 0.0
Red clover living mulch	428.1 / 332.4	39.2 / 98.7	1.0 / 1.0	0.01 / 0.1	429.1 / 333.4	39.2** / 98.8	0.0 / 0.0
LSD_{05}	221.39 / 185.33	40.24 / 63.64	6.03 / 8.23	0.580 / 3.098	221.12 / 186.30	40.29 / 63.52	–
LSD_{01}	301.41 / 252.33	54.79 / 86.64	8.21 / 11.20	0.785 / 4.218	301.06 / 253.65	54.85 / 86.48	–
BBCH 31–32							
Hand weeding	127.1 / 180.2	15.60 / 34.5	0.0 / 4.2	0.0 / 3.3	127.1 / 84.4	15.6 / 37.8	– / –
Spring oilseed rape living mulch	276.0* / 126.2	142.9** / 83.6	0.0 / 12.5*	0.0 / 3.9	276.0* / 138.7*	142.9** / 87.5	27.1 / 0.4**
White mustard living mulch	268.8* / 111.1	105.5 / 117.7	2.1 / 5.2	0.8 / 1.3	270.9* / 116.3	108.3** / 119.0	1.2 / 20.7**
Spring barley living mulch	264.6* / 152.1**	88.8 / 115.6	0.0 / 2.1	0.0 / 0.3	264.6* / 154.2**	88.8* / 115.9	95.5 / 3.0**
Italian ryegrass living mulch	53.1 / 117.7	14.1 / 72.4	0.0 / 3.1	0.0 / 1.2	53.1 / 120.8	14.1 / 73.6	245.7** / 104.7
Black medic living mulch	209.4 / 117.7	78.9 / 202.7*	0.0 / 5.2	0.0 / 1.6	209.4 / 122.9	78.9 / 204.3	36.0 / 51.6**
Persian clover living mulch	39.6 / 46.8	38.7 / 30.0	0.0 / 0.0	0.0 / 0.0	39.6 / 46.8	38.7 / 30.0	262.0** / 152.2
Red clover living mulch	213.5 / 69.8	92.0 / 69.8	0.0 / 3.1	0.0 / 1.8	213.5 / 72.9	92.0* / 71.6	50.6 / 162.7
LSD_{05}	127.64 / 49.04	70.54 / 137.11	2.16 / 7.40	0.86 / 4.15	127.80 / 50.13	64.81 / 136.93	50.21 / 75.99
LSD_{01}	173.78 / 66.77	96.04 / 186.68	2.95 / 10.07	1.18 / 5.66	174.00 / 68.25	88.24 / 186.43	68.79 / 104.11
BBCH 63–65							
Hand weeding	130.2	55.7	2.1	0.3	132.3	56.0	–
Spring oilseed rape living mulch	106.2	55.7	4.2	0.4	110.4	56.1	0.5
White mustard living mulch	139.6	72.7	2.1	0.2	141.7	72.9	0.1
Spring barley living mulch	85.8	42.9	6.3	1.5**	102.1	44.4	5.8
Italian ryegrass living mulch	9.4**	5.3**	1.0	0.02	10.4**	5.3**	111.9
Black medic living mulch	54.2**	28.8	0.0	0.0	54.2**	28.8	26.6
Persian clover living mulch	10.4**	13.0*	0.0	0.0	10.4**	13.0*	129.3*
Red clover living mulch	44.8**	26.4	0.0	0.0	44.8**	26.4	61.3
LSD_{05}	55.79	34.37	4.46	0.51	54.07	34.39	61.66
LSD_{01}	75.95	46.79	6.07	0.70	73.61	46.82	84.47
BBCH 87–88							
Hand weeding	69.8 / 41.6	20.6 / 16.1	7.3 / 6.3	1.4 / 5.4	77.1 / 47.9	22.0 / 21.5	– / –
Spring oilseed rape living mulch	94.8 / 58.6	54.3 / 47.4*	15.6 / 31.5**	3.9 / 11.3	110.4 / 90.1*	58.2 / 58.7	0.0** / 0.0**
White mustard living mulch	118.8 / 62.5	79.1** / 37.3	14.6 / 24.9*	3.8 / 10.7	133.4* / 87.4*	82.9** / 48.0	0.0** / 0.0**

Table 5 continued

1	2	3	4	5	6	7	8
Spring barley	81.2	40.5	22.9**	6.8**	104.1	47.3	0.0**
living mulch	54.1	38.9	28.1*	59.7*	82.2*	98.6**	0.0**
Italian ryegrass	10.4*	2.0	5.2	0.9	15.6*	2.9	86.0
living mulch	8.4*	2.3	7.3	8.3	15.7*	10.6	88.4
Black medic	57.3	26.2	9.4	1.2	66.7	27.4	68.4*
living mulch	63.8	40.7	14.6	6.8	78.4	47.5	69.0
Persian clover	20.8	5.1	1.1	0.1	21.9**	5.2	60.3*
living mulch	20.8	24.3	9.3	3.3	30.1	27.6	61.2*
Red clover	5.2*	1.0	0.0	0.0	5.2*	1.0	124.3
living mulch	7.3**	5.8	2.1	2.1	9.4*	7.9	116.5
LSD_{05}	53.69	39.38	9.22	3.26	54.83	38.45	50.39
	24.81	29.29	18.00	45.11	31.06	50.08	48.83
LSD_{01}	73.09	53.62	12.56	4.446	74.65	52.35	69.05
	33.78	39.88	24.51	61.42	42.29	68.18	66.90

* – significant differences from the control treatment (hand weeding – for weeds, red clover mulch – for living mulch) at 95% probability level, ** – at 99% probability level

At maize stem elongation stage (BBCH 31–32) (after the first cutting) spring oilseed rape, white mustard and spring barley living mulches did not widely re-grow and the mass and number of all weeds became higher than in weeded plots. The number of weeds influenced their total mass (r_{2009} = 0.914**, r_{2010} = 0.604). The most competitive were Italian ryegrass and Persian clover plants, whose regeneration after cutting was rapid. Correlation and regression analysis of experimental data showed strong or average negative dependence of air-dry mass of living mulch (x, g m^{-2}) on number (Y_1, m^{-2}) and air-dry mass (Y_2, g m^{-2}) of total weeds: r_{2009} = −0.938**, $Y_{1(2009)}$ = 280.653–0.888x and r_{2009} = −0.88**, $Y_{2(2009)}$ = 116.443–0.351x; r_{2010} = −0.884**, $Y_{1(2010)}$ = 144.372–0.481x and r_{2010} = −0.543, $Y_{2(2010)}$ = 102.27626–4.8007x.

In 2009, at flowering stage of maize (BBCH 63–65) significantly lower number and/or mass of weeds were found in maize inter-rows covered with Italian ryegrass, black medic, Persian and red clover living mulches, which re-grew after the second cut. Similarly as before, we calculated a strong negative dependence of air-dry mass of living mulch (x, g m^{-2}) and its number (Y_1, m^{-2}) on air-dry mass (Y_2, g m^{-2}) of weeds: r = −0.921**, Y_1 = 109.403–0.87x and r = −0.882**, Y_2 = 53.951–0.39x. In 2010, in BBCH 63–65 stage, living mulch plants and weeds were not cut, counted and weighed.

Similarly as before, at the end of maize vegetation (BBCH 87–88) Italian ryegrass, Persian and red clover living mulches effectively competed with weeds because of rapid re-growth after the last cutting. Statistical analysis showed a strong negative dependence of air-dry mass of living mulch (x, g m^{-2}) on number (Y_1, m^{-2}) and air-dry mass (Y_2, g m^{-2}) of total weeds: r_{2009} = −0.925**, $Y_{1(2009)}$ = 112.219–0.968x and r_{2009} = −0.881**, $Y_{2(2009)}$ = 59.49–0.565x; r_{2010} = −0.875**, $Y_{1(2010)}$ = 87.618–0.657x and r_{2010} = −0.828*, $Y_{2(2010)}$ = 68.573–0.54x.

Generally, the highest total (during vegetation season) air-dry biomass was accumulated by Italian ryegrass (in 2009 – 473.2 and in 2010 – 193.1 g m^{-2}), Persian clover (in 2009 – 451.6 and in 2010 – 213.4 g m^{-2}) and red clover (in 2009 – 236.2 and in 2010 – 279.3 g m^{-2}) living mulches. Statistical analysis of 2009 data showed correlation between total air-dry mass of living mulch plants (x, g m^{-2}) and air-dry mass of annual (Y_1, g m^{-2}), perennial (Y_2, g m^{-2}) and total (Y_3, g m^{-2}) weeds during all vege-tation: r = −0.93**, Y_1 = 335.089–0.499x; r = −0.639, Y_2 = 5.74–0.012x; r = −0.93**, Y = 340.783–0.511. In 2010, the relationship between these factors was slightly less (r = −0.615, r = −0.666, r = −0.753).

Living mulch may compete with the maize crop, leading to smaller yields (Liedgens et al., 2004 b). We found a similar effect in our experiment (Table 6). As in Gul et al. (2009) field experiment, the highest maize shoot biomass and grain yield were recorded in the hand weeded plots.

Czapar et al. (2002) found, that hairy vetch cover crop decreased the height of corn up to approximately 20%. In our experiment, the highest negative significant influence of living mulch was on the height (r_{2009} = −0.795*, r_{2010} = −0.844*) and dry biomass of stems and leaves (r_{2009} = −0.74, r_{2010} = −0.689) of maize. Maize height was a key parameter, which strongly influenced other morphometric and productivity parameters: length of cob (r_{2009} = 0.901**, r_{2010} = 0.726), number of kernels per row of cob (r_{2009} = 0.943**, r_{2010} = 0.729), dry biomass of cobs (r_{2009} = 0.887**, r_{2010} = 0.822*), stems and leaves (r_{2009} = 0.917**, r_{2010} = 0.895**), total dry shoot biomass (r_{2009} = 0.931**, r_{2010} = 0.889**) and grain yield (r_{2009} = 0.968**, r_{2010} = 0.795*). Thus, living mulch plants slightly influenced all mentioned parameters too. We did not find any relationship between maize crop density and productivity parameters.

In our previous field experiments (2004–2005), the allopathic and choking properties of Italian ryegrass decreased sugar beet crop yield and sucrose content, and increased the amount of sodium in the roots. The highest sugar beet crop productivity was observed in hand weeded plots and in plots with oilseed rape living mulch (Adamavičienė et al., 2009). Similarly as before, the lowest effect of competition was shown between maize crop and spring oilseed rape or spring barley living mulches because these plants were early eliminated from maize crop by cutting. In 2009, Italian ryegrass living mulch was extremely aggressive and significantly decreased shoot dry biomass and grain yield of maize because of rapid re-growth after each cutting. Similar results were found by Liedgens et al. (2004 a). According to Akobundu and Okigbo (1984), high maize yield was obtained in the live mulch in which weed competition was minimized by the legume cover. However, Hiltbrunner et al. (2007) found significant negative correlation between the cover crop (*Trifolium repens* L., *Trifolium subterraneum* L., *Lotus corniculatus* L.) and the winter wheat at wheat anthesis. Hollander et al. (2007) indicated that Persian clover and red clover cover crops gave the strongest negative effect on dry matter accumulation in leek (reduction between 70% and 90%). In our field experiment, legumes (black medic, Persian and red clovers) decreased maize productivity because of their rapid re-growth and possibility to produce high rates of biomass. Persian clover produced 451.6 and 213.4 g m^{-2}, red clover – 236.2 and 279.3 g m^{-2} in 2009 and 2010, accordingly).

Table 6. The influence of living mulch on morphometric and productivity parameters of maize crop
LUA Experimental Station, 2009–2010

Weed control treatment	Maize height cm	Cob length cm	Dry biomass t ha^{-1} cobs	Dry biomass t ha^{-1} stems and leaves	Dry biomass t ha^{-1} total	Grain yield t ha^{-1}	1000 kernel weight g
Hand weeding	209.5 172.7	12.6 13.1	6.32 10.98	6.50 3.94	12.82 14.92	5.99 8.34	166.28 272.11
Spring oilseed rape living mulch	193.6 155.9	12.9 11.8	7.01 8.78	4.02** 3.22	11.03 12.00	6.53 7.42	174.38 287.95
White mustard living mulch	162.1** 141.9**	10.9 11.4	4.92 7.65**	3.33** 2.57*	8.25* 10.22**	4.22 6.37	161.91 284.91
Spring barley living mulch	171.1* 150.7*	11.8 11.3	6.69 8.63	3.21** 2.64*	9.90 11.27*	4.59 6.90	184.56 309.36
Italian ryegrass living mulch	140.7** 143.5**	8.4** 11.3	3.60 8.12*	2.30** 2.61*	5.90** 10.73*	2.42* 6.51	176.13 272.81
Black medic living mulch	157.5** 143.6**	8.9** 11.1*	4.55 7.29**	3.03** 2.49**	7.58** 9.78**	3.03 5.86*	168.76 267.97
Persian clover living mulch	152.6** 134.1**	9.9 10.3**	5.42 7.44**	3.03** 2.35**	8.45 9.79**	3.68 6.00*	159.94 262.81
Red clover living mulch	163.0* 135.3**	9.4* 11.3	5.64 7.72*	3.52** 2.37**	9.16 10.09**	4.27 6.43	164.75 282.96
LSD_{05}	34.54 21.09	2.70 1.88	3.251 2.404	1.370 1.052	4.429 3.210	2.972 1.974	23.751 39.224
LSD_{01}	47.02 28.72	3.68 2.57	4.433 3.273	1.861 1.432	6.032 4.369	4.039 2.688	32.308 53.403

Notes. * – significant differences from the control treatment (hand weeding) at 95% probability level, ** – at 99% probability level. Grain moisture content – 15%.

Conclusions

1. The competiveness of living mulch and weeds depended on the germination, development and re-growth rates of living mulch plant species. Rapidly developing living mulch species (spring oilseed rape, white mustard, spring barley, Italian ryegrass and Persian clover) mostly covered soil surface, more effectively choked weeds and better competed for space and light at the early stages of maize crop. There was found a strong negative linear relationship among living mulch (x, %) and weed coverage (Y, %) (r_{2009} = −0.90**, r_{2010} = −0.98**), coverage of living mulch (x, %) and irradiance (Y, %) (r_{2009} = −0.899**, r_{2010} = −0.860*), total air-dry mass of living mulch plants (x, g m^{-2}) and air-dry mass of annual, perennial and total (Y, g m^{-2}) weeds: r_{2009} = −0.93** and r_{2010} = −0.615, r_{2009} = −0.639 and r_{2010} = −0.666, r_{2009} = −0.93** and r_{2010} = −0.753).

2. Living mulches competed with the maize crop and decreased yields and other growth parameters. Living mulch exerted the highest negative significant influence on the height (r_{2009} = −0.795*, r_{2010} = −0.844*) and dry biomass of stems and leaves (r_{2009} = −0.74, r_{2010} = −0.689) of maize.

3. Italian ryegrass living mulch mostly decreased shoot dry biomass of maize because of rapid re-growth after each cutting. Legumes (black medic, Persian and red clovers) decreased maize productivity because of rapid re-growth and production of high rates of biomass.

4. Spring oilseed rape, white mustard and spring barley living mulches were eliminated from maize crop after the first or the second cutting; however, they fairly competed with weeds at first stages of development and had the lowest negative influence on maize productivity. These plants might be suggested to be grown as living mulches in maize crop inter-rows.

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Kukurūzų ir įsėlinių tarpinių augalų sąveika. Pasėlio piktžolėtumas bei produktyvumas

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Santrauka

Lauko bandymai vykdyti 2009–2010 m. Lietuvos žemės ūkio universiteto Bandymų stotyje (54º52′ N, 23º49′ E) tarpinio – jūrinio-kontinentinio – klimato sąlygomis. Bandymų dirvožemis – dulkiškas priemolis, grupė – išplautžemis (IDg8-k). Tyrimų tikslas – ištirti kukurūzų bei įsėlinių tarpinių augalų sąveiką ir jos įtaką kukurūzų pasėlio piktžolėtumui bei produktyvumui. Kukurūzų tarpueiliai užsėti vasarinio rapso (*Brassica napus* L.), baltosios garstyčios (*Sinapis alba* L.), vasarinio miežio (*Hordeum vulgare* L.), gausiažiedės svidrės (*Lolium multiflorum* Lamk.), apyninės liucernos (*Medicago lupulina* L.), vienamečio persinio dobilo (*Trifolium resupinatum* L.) ir raudonojo dobilo (*Trifolium pratense* L.) tarpiniais augalais. Juos nupjovus dirvos paviršius buvo mulčiuotas.

Nustatyti stipri neigiama priklausomybė tarp tarpueilių padengimo įsėliniais tarpiniais augalais (x, %) ir piktžolėmis (Y, %) ($r_{2009} = -0.90$**, $r_{2010} = -0.98$**), tarpueilių padengimo įsėliniais tarpiniais augalais (x, %) ir apšvitos (Y, %) ($r_{2009} = -0.899$**, $r_{2010} = -0.860$*), įsėlinių tarpinių augalų sausųjų medžiagų bendrosios masės (x, g m^{-2}) ir trumpaamžių, daugiamečių bei visų piktžolių sausųjų medžiagų masės (Y, g m^{-2}) (atitinkamai $r_{2009} = -0.93$**, $r_{2010} = -0.615$; $r_{2009} = -0.639$, $r_{2010} = -0.666$; $r_{2009} = -0.93$**, $r_{2010} = -0.753$).

Įsėliniai tarpiniai augalai sąveikavo su kukurūzais ir sumažino jų derlių bei kitus rodiklius. Didžiausia esminė neigiama įtaka nustatyta kukurūzo augalo vidutiniam aukščiui ($r_{2009} = -0.795$*, $r_{2010} = -0.844$*) ir stiebų bei lapų sausųjų medžiagų derlingumui ($r_{2009} = -0.74$, $r_{2010} = -0.689$). Gausiažiedės svidrės labiausiai mažino kukurūzų antžeminės dalies sausosios biomasės derlių, nes po kiekvieno nupjovimo jos greitai ataugdavo. Dėl ilgos vegetacijos pupiniai įsėliniai tarpiniai augalai (apyninės liucernos, persiniai ir raudonieji dobilai) taip pat mažino kukurūzų produktyvumą. Vasariniai rapsai, baltosios garstyčios ir vasariniai miežiai pirmaisiais vystymosi tarpsniais pakankamai efektyviai stelbė piktžoles ir turėjo mažiausią neigiamą įtaką kukurūzų produktyvumui. Šie augalai ir rekomenduotini įsėti į kukurūzų tarpueilius.

Reikšminiai žodžiai: kukurūzų pasėlis, įsėliniai tarpiniai augalai mulčiui, piktžolės, sąveika, produktyvumas.