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EFFECT OF LIVING MULCH AND LINURON ON WEEDS AND YIELD OF CARROT UNDER RIDGE CULTIVATION

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Abstract. A two years' field study was conducted to compare the influence of perennial ryegrass (*Lolium perenne* L.), white clover (*Trifolium repens* L.), perennial ryegrass + white clover mixture and mowed weeds used as living mulches with the influence of linuron 675 g·ha^{-1} on weed infestation and yield of carrot (*Daucus carota* L.) 'Flakkese 2' under ridge cultivation. Living mulches did not affect growth of weeds during first five weeks after carrot sowing and they reduced weed infestation significantly at the end of vegetation period. Living mulches and mowed weeds caused decrease of total and marketable yield of carrot roots and in a less degree also decrease of carrot leaves fresh weight. Share of roots damaged by insects and snails and with disease symptoms in nonmarketable yields harvested on plots covered with living mulches and mowed weeds was smaller and share of bifurcated roots and roots with diameter < 20 mm was bigger than that on plots sprayed with linuron 675 g·ha^{-1}. Mowed weeds were less useful as a living mulch under carrot ridge cultivation than perennial ryegrass, white clover and perennial ryegrass – white clover mixture.

Key words: perennial ryegrass, white clover, mowing, yield structure

INTRODUCTION

Carrot as a root vegetable is sensitive to soil quality, and especially to soil compaction [Strandberg and White 1979, Kęsik and Konopiński 1993]. The root growth conditions can be improved under ridge cultivation [Ponjičan et al. 2012]. Several authors shoved that the yield of carrot cultivated on ridges was higher and of better quality in comparison to the yield obtained under flat cultivation [Babik et al. 1998, Cebulak and

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Sady 2000]. Moreover in the northern European climate, ridge cultivation allows earlier sowing and promotes earlier growth of carrot plants [Taivalmaa and Talvitie 1997]. In Poland, cultivation of carrot on ridges is known since a long time [Hellwigowa and Koczańska 1960–61], however its practical significance increased considerably in recent years [Babik et al. 1998, Kowalczyk 2004]. This method is recommended for compact and wet soils and especially for cultivation of cultivars developing very long roots [Helwigowa and Koczańska 1960–61, Kowalczyk 2004]. Carrot cultivated on ridges produces longer and more uniform roots in comparison to flat cultivation [Dyśko and Kaniszewski 2007, Ponjičan et al. 2012]. Moreover ridge cultivation is a proven soil conservation technology [Pimentel et al. 1995] reducing wind erosion [Liu et al. 2006], however weed control on the ridges is more difficult than in a flat field [Babik and Dudek 2003] and carrot is very sensitive to weed competition [Dobrzański 1999, Swanton at al. 2010]. In the last years living mulch is considered as an important tool in sustainable weed management [Labrada 2006] and especially in cultivated from transplants, toll growing crops characterized by long vegetation period [Masiunas 1998, Leary and DeFrank 2000, Hartwig and Ammon 2002, Kołota and Adamczewska-Sowińska 2013]. Slow germination and slow initial growth make carrot sensitive to competition caused by faster growing weeds [Dobrzański 1999, Swanton et al. 2010]. Similarly, fast growing living mulch can compete with vegetable plant and inhibit its growth [Wiles et al. 1989, Borowy 2012] but this difficulty can be eliminated partially under ridge cultivation in which living mulch is seeded in furrows and vegetable plant on ridges. Light is one of the major factors of competition between plants [Zimdahl 2004] and a crop grown on ridges has better accessibility to it. Excessive growth of living mulch can be suppressed mechanically [Wiles et al. 1989, Brandsæter et al. 1998, Greenland 2000, Adamczewska-Sowińska 2008]. Besides inhibiting growth of weeds, living mulch offers several other advantages: decrease of soil compaction [Nicholson and Wien 1983] and pest infestation [Costello and Altieri 1994, Hooks and Johnson 2004], prevention of soil erosion [Hartwig and Ammon 2002, Lal 2008], increase of organic matter content and improvement of soil structure [Poniedziałek and Stokowska 1999]. Living mulch system can provide a comprehensive integrated pest management scheme, with potential for eliminating synthetic pesticides [Leary and DeFrank 2000]. Among species recommended in moderate climate for cultivation as a living mulch in vegetable crops are white clover [Nicholson and Wien 1983, Brandsæter et al. 1998, Poniedziałek and Stokowska 1999, Adamczewska-Sowińska 2004, 2008, Kołota and Adamczewska-Sowińska 2013] and perennial ryegrass [Wiles et al. 1989, Masiunas et al. 1997, Adamczewska-Sowińska 2004, 2008, Kołota and Adamczewska-Sowińska 2013]. Naturally occurring weeds can be also used as an alternative living mulch [Hartwig and Ammon 2002]. Weed population is a dynamic changing community composed by species related with cultivated plant and environmental conditions [Heller 1998, Chmielowiec and Borowy 2005]. Weed communities occurring in carrot cultivated in Poland consists mainly of several annual dicotyledonous and few grass species [Dobrzański 1999]. Among them there are toll growing weeds like barnyard grass, lamb's quarters and redroot pigweed characterized by a big competitive ability [Zimdahl 2004, Błażewicz-Woźniak et al. 2014]. Spring-seeded living mulches which are established with vegetables are less competitive to the crop than those established in the fall, however their slow initial growth can be conducive to the growth of early-season weeds [Masiunas et al. 1997, Brandsæter et al. 1998, Masiunas 1998] and their weed suppressing effect becomes visible not till late summer [Brandsæter et al. 1998]. Since many years, linuron is one of the principal herbicides used for weed control in conventional cultivation of carrot [Dobrzański 1999, Swanton et al. 2010]. Until now there is no information in the literature about using of living mulch in carrot crop. The aim of this study was to compare the effect of perennial ryegrass and white clover grown in pure stand and in mixture as living mulches in the furrows with the effect of fourfold weed mowing and of linuron application on weed infestation and on yield of carrot under ridge cultivation.

MATERIAL AND METHODS

The experiment was carried out in the years 2011–2012 in the Felin Experimental Farm (215 m above sea level, 51°14'N latitude, 22°38'W longitude) belonging to the University of Life Science in Lublin. Carrot was cultivated on podzolic soil developed from medium loam containing 1.8% of organic matter and with pH of 6.7. Content of nitrogen, phosphorus and potassium in the soil was adjusted to the level of 120 mg $N \cdot dm^{-3}$ using urea fertilizer, 80 mg $P \cdot dm^{-3}$ using triple superphosphate and 120 mg $K \cdot dm^{-3}$ using potassium nitrate. In the middle of July, 50 kg N was applied in the ammonium nitrate form as a top dressing. The 23 cm high and 20 cm wide on top ridges were formed 67.5 cm apart directly before seeding. Seeds of carrot (*Daucus carota* L.) 'Flakkese 2' were seeded at the rate 1.5 $kg \cdot ha^{-1}$ using a hand seeder on May 10th, 2011 and on May 11th, 2012. Seeds were sown on the top of ridge in two rows with the 10-12 cm distance between them. On the same day, the seeds of white clover (*Trifolium repens* L.) cv. Haifa 7 15.0 $kg \cdot ha^{-1}$ and of perennial ryegrass (*Lolium perenne* L.) cv. Solen 30 $kg \cdot ha^{-1}$ and also the mixture of these seeds (white clover 7.5 $kg \cdot ha^{-1}$ + perennial ryegrass 15.0 $kg \cdot ha^{-1}$) were seeded by hand in the furrows. There were also two treatments without living mulch: one sprayed with linuron 675 $g \cdot ha^{-1}$ immediately after seed sowing with two supplementary hand weeding (in the middle of July and in the middle of August) and also one treatment with fourfold weed mowing. Weed infestation was evaluated twice: in June, five weeks after seed sowing and in October, one week before carrot harvest. During this evaluation the number and the fresh weight of weeds growing in the furrows on 0.4 m^{-2} area of each plot was determined. Upper parts of ridges were weeded by hand at the end of May and at the end of June. After attaining a height of about 40 cm, living mulches and weeds growing in furrows were mowed by hand at 8 to 10 cm using power scythe. In 2011 the mowing was effected on June 27th, July 22nd, August 18th, and September 8th and in 2012 it was done on June 22nd, July 12th, August 16th, and September 12th. At the time of second weed measurement, above ground parts of living mulches were cut on 0.4 m^{-2} area and then their fresh weight was measured. Carrot was harvested on October 20th, 2011 and on October 16th, 2012. After harvest the leaves were cut off and their fresh weight as well as the total yield of roots were determined. Then the roots were divided according to their diameter into following selections: < 20, 21–30, 31–40, 41–50, 51–60, 61–70 and > 70 mm. At the same time, the roots were divided into following selections: bifurcated, split, with disease symptoms (*Sclerotinia sclerotiorum* (Lib.) de Bary, *Alter-*

naria sp, *Fusarium oxysporum* Schlecht. emend. Snyder & Hansen) and damaged by turnip moth (*Agrotis segetum* Schiff.), setaceous tlebrew character (*Rhyacia c-nigrum* L.), click beetles (*Elateridae*) and snails (*Deroceras agreste* L.). These selections and also the roots of diameter smaller than 20 mm were classified as nonmarketable and all straight, undamaged and healthy roots of diameter bigger than 20 mm were classified as marketable. The experiment was established in randomized blocks design with four replications and the area of one plot was 17.0 m^2 (5.0 m × 3.4 m). Obtained results were studied by analysis of variance and the significance of differences was determined using Tukey's test at 0.05 probability level.

Table 1. Average monthly and many year's (1951–2005) air temperatures and sums of rainfalls in Felin Experimental Farm in 2011–2012

Month	Temperature, °C			Rainfalls, mm		
	2011	2012	1951–2005	2011	2012	1951–2005
May	14.3	15.1	13.0	42.2	56.3	57.7
June	18.6	17.3	16.2	67.8	62.8	65.7
July	18.4	21.5	17.8	189.0	52.3	83.5
August	18.8	19.2	17.1	65.3	37.6	68.6
September	15.2	15.0	12.6	5.4	25.5	51.6
October	7.9	8.0	7.8	28.5	88.8	40.1

In both years of study the air temperatures were higher than many years' (1951–2005) air average temperature for this period (tab. 1). In the year 2011 heavy rainfalls were in July and there were almost no rain in September. In 2012 the precipitations occurring from July to September were insufficient to cover the needs of intensive growing carrot roots. More intensive rainfalls (54.5 mm) occurred in the last ten days of October after harvest of carrot.

RESULTS

During two study years, 26 weed species occurred in the experiment. Among them gallant soldier (*Galinsoga parviflora* Cav.), lamb's quarters (*Chenopodium album* L.), shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.), barnyard grass (*Echinochloa cruss-galli* (L.) P.B.), hairy galinsoga (*Galinsoga quadriradiata* Ruiz et Pav.), redroot pigweed (*Amaranthus retroflexus* L.), henbit deadnettle (*Lamium amplexicaule* L.), and common chickweed (*Stellaria media* (L.) Vill.) dominated and made 97% of all weeds growing on no weeded plots (tab. 2). Emergence of weeds started one week after sowing of carrot seeds and then the weeds grew fast. Five weeks after carrot sowing, 329 weeds grew on 1 m^{-2} of no weeded plot in 2011 and 745 weeds grew in 2012 and their fresh weight was 1208 g·m^{-2} and 2462 g·m^{-2} respectively. In this time the weeds covered from 30 to 65% of soil surface. Living mulches did not influence the growth of weeds and the best weed control was observed on plots treated with linuron 675 g·ha^{-1} which controlled about 90% of weeds in both years of study (tab. 2). Four months later and one week before harvest of carrot, number and frequency of weed species occurring in the experiment decreased, especially in 2012 (tab. 3). Dominating species were hairy galinsoga, gallant soldier, common chickweed and annual meadow grass (*Poa annua* L.) which made about 90% of all weeds on an average. Fresh weight of weeds was also smaller, especially in 2011. One week before harvest, 236 weeds on an average grew on 1 m^{-2} of no weeded plot with fourfold moving in 2011 and 79 weeds grew in 2012 and their fresh weight was 320 $g·m^{-2}$ and 1160 $g·m^{-2}$ respectively with the differences being significant. In this time, the number and the fresh weight of weeds growing on plots covered with living mulches were much lower and linuron 675 $g·ha^{-1}$ did not affect these features.

Ryegrass and white clover emerged in the same time as weeds but their growth was much slower. Five weeks after carrot sowing, they covered 5–15% of soil surface and in the middle of July this area increased to 50%. White clover plants grew up to 20–25 cm high and the stand formed by ryegrass leaves attained an average height of 30 cm. In the summer, ryegrass plants developed many flowering stems growing up to 80 cm high which were mowed together with the weeds after reaching the height of 40 cm. Fresh weight of above ground parts measured in the second week of October depended on the year of study and also on the interaction between living mulch species and year. Living mulches developed bigger biomass of above ground parts in 2012 (tab. 4). An average fresh weight of white clover above ground parts (885.9 $g·m^{-2}$) was the lowest and the least variable and that of white clover + perennial ryegrass (1005.1 $g·m^{-2}$) was the highest and the most variable. The fresh weight of living mulches above ground parts measured one week before carrot harvest was considerably lower than that of weeds measured five weeks after carrot seed sowing and approximated fresh weight of weeds measured in October.

Emergence of carrot started two weeks after seed sowing and the initial growth of carrot plants was very slow. In the middle of vegetation period, carrot leaves formed a dense stand 30 cm high and covered well the tops of ridges. Yield of carrot roots and fresh weight of carrot leaves depended more on year of study than on living mulch or weeding method (tab. 5). Carrot plants produced significantly higher total and marketable yield of roots and biomass of leaves in the year 2011 characterized by bigger sum of rainfalls during vegetation period. In both years, the highest total and marketable yields of roots were harvested on plots sprayed with linuron 675 $g·ha^{-1}$ and average differences between these yields and yields obtained in remaining treatments were significant. Total and marketable yields of carrot roots harvested on plots covered with living mulches did not differ significantly, however every year there was a tendency for better yielding on plots covered with ryegrass. Yields harvested on plots with fourfold weed mowing were similar to those from plots covered with white clover and white clover + ryegrass. Marketable roots made 57.9% of total yield on an average in 2011 and 67.4% in 2012. Their share in the yields harvested on plots covered with white clover + ryegrass and on plots sprayed with linuron 675 $g·ha^{-1}$ was higher and their share in the yield harvested on plots with fourfold weed mowing was lower in comparison to remaining treatments. Effect of living mulch and weeding method on fresh weight of carrot leaves was less distinct and significant in 2012 only (tab. 5). The highest biomass of leaves was produced by carrot plants on plots sprayed with linuron 675 $g·ha^{-1}$ and the lowest biomass of leaves was produced by carrot plants on plots covered with ryegrass.

In total yield of carrot roots, the biggest share made roots of 21–30 mm diameter (23.2% on an average) and then of 41–50 mm diameter (22.3%) and of 31–40 mm diameter (21.7%) and the smallest share made roots of diameter bigger than 70 mm (0.06%)

Table 2. Number (no. m^{-2}) and fresh weight ($g \cdot m^{-2}$) of weeds growing in the experiment 5 weeks after carrot seeds sowing in dependence on living mulch and weeding method in the years 2011–2012

Weed species	Treatments																	
	perennial ryegrass			white clover			white clover + perennial ryegrass			Linuron 675 $g \cdot ha^{-1}$			no weeding			mean		
	2011	2012	mean	2011	2012	mean	2011	2012	mean	2011	2012	mean	2011	2012	mean	2011	2012	mean
Amaranthus lividus L. Amali.	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Amaranthus retroflexus L.	11	19	15	4	44	24	14	17	16	3	5	4	20	40	30	11	25	18
Anthemis arvensis L.	0	2	1	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1
Artemisia absinthium L.	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
Capsella bursa-pastoris (L.) Medik.	125	19	72	105	42	74	136	15	75	7	0	4	157	21	89	106	19	63
Chenopodium album L.	42	260	151	8	121	65	13	173	93	0	8	4	13	190	102	15	151	83
Cirsium arvense (L.) Scop.	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Echinochloa crus-galli (L.) P.B.	15	40	27	23	112	68	34	46	40	17	29	23	23	31	27	23	52	38
Epilobium parviflorum Schreb.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Galinsoga parviflora Cav.	1	329	165	10	220	115	3	263	133	2	9	5	0	333	166	3	231	117
Galinsoga quadriradiata Ruiz et Pav.	43	52	47	28	4	16	50	29	40	1	3	2	46	110	78	34	40	37
Geranium pusillum L.	1	0	1	6	0	3	0	0	0	0	0	0	0	0	0	1	0	1
Lamium amplexicaule L.	52	0	26	39	0	20	48	0	24	12	0	6	18	0	9	34	0	17
Lamium purpureum L.	23	0	11	1	0	1	7	0	3	4	0	2	3	0	2	8	0	4
Matricaria chamomilla L.	1	0	1	2	0	1	3	0	1	0	0	0	4	0	2	2	0	1
Plantago maior L.	1	0	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0
Poa annua L.	0	0	0	3	0	1	2	0	1	2	0	1	3	0	1	2	0	1
Polygonum convolvulus L.	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polygonum persicaria L.	2	2	2	0	0	0	0	0	0	0	0	0	1	2	1	1	1	1

Senecio vulgaris L.	1	0	1	1	0	0	4	0	2	0	0	0	3	2	3	2	0	1
Stellaria media (L.) Vill.	18	0	9	18	0	9	26	0	13	2	0	1	33	4	19	19	1	10
Taraxacum offcinale Web.	0	0	0	0	0	0	0	2	1	0	0	0	1	2	1	0	1	1
Thlaspi arvense L.	0	2	1	0	0	0	0	0	0	0	0	0	1	4	3	0	1	1
Tripleurospermum inodorum (L.)	0	2	1	0	2	1	0	4	2	0	0	0	0	4	2	0	2	1
Urtica urens L.	1	4	2	1	0	0	3	2	3	0	0	0	2	0	1	1	1	1
Vicia cracca L.	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0
Sum	337	731	534	253	547	400	343	553	448	50	55	53	329	745	537	262	526	394
Number of weeds	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
LSD $_{0.05}$ Year (A)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	86.0
Treatments (B)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	75.8	169.7	192.01
A × B	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	n.s.
Weight of weeds (g m^{-2})	1226	856	1041	968	1853	1410	1115	1443	1279	103	95	99	1208	2462	1835	924	1342	1133
LSD $_{0.05}$ Year (A)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	241.14
Treatments (B)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	104.12	495.54	540.92
A × B	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	898.35

Table 3. Number (no. m^{-2}) and fresh weight (g m^{-2}) of weeds growing in the experiment 5 months after carrot seeds sowing in dependence on living mulch and weeding method in the years 2011–2012

Weed species	Treatments																	
	perennial ryegrass			white clover			white clover + perennial ryegrass			Linuron 675 g·ha^{-1}			weed mowing			mean		
		2011	2012	mean	2011	2012	mean	2011	2012	mean	2011	2012	mean	2011	2012	mean	2011	2012
Amaranthus lividus L. Amali.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Amaranthus retroflexus L.	3	0	2	1	0	0	1	0	0	3	3	3	4	3	3	2	1	2
Capsella bursa-pastoris (L.) Medik.	0	0	0	0	0	0	0	0	0	8	0	4	11	0	5	4	0	2
Chenopodium album L.	3	0	1	1	0	0	1	0	0	2	0	1	1	0	0	2	0	1
Cirsium arvense (L.) Scop.	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0
Convolvulus arvensis L	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Echinochloa crus-galli (L.) P.B.	0	0	0	0	0	0	1	0	0	9	0	4	8	0	4	4	0	2
Galinsoga parviflora Cav.	16	13	14	16	8	12	16	48	32	15	79	47	17	73	45	16	44	30
Galinsoga quadriradiata Ruiz et Pav.	19	0	10	11	0	5	31	18	24	96	4	50	105	3	54	52	5	29
Geranium pusillum L.	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gnaphalium uliginosum L.	0	0	0	0	0	0	0	0	0	2	0	1	2	0	1	1	0	0
Lamium amplexicaule L.	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0
Matricaria chamomilla L.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poa annua L.	1	0	0	6	0	3	4	0	2	44	0	22	41	0	20	19	0	10
Senecio vulgaris L.	0	0	0	0	0	0	0	0	0	2	0	1	3	0	2	1	0	0
Stellaria media (L.) Vill.	1	0	0	4	0	2	2	0	1	32	0	16	40	0	20	16	0	8
Taraxacum offcinale Web.	0	0	0	0	0	0	0	3	1	0	1	1	0	0	0	0	1	0
Urtica urens L.	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Sum	46	13	28	41	8	22	56	69	60	214	87	151	236	79	154	118	51	84
Number of weeds	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
LSD $_{0.05}$ Year (A)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	24.1
Treatments (B)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	114.9	30.3	54.2
A × B	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	90.1
Weight of weeds (g m^{-2})	92	16	54	115	91	103	138	604	371	319	953	637	320	1160	740	197	565	381
LSD $_{0.05}$ Year (A)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	145.58
Treatments (B)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	201.83	666.23	326.56
A × B	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	542.93

Table 4. Fresh weight of living mulches above ground parts the second week of October 2011 and 2012 ($g \cdot m^{-2}$)

Living mulch	2011	2012	Mean
Perennial ryegrass	624.8	1242.8	933.7
White clover	857.9	914.0	885.9
Perennial ryegrass + white clover	698.7	1311.5	1005.1
Mean	727.1	1156.1	941.6
$LSD_{0.05}$	–	–	–
Year (A)	–	–	198.97
Living mulch (B)	110.23	224.05	n.i.
A × B	–	–	521.01

and then of 61–70 mm diameter (8%) and of diameter smaller than 20 mm (8.4%). Living mulches and weeding methods did not affect the yield of smallest roots (diameter smaller than 20 and 21–30 mm) and of roots of 61–70 mm diameter (tab. 6). In the case of roots of the 31–40, 41–50 and 51–60 mm diameter, significantly higher yields were harvested on plots sprayed with linuron (except for the yield of 31–40 mm roots from plots covered with ryegrass). There were no differences between yields harvested on plots covered with living mulches and on plots with weed moving (except for the yield of 51–60 mm roots from plots covered with white clover + ryegrass and from plots with weed moving). Few roots of diameter bigger than 70 mm were harvested on plots covered with ryegrass and with ryegrass + white clover in 2011 only. Moreover, the yield of four carrot roots selections (21–30, 41–50, 61–70 and >70 mm) was dependent on the interaction between living mulch/weeding method and year.

The quantity and the structure of nonmarketable yield of carrot roots was dependent mainly on the year of study and also on interaction between the year and the treatment and in a less degree on the living mulch and weeding method (tab. 7). Nonmarketable yield harvested in 2011 was significantly higher than in 2012 and its share in total yield was also higher however this difference was much smaller. Moreover in 2011 the share of all selections of nonmarketable roots (except for roots of < 20 mm diameter) in total nonmarketable yield was higher than in 2012 and this was visible especially for split roots. However, the share of roots of diameter < 20 mm was in 2011 six times smaller than in 2012. Yield of nonmarketable roots harvested on plots sprayed with linuron 675 $g \cdot ha^{-1}$ was characterized by low share of bifurcated roots and high share of roots with disease symptoms and damaged roots. Yield of nonmarketable roots harvested on plots with fourfold weed mowing was characterized by high share of bifurcated and damaged roots and lack of roots with disease symptoms. There were small differences between share of bifurcated and damaged roots in total nonmarketable yield harvested on plots covered with different living mulches. The highest share of bifurcated roots was in the yield harvested on plots covered with white clover and the lowest was in the yield from plots covered with mixture of white clover and ryegrass. The highest share of roots with disease symptoms was in the yield obtained from plots covered with rye grass and the lowest was in the yield from plots covered with white clover.

Table 5. Effect of living mulch and weeding method on yield of carrot (t·ha^{-1}) in the years 2011–2012

Treatments	Yield of carrots roots						Share of marketable roots in total yield (%)			Fresh weight of leaves		
	total			marketable								
	2011	2012	mean	2011	2012	mean	2011	2012	mean	2011	2012	mean
Perennial ryegrass	44.6	21.5	33.1	24.0	14.9	19.5	53.8	69.3	61.6	10	4.1	7
White clover	43.0	16.5	29.7	24.8	11.1	18.0	57.7	67.3	62.5	10.5	4.5	7.5
Perennial ryegrass + white clover	40.6	18.0	29.3	25.0	12.4	18.7	61.6	68.9	65.2	9.3	5.2	7.3
Linuron 675 g·ha^{-1}	56.1	24.5	40.3	34.3	17.0	25.7	61.1	69.4	65.3	12.6	6.7	9.7
Weed mowing	40.8	17.6	29.2	22.5	10.9	16.7	55.1	61.9	58.5	10.3	4.2	7.3
Mean	45.0	19.6	32.3	26.1	13.3	19.7	57.9	67.4	62.6	10.5	4.9	7.7
LSD $_{0.05}$ Year (A)	–	–	2.85	–	–	1.82	–	–	–	–	–	1.18
Treatments (B)	11.51	7.72	6.41	6.57	5.71	4.08	–	–	–	n.s.	2.28	n.s.
A × B	–	–	n.s.	–	–	n.s.	–	–	–	–	–	n.s.

Table 6. Effect of living mulch and weeding method on structure of carrot total yield (t·ha^{-1}) in the years 2011–2012

Treatments	Roots diameter (mm)																				
	<20			20–30			30–40			40–50			50–60			60–70			>70		
	2011	2012	mean	2011	2012	mean	2011	2012	mean	2011	2012	mean	2011	2012	mean	2011	2012	mean	2011	2012	mean
Perennial ryegrass	1.9	4.7	3.3	5.5	11.7	8.6	9.8	5.2	7.5	12.5	0.0	6.3	9.6	0.0	4.8	4.9	0.0	2.4	0.4	0.0	0.2
White clover	1.8	3.4	2.6	5.0	7.8	6.4	8.3	4.1	6.2	13.0	1.0	7.0	9.6	0.0	4.8	5.2	0.2	2.7	0.0	0.0	0.0
Perennial ryegrass + white clover	1.7	4.3	3.0	4.7	9.7	7.2	8.9	3.5	6.2	12.2	0.4	6.3	8.2	0.0	4.1	4.7	0.0	2.4	0.1	0.0	0.1
Linuron 675 g ha^{-1}	2.0	2.7	2.3	5.0	12.9	9.0	11.7	6.5	9.1	18.0	2.4	10.2	13.8	0.0	6.9	5.8	0.0	2.9	0.0	0.0	0.0
Weed mowing	1.8	3.5	2.6	5.5	7.6	6.5	7.4	4.6	6.0	10.7	1.8	6.2	10.8	0.1	5.4	4.7	0.0	2.4	0.0	0.0	0.0
Mean	1.8	3.7	2.7	5.1	9.9	7.5	9.2	4.8	7.0	13.3	1.1	7.2	10.4	0.0	5.2	5.1	0.0	2.6	0.1	0.0	0.1
LSD $_{0.05}$ Year (A)	–	–	0.70	–	–	1.30	–	–	0.85	–	–	0.76	–	–	0.55	–	–	0.43	–	–	0.02
Treatments (B)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	2.47	n.s.	1.82	3.19	1.76	1.71	2.66	n.s.	1.25	n.s.	n.s.	n.s.	0.10	n.s.	0.05
A × B	–	–	n.s.	–	–	4.86	–	–	n.s.	–	–	2.84	–	–	2.08	–	–	n.s.	–	–	0.08

Table 7. Effect of living mulch and weeding method on structure of nonmarketable yield of carrot roots ($t \cdot ha^{-1}$)

Treatment	Bifurcated						Split						With disease symptoms					
	2011		2012		mean		2011		2012		mean		2011		2012		mean	
	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*
Perennial ryegrass	10.9	52.7	1.5	22.4	6.2	45.3	1.5	7.2	0.0	0.0	0.7	5.1	0.7	3.4	0.0	0.0	0.4	2.9
White clover	10.2	56.0	1.3	23.6	5.7	47.9	2.0	11.0	0.1	1.8	1.1	9.2	0.0	0.0	0.1	1.8	0.1	0.4
White clover + perennial ryegrass	9.3	69.6	0.7	12.5	5.0	47.2	1.0	6.4	0.0	0.0	0.5	4.7	0.4	2.6	0.1	1.8	0.3	2.8
Linuron 675 g ha^{-1}	8.2	37.4	2.5	33.3	5.3	36.1	2.3	10.5	0.1	1.3	1.2	8.2	2.0	9.1	0.1	1.3	1.1	7.5
Weed moving	10.6	57.9	1.5	22.7	6.0	48.4	1.2	6.6	0.1	1.5	0.7	6.6	0.0	0.0	0.0	0.0	0.0	0.0
Mean	9.8	52.1	1.5	23.4	5.6	44.4	1.6	8.5	0.1	1.6	0.8	6.3	0.6	3.2	0.1	1.6	0.4	3.2
LSD $_{0.05}$	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Year (A)	–	–	–	–	0.65	–	–	–	–	–	0.18	–	–	–	–	–	0.12	–
Treatment (B)	2.63	–	n.s.	–	n.s.	–	0.85	–	n.s.	–	0.41	–	0.47	–	n.s.	–	0.28	–
A × B	–	–	–	–	2.45	–	–	–	–	–	0.69	–	–	–	–	–	0.47	–

Treatment	Damaged						Diameter > 20 mm						Nonmarketable yield					
	2011		2012		mean		2011		2012		mean		2011		2012		mean	
	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%*	$t \cdot ha^{-1}$	%**	$t \cdot ha^{-1}$	%**	$t \cdot ha^{-1}$	%**
Perennial ryegrass	5.7	27.5	0.5	7.5	3.1	22.6	1.9	9.2	4.7	70.1	3.3	24.1	20.7	46.2	6.7	30.7	13.7	38.4
White clover	4.2	23.1	0.6	10.9	2.4	20.2	1.8	9.9	3.4	61.8	2.6	21.8	18.2	43.2	5.5	32.7	11.9	37.5
White clover + perennial ryegrass	3.2	20.5	0.5	8.9	1.9	17.9	1.7	10.9	4.3	76.8	3.0	28.3	15.6	38.4	5.6	31.1	10.6	34.8
Linuron 675 g ha^{-1}	7.4	33.8	2.1	28.0	4.8	32.7	2.0	9.1	2.7	36.0	2.3	15.6	21.9	38.9	7.5	30.6	14.7	34.7
Weed moving	4.7	25.7	1.5	22.7	3.1	25.0	1.8	9.8	3.5	53.0	2.6	21.0	18.3	44.9	6.6	38.1	12.4	41.5
Mean	5.0	25.6	1.0	15.6	3.0	23.8	1.8	9.6	3.7	57.8	2.7	21.4	18.8	42.1	6.4	32.6	12.6	37.4
LSD $_{0.05}$	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Year (A)	–	–	–	–	0.52	–	–	–	–	–	0.70	–	–	–	–	–	1.07	–
Treatment (B)	1.50	–	n.s.	–	1.18	–	n.s.	–	n.s.	–	n.s.	–	–	–	–	–	2.41	–
A × B	–	–	–	–	1.96	–	–	–	–	–	n.s.	–	–	–	–	–	n.s.	–

* % of nonmarketable yield

** % of total yield

DISCUSSION

Weed species occurring in the experiment were typical for carrot crop and the number and the fresh weight of weeds growing five weeks after carrot seed sowing were similar to those occurring in other vegetable crops in Poland [Dobrzański 1999]. Among dominating species were barnyard grass, lamb's quarters and redroot pigweed which can grow up to 100–120 cm high [Błażewicz-Woźniak et al. 2014] and cause considerable yield losses [Zimdahl 2004]. The weeds formed a population characterized by big density and rapid growth and also by considerable variability in regard to weed species, weed number and fresh weight in dependence on the year. At the end of vegetation period the number of weed species, their frequency and their fresh weight decreased as a result of mowing and also of decaying of some short living weeds, mainly shepherd's purse. Similar changes of weed population were stated by Chmielowiec and Borowy [2005] in an experiment carried out in the same natural conditions. Moreover, in this time the share of hairy galinsoga and gallant soldier in weed infestation increased as a result of germination of seeds produced by first generation of these weeds what agrees with the observations made by Heller [1998]. The share of low growing and resistant to mowing weeds like common chickweed and annual meadow grass increased also. Cultivation on ridges and mowing limited competitiveness of weeds to carrot but nevertheless the share of marketable roots in total yield was in this treatment lower. Big competitiveness and variability make natural weed population little useful as a living mulch under carrot ridge cultivation.

Perennial ryegrass and white clover emerged in the same time as weeds but initially they grew much slower and did not affect the number nor the fresh weight of weeds growing five weeks after carrot sowing. Similarly in the experiment carried out by Masiunas et al. [1997] perennial ryegrass used as a living mulch did not reduce the number of weeds which grew between 2 and 10 weeks after planting of cabbage and snap bean. Also in the experiment carried out by Brandsæter et al. [1998] white clover used as a living mulch did not affect the number nor the fresh weight of weeds growing in white cabbage crop 5 weeks after transplant plantation. However, Poniedziałek and Stokowska [1999] stated considerable weed reduction in white cabbage crop on plots covered with white clover living mulch 6 weeks after clover seed sowing and no weeds on these plots 6 weeks later. In the second part of the vegetation period, living mulches covered majority of soil surface leaving little place for weeds. In the second week of October, fresh weight of above ground parts of studied living mulches did not differ significantly and this agrees with the results obtained by Adamczewska-Sowińska [2008]. In this time, white clover and ryegrass reduced number of weeds by 82 and 85% and fresh weight of weeds by 86 and 93% on an average and for ryegrass + white clover these values were 61 and 50% respectively. Brandsæter et al. [1998] stated lower weed infestation on plots covered with white clover living mulch in the beginning of August. Living mulches and weeds produced lower biomass of above ground parts in 2011 because their growth was partially limited by intensively growing carrot leaves in this year (tabs 4, 5).

Carrot emerged one week later than the weeds and living mulches and grew much slower than the weeds and therefore ridge cultivation protected carrot plants from weed competition in the beginning of vegetation period. Later, excessive growth of weeds and living mulches was limited by mowing and carrot had always full access to the light.

However, living mulches and weeds competed with carrot for nutrients and especially for water and this could be the reason of lower carrot yielding in these treatments (tab. 5). Moreover this competition increased the share of bifurcated roots and roots of diameter smaller than 20 mm in nonmarketable yield (tab. 7). Several authors stated negative effect of living mulch on yield and quality of vegetable plants [Nicholson and Wien 1983, Wiles et al. 1989, Masiunas et al. 1997, Adamczewska-Sowińska 2004, Borowy 2012]. Excessive competitiveness of living mulches is one of the main factors limiting their use in vegetable crops [Masiunas 1998, Kołota and Adamczewska-Sowińska 2013]. However, the share of roots damaged by insects and snails and of roots with disease symptoms in nonmarketable yield harvested on plots covered with living mulches and mowed weeds was smaller than that harvested on plots sprayed with linuron 675 $g \cdot ha^{-1}$ and this is in line with the results obtained by Costello and Altieri [1994] and by Hooks and Johnson [2004]. Effect of living mulch and weeding method on yield of roots was bigger than that on fresh weight of leaves. Effect of mowed weeds on yield of carrot roots and fresh weight of leaves was similar to that of living mulches. The highest and the best quality yields were harvested on plots sprayed with linuron 675 $g \cdot ha^{-1}$ which controlled weeds very well during first weeks after seeding of carrot seeds (tab. 2). This is the period of critical weed competition and after passing it, presence of weeds is less harmful to carrot plants [Swanton et al. 2010].

Results obtained in this experiment confirm the opinion of Masiunas et al. [1997] that the mulches used in vegetable crops are more management intensive and variable than the conventional cultivation, however offering several advantages [Masiunas 1998, Kołota and Adamczewska-Sowińska 2013] and being an important tool in sustainable horticulture [Labrada 2006, Lal 2008] they should be an object of further studies.

CONCLUSIONS

1. Living mulches did not affect growth of weeds during first five weeks after carrot sowing and they reduced weed infestation significantly at the end of vegetation period.
2. Living mulches and mowed weeds caused decrease of total and marketable yield of carrot roots and in a less degree also decrease of carrot leaves fresh weight.
3. Share of roots damaged by insects and snails and with disease symptoms in the nomarketable yields harvested on plots covered with living mulches and mowed weeds was smaller and share of bifurcated roots and roots with diameter smaller than 20 mm was bigger than that on plots sprayed with linuron 675 $g \cdot ha^{-1}$.
4. Mowed weeds are less useful as a living mulch under carrot ridge cultivation than perennial ryegrass, white clover and perennial ryegrass – white clover mixture.

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WPŁYW ŻYWYCH ŚCIÓŁEK I LINURONU NA ZACHWASZCZENIE ORAZ PLON MARCHWI UPRAWIANEJ NA REDLINACH

Streszczenie. W dwuletnim doświadczeniu polowym porównano wpływ koniczyny białej (*Trifolium repens* L.), życicy trwałej (*Lolium perenne* L.), mieszanki koniczyny białej z życicą trwałą oraz przykaszanych chwastów, stosowanych jako żywe ściółki, z wpływem linuronu 675 g·ha^{-1} na zachwaszczenie pola oraz plon marchwi (*Daucus carota* L.) 'Flakkese 2' uprawianej na redlinach. Żywe ściółki nie miały wpływu na wzrost chwastów podczas pięciu tygodni po siewie nasion marchwi i zmniejszały zachwaszczenie pola w sposób istotny pod koniec okresu uprawy. Żywe ściółki i przykaszane chwasty powodowały zmniejszenie plonu ogółem i plonu handlowego korzeni marchwi; w mniejszym stopniu zmniejszały także świeżą masę liści marchwi. Udział korzeni uszkodzonych przez owady i ślimaki oraz korzeni z objawami chorobowymi w plonie niehandlowym zebranym z poletek okrytych żywymi ściółkami i przykaszanymi chwastami był mniejszy, a udział korzeni rozwidlonych oraz korzeni o średnicy mniejszej niż 20 mm był większy niż na poletkach opryskanych linuronem 675 g·ha^{-1}. Przykaszane chwasty były mniej przydatne jako żywa ściółka w uprawie marchwi na redlinach niż koniczyna biała, życica trwała i mieszanka tych dwóch gatunków.

Słowa kluczowe: życica trwała, koniczyna biała, koszenie, struktura plonu

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