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ORIGINAL PAPER

IMPACT OF NON-CHEMICAL WEED CONTROL METHODS ON SOIL AND SUGAR BEET ROOT CHEMICAL COMPOSITION*

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Abstract

A short-term, stationary field experiment was carried out at the Experimental Station of the Aleksandras Stulginskis University (ASU) in 2015–2016. The soil under the experiment was silty loam Planosol *(Endohypogleyic-Eutric – Ple-gln-w)*. The research objective was to determine the influence of different non-chemical weed control treatments on soil and sugar beet root chemical composition under organic farming conditions. Six weed control methods were tested: inter-row loosening (CT, control treatment), cutting and mulching with weeds (MW), Persian clover (MC), white mustard (MM) and spring barley (MB), inter-row steaming (ST). According to the results of the investigation, during the two plant growing seasons, the accumulated biomass of inter-row plants positively influenced the content of nitrogen, phosphorus and potassium in the soil, but decreased the proportion of magnesium and sulfur. Inter-row loosening (control treatment) positively affected nearly all the tested soil chemical properties (especially total nitrogen and magnesium), except for the content of sulfur. Although inter-row mulching with weeds drastically decreased the content of phosphorus, the concentration of potassium increased. Mulching with the Persian clover improved the contents of total nitrogen and available potassium. However, this impact was common. Mulching with white mustard significantly increased the contents of potassium and magnesium. Similar results were found in the plots with spring barley living mulch. In the steamed plots, due to the lack of plant residues, the soil properties did not improve and the losses of phosphorus and magnesium were the highest in the entire

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experiment. Different non-chemical weed control methods decreased the yield and the sucrose content in sugar beet roots. The content of potassium, sodium and alpha amino nitrogen in the roots did not significantly depend on the methods of weed control.

Keywords: *Beta vulgaris*, inter-cropping, steaming, soil and yield chemical composition.

INTRODUCTION

Agricultural technologies based on chemical pest control system are widespread in today's traditional agriculture (Bennett et al. 2004, Domaradzki 2007). In order to prevent destruction of the natural balance and to limit the risk of contamination of agricultural production by chemical residues (harmful for humans), cultivation of tolerant varieties and ecological (organic) farming methods are recommended (Jaskulska et al. 2017). Weeds are a major problem in organic farming, and the use of non-chemical weed control methods is less effective than the use of herbicides in intensive farming systems (Liebman et al. 2003, Pilipavičius et al. 2011). Catch (cover) crops might reduce external costs due to the purchase of pesticides, fertilizers and other chemicals. At the same time, these methods suppress weeds and improve or maintain the fertility of soil (Kader et al. 2017, Pannacci et al. 2017). The growth of catch crop plants usually finishes before the sowing or planting of main crops, but sometimes catch crop inter-cropping, known as "living mulch" is practiced (Robačer et al. 2016).

According to some German scientists, sugar beet is very sensitive to weed competition in the 4-10 leaf stage, and mulching at that time is the most effective (Petersen, Röver 2005). In 2014-2015, Kunz et al. (2016) investigated the ability of black medic (*Medicago lupulina* L.), clover (*Trifolium subterraneum* L.) and *Festulolium* hybrids to suppress weeds in sugar beet fields. The most effective was clover (*Trifolium subterraneum* L.), which suppressed the weed growth by 71%. Similar findings were reported by other scientists, e.g. Den Hollander et al. (2007*a*). Masilionyte et al. (2017) found that white mustard (r = 0.824** and r = 0.877**) and white mustard + buckwheat (r = 0.908** and r = 0.788*) had the highest influence on weed biomass in low humus (1.90-2.01%) soil.

In our earlier pilot investigations, various living mulch plants and straw cover had been found to affect the number of weeds and weed dry weight in sugar beet fields. Annual ryegrass and white mustard living mulches suppressed weed growth the most efficiently (Romaneckas et al. 2009). In general, sugar beet crop cultivation with living mulches is not a widely investigated problem. We usually find reports about the inter-cropping of legumes in cereals, corn (maize) and other crops because legumes are as a key functional group for promoting the efficiency of ecosystems (Duchene et al. 2017). Verret et al. (2017), who reviewed 34 scientific articles, summarised that the most effective legume inter-cropping had been reported in maize cultivation, because the yield of maize was 37% higher than in non-weeded control treatments.

Therefore, the aims of our investigations were (1) to evaluate the impact of sugar beet inter-rows covering with living mulch, inter-rows loosening and steaming on the soil pH, content of total N, available P, K, Mg, S at the beginning and end of sugar beet growth; and (2) to establish main sugar beet qualitative parameters – content of sucrose, K, Na and α-amino N. We hypothesized that non-chemical weed control methods would reduce weed infestation and therefore increase soil and sugar beet quality under an organic farming system.

MATERIAL AND METHODS

A field experiment was performed in 2015 and 2016 at the Experimental Station (54°52′ N, 23°49′ E) of the Aleksandras Stulginskis University (ASU), Lithuania. Six weed control methods were tested: inter-row loosening (CT, control treatment), cutting and mulching with weeds (MW), Persian clover (MC), white mustard (MM) and spring barley (MB), and inter-row steaming (ST). MW treatment simulates a "natural farming" system, in which no-tillage with weed cover mulching is used (Yagioka et al. 2015).

The soil of experiment was silty loam (on average 46% sand, 42% silt, 12% clay) Planosol *(Endohypogleyic-Eutric – Ple-gln-w)* (WRB 2014). The meteorological conditions during the investigations in 2015 and 2016 are presented in Table 1.

An experiment was performed with four replications and in a randomized plot design. Each plot was 27 m^2 in size, and the total number of plots was 24. In 2015, the preceding crop for sugar beet was spring barley and in 2016 it was sugar beet. Thus, in that year, sugar beet crop was cultivated continuously in the experiment. The agronomical practice applied is presented in Table 2. The most important agrotechnical operations were chosen accor-

Table 1

Temperature and precipitation during the experiment, Kaunas Meteorological Station, 2015-2016

Years/months	April	May	June	July	August	September
Average air temperature (°C)						
2015	7.1	11.4	15.4	17.4	20.3	14.3
2016	7.4	15.7	17.2	17.9	16.9	13.5
LTA[a]	6.9	13.2	16.1	18.7	17.3	12.6
Precipitation rate (mm)						
2015	46.0	43.8	16.4	72.4	6.9	56.6
2016	41.2	36.4	83.9	162.9	114.9	22.5
LTA	41.3	61.7	76.9	96.6	88.9	60.0

[a] LTA is a long-term (1974–2013) average

Table 2

Agronomical practice in the experiment

Agrotechnical operations	Timing
Straw loosening (only in 2014), manure distribution and incorporation by ploughing	beginning of October
Presowing soil tillage in spring	the end of April, at the time of soil physical maturity
Sugar beet sowing	just after presowing soil tillage
Inter-row loosening before living mulch plants sowing	the end of May, after the emergence of sugar beet sprouts
Sowing of living mulch crops	just after inter-row loosening
Inter-row steaming	the beginning of June, when weed sprouts emerge
Inter-row loosening, cutting and mulching	3 times up to the time of inter-row occupation with beet leaves
Harvesting	the beginning of October

ding to the common sugar beet growing practice in Lithuania (ROMANECKAS 2011). Pesticides and mineral fertilizers were not used in the experiment. The distance between rows was 45 cm, and between seeds – it was 16 cm. White mustard and Persian clover were sown at a seed dose of 10 kg ha^{-1}. The sowing dose of spring barley was 200 kg ha^{-1}. The living mulch plants were cut and spread over the soil surface 3 times, with the help of a manually operated brush cutter Stihl FS-550. Inter-row steaming was performed with a mobile steaming machine, which had been designed and manufactured in the ASU (patents LT5620B and LT55332B).

Weeds and living mulch plants for biomass evaluation were cut on five randomly selected plots over an area of 0.06 m^2 in each plot. Canopies of plants were dried up to dry weight and weighed. Dry matter weight was recalculated into g m^{-2}. The samples for sugar beet root productivity and quality assessment were taken from an area of 19 m^2 per each plot of experiment. Analyses of sugar beet root chemical composition were performed in the laboratory of the Kėdainiai sugar factory ("Nordic Sugar Kedainiai") with the standardized rapid tests.

Soil analyses were performed at the Laboratory of Chemical Research of Lithuanian Research Centre for Agriculture and Forestry. The content of total nitrogen in the soil was established by the Kjeldahl method. The content of available phosphorus and magnesium was determined by the CAL method using a spectrophotometer. The available potassium content was determined by the CAL method using a flame photometer, and sulfur was assayed with the Diuma method. The soil pH_{KCl} was checked with a pH-meter, using a potentiometric method in 1N KCl extract. ANOVA was applied for the statistical evaluation of research data. The treatment effect was tested by LSD_{05}, LSD_{01} and P tests, included in a software package SigmaStat. If $P \leq 0.05 > 0.01$ the differences from the control treatment (CT) were significant at 95% probability level; if $P \leq 0.01$ – at 99% probability level, and if $P > 0.05$, there is no significant difference. Correlation analysis was supported by SigmaPlot software.

RESULTS AND DISCUSSION

The biomass of plants in sugar beet inter-rows

Soil chemical characteristics mainly depend on the content of plant residues left after crop harvesting. In our earlier investigations with intercropped maize, we had found relations between the dry shoot biomass of living mulch plants and the content of potassium (r = 0.465), total nitrogen (r = 0.411), or phosphorus (r = -0.543) in the top soil layer (Adamavičienė et al. 2012).

The precipitation amounts during sugar beet vegetation influenced the growth of living mulch and weeds. For example, Masilionytė and Maikštėnienė (2011) and Liu et al. (2015) found that the development of catch crops' shoot biomass strongly depended on doses of precipitation. The plant growing season of 2015 in Lithuania was mainly dry and the biomass of weeds and living mulch was lesser than in 2016 (Table 3). The highest dry biomass of weeds during the experiment was observed in the experimental plots and mulched with weeds only. The arid plant growing season of 2015 was favourable to spring barley, while the humid year 2016 fostered white mustard development. In 2015, the highest total biomass of inter-row plants was observed in the plots with Persian clover living mulch, while in 2016 it was the highest on plots with white mustard and Persian clover.

Soil pH, content of total nitrogen and available phosphorus

In our earlier experiment with maize inter-cropping with living mulch, during the three years of that experiment, soil pH in 0-10 and 10-20 cm layers increased by 4% on average, the content of organic carbon rose by 42 and 34%, total nitrogen was higher by 62% and 43%, whereas phosphorus increased by 18 and 21%, and potassium was richer by 22 and 27% (Adamavičienė et al. 2012). Similarly, Liu et al. (2015) suggests that catch crops were an effective method to reduce phosphorus losses in soil. In our experiment, during the first year of the investigation (2015), different non -chemical weed control methods had an insignificant effect on soil pH, content of nitrogen and phosphorus (Table 4). During the plant growth, soil pH mainly increased, but the content of nitrogen and phosphorus decreased in most of the cases. In 2016, the variation of soil pH and phosphorus was insignificant, but mainly negative during the plant growth. Den Hollander et al.

Table 3

Impact of the weed control methods on the dry biomass of inter-row plants in organically grown sugar beet cultivation (Mg ha^{-1}), 2015-2016

Weed control treatment	Weeds	Living mulch	Total inter-row plants
2015			
Inter-row loosening (control treatment)	1.217*b*	-	1.217*b*
Inter-row cutting and mulching with weed	3.238**a*	-	3.238**a*
Inter-row cutting and mulching with the Persian clover	2.963**a*	0.635*a*	3.598**a*
Inter-row cutting and mulching with white mustard	2.525*ab*	0.180*b*	2.705*ab*
Inter-row cutting and mulching with spring barley	1.792*ab*	0.847*a*	2.639*ab*
Inter-row steaming	2.690*ab*	-	2.690*ab*
2016			
Inter-row loosening (control treatment)	3.706*b*	-	3.706*c*
Inter-row cutting and mulching with weed	8.494**a*	-	8.494**ab*
Inter-row cutting and mulching with the Persian clover	4.119*b*	4.513*a*	8.632**ab*
Inter-row cutting and mulching with white mustard	7.080*ab*	5.286*a*	12.366***a*
Inter-row cutting and mulching with spring barley	5.839*ab*	0.053*b*	5.892*bc*
Inter-row steaming	4.376*b*	-	4.376*bc*

Note: * – significant differences from the control treatment (CT) at $P < 0.05$, ** – at $P < 0.01$, *a*, *b*, … – values with different letters mean significant differences between treatments at a 95% probability level.

(2007b) found a strong positive correlation between early soil coverage by clover and nitrogen accumulation, which is similar in our experiment, where the total nitrogen content increased in nearly all plots, but the most significant increase during the plant growing period occurred in the plots with Persian clover living mulch (0.24 g kg^{-1}).

Content of available potassium, magnesium and sulfur

In 2015, weed control methods mainly had insignificant effects on the content of available magnesium and sulfur during the plant growth season (Table 5). However, the concentration of the aforementioned elements decreased during the plant growth period. The content of potassium significantly varied only at the beginning of the season. At the end of it, differences became insignificant, but the general effect was positive. In 2016, at the end of the plant growing period, a decrease in the concentration of potassium was noted. The differentiation partly depended on the higher precipitation in that year (r = 0.376). The difference in the magnesium content during the plant growth season was insignificant and negative in most cases except in plots that were loosened (control treatment) and mulched with weeds. Sulfur variation during the sugar beet growth e period was similar to the one in 2015.

Table 4

Impact of the weed control methods on soil pH, the content of total nitrogen (N_{total}) and available phosphorus (P) both at the beginning and end of sugar beet growing season in 2015 and 2016

Weed control treatment	pH_{KCl} (mol L^{-1})			N_{total} (g kg^{-1})			P (mg kg^{-1})		
	beginning	end	difference ±	beginning	end	difference ±	beginning	end	difference ±
2015									
CT	7.3	7.6*a*	+0.3	1.10	1.08*a*	-0.02	210.8	211.2*a*	+0.4
MW	7.3	7.7*a*	+0.4	1.18	1.15*a*	-0.03	228.8	222.0*a*	-6.8
MC	7.7	7.6*a*	-0.1	1.16	1.08*a*	-0.08	248.2	224.8*a*	-23.4
MM	7.6	7.6*a*	0.0	1.17	1.11*a*	-0.06	226.8	209.5*a*	-17.3
MB	7.6	7.7*a*	+0.1	1.12	1.09*a*	-0.03	212.2	217.5*a*	+5.3
ST	7.5	7.7*a*	+0.2	1.13	1.09*a*	-0.04	227.2	215.0*a*	-12.2
2016									
CT	7.6*a*	7.5*a*	-0.1	1.24*a*	1.28*ab*	+0.04	214.5*a*	211.8*a*	-2.7
MW	7.6*a*	7.5*a*	-0.1	1.24*a*	1.20*b*	-0.04	217.8*a*	211.0*a*	-6.8
MC	7.6*a*	7.4*a*	-0.2	1.18*a*	1.42*a*	+0.24	238.8*a*	230.5*a*	-8.3
MM	7.5*ab*	7.5*a*	0.0	1.20*a*	1.25*ab*	+0.05	211.5*a*	217.5*a*	+6.0
MB	7.4*b*	7.4*a*	0.0	1.18*a*	1.19*b*	+0.01	206.5*a*	200.8*a*	-5.7
ST	7.6*a*	7.5*a*	-0.1	1.17*a*	1.23*ab*	+0.06	227.0*a*	202.0*a*	-25.0

Note: *a*, *b*, … – values with different letters mean significant differences between treatments at 95% probability level, $P > 0.05$, CT – inter-row loosening (control treatment), MW – inter-row cutting and mulching with weeds, MC – inter-row cutting and mulching with the Persian clover, MM – inter-row cutting and mulching with white mustard, MB – inter-row cutting and mulching with spring barley, ST – inter-row steaming.

In summary, during the two years of our investigation, several non-chemical weed control methods had different effects on the soil chemical properties (Table 6). Inter-row loosening (control treatment) positively affected nearly all the tested soil chemical properties (especially total nitrogen and magnesium), except for the content of sulfur. Besides, the content of sulfur decreased in all the experimental plots.

Although inter-row cutting and mulching with weeds initiated similar effects as in the control, it drastically decreased the content of phosphorus and increased the concentration of potassium. The content of potassium was the highest in the entire experiment. Lumbanraja et al. (2004) established that weed as a cover plant was an effective method in coffee fields and improved soil chemical properties too.

In Deguchi et al. (2017), investigations with inter-cropped corn were reported and white clover living mulch was found to have increased the uptake of phosphorus and the yield of silage corn, and could have made phosphorus

Table 5

Impact of the weed control methods on the content of available potassium (K), magnesium (Mg) and sulfur (S) in the soil at the beginning and end of sugar beet growing season in 2015 and 2016

Weed control treatment	K (mg kg^{-1})			Mg (mg kg^{-1})			S (mg kg^{-1})		
	beginning	end	difference ±	beginning	end	difference ±	beginning	end	difference ±
2015									
CT	88.0	130.0*a*	+42.0	657.0	674.0*a*	+17.0	2.4	1.9*a*	-0.5
MW	92.0	123.8*a*	+31.8	635.0	615.5*a*	-19.5	2.6	1.8*a*	-0.8
MC	98.8	129.5*a*	+30.7	657.5	592.0*a*	-65.5	2.6	2.0*a*	-0.6
MM	92.0	118.8*a*	+26.8	618.5	585.0*a*	-33.5	2.7	1.7*a*	-1.0
MB	86.5	118.8*a*	+23.3	664.0	657.5*a*	-6.5	2.5	1.8*a*	-0.7
ST	94.5	121.0*a*	+26.5	712.0	658.0*a*	-54.0	2.5	1.9*a*	-0.6
2016									
CT	145.0*ab*	115.2*ab*	-29.8	711.5*a*	796.0*a*	+84.5	2.1a	1.5*a*	-0.6
MW	151.2*ab*	126.2*a*	-25.0	632.0*a*	657.5*a*	+25.5	1.8a	1.6*a*	-0.2
MC	157.5*a*	125.2*ab*	-32.3	660.0*a*	641.5*a*	-18.5	2.0a	1.7*a*	-0.3
MM	129.0*b*	121.2*ab*	-7.8	649.5*a*	641.0*a*	-8.5	1.7a	1.4*a*	-0.3
MB	135.2*ab*	109.5*ab*	-25.7	649.0*a*	677.0*a*	-28.0	1.9a	1.5*a*	-0.4
ST	137.8*ab*	101.2*b*	-36.6	669.0*a*	630.5*a*	-38.5	1.8a	2.0*a*	+0.2

Note: *a*, *b*, … – values with different letters mean significant differences between treatments at 95% probability level, $P > 0.05$. The same as above.

Table 6

The impact of weed control methods on difference (±) of soil chemical composition during investigations, 2015-2016

Weed control treatment	pH_{KCl} (mol L^{-1})	N_{total} (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})
CT	+0.2	+0.18	+1.0	+27.2	+139.0	-0.9
MW	+0.2	+0.02	-17.8	+34.2	+22.5	-1.0
MC	-0.3	+0.26	-17.7	+26.4	-16.0	-0.9
MM	-0.1	+0.08	-9.3	+29.2	+22.5	-1.3
MB	-0.2	+0.07	-11.4	+23.0	+13.0	-1.0
ST	0.0	+0.10	-25.2	+6.7	-81.5	-0.5

Note: the same as above.

fertilization redundant. In our experiment, sugar beet inter-row cutting and mulching with Persian clover improved only the two characteristics of the soil: the content of total nitrogen and available potassium. However, this impact was common.

In a short-term experiment conducted by Marinari et al. (2015), mulching with white mustard was sensitive for nutrient storage, especially carbon and nitrogen. In our experiment, inter-row cutting and mulching with white mustard has slightly contributed to an increase of total nitrogen, but significantly increased the content of potassium and magnesium. Similar results (on a smaller scale) were found in the plots with spring barley living mulch. In steamed plots, due to the lack of plant residues, soil properties was almost unimproved. A minor positive effect was on the content of total nitrogen and potassium, but the losses of phosphorus and magnesium were the highest in the experiment.

The correlation analysis of 2015-2016 research data showed correlations between dry biomass of inter-row plants and soil chemical composition. In most cases, biomass positively influenced the content of nitrogen, phosphorus and potassium in the soil, but decreased the proportion of magnesium and sulfur (Table 7).

Table 7

Correlation between inter-row plant dry biomass and soil chemical composition at the end of sugar beet growing season

Year	*X*	*Y*					
		pH_{KCl} (mol L^{-1})	N_{total} (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})
2015 2016	weed biomass	*n* *n*	0.576 -0.556	0.599 *n*	*n* 0.451	-0.694 -0.385	*n* -0.380
2015 2016	total inter-row plant biomass	*n* *n*	0.361 *n*	0.749 0.549	n 0.673	-0.712 -0.545	*n* -0.447

Note: *n* – weak correlation.

The yield and biochemical composition of sugar beet root

In 2015, the first year of investigations, different non-chemical weed control methods significantly decreased the yield of sugar beet roots, approximately by 2– to 3-fold, except the treatment with inter-row steaming (Table 8). The lowest yield was harvested from the plots where weeds were used as living mulch. Similar tendencies were revealed in 2016, although yields were nearly twice as high as in 2015 (cumulative effect). It should be noted that the higher precipitation in 2016 had a negative influence on the yield of roots (r = -0.667).

The potassium content in sugar beet roots did not depend on the weed control methods. In 2016, the concentration of potassium in the roots was higher than in 2015 because of the increase in the soil potassium content (r_{2016} = 0.979**) – Tables 8 and 9. Similar results were found while testing the content of sodium and α-amino nitrogen (Table 8).

The correlation analysis of the research data highlighted that inter-row

Table 8

The impact of weed control methods on sugar beet root yield and chemical composition, 2015-2016

Weed control treatment	Yield (Mg ha^{-1})	Sucrose (g kg^{-1})	K (mmol kg^{-1})	Na (mmol kg^{-1})	α-amino N (g kg^{-1})
2015					
CT	40.57*a*	173.2*a*	28.7*a*	2.1*a*	0.918*a*
MW	13.73**c*	166.2*ab*	27.4*a*	2.6*a*	0.815*a*
MC	17.46**bc*	166.6*ab*	28.2*a*	2.7*a*	0.735*a*
MM	18.05**bc*	163.2**b*	28.9*a*	2.6*a*	0.808*a*
MB	18.23**bc*	164.4*ab*	28.8*a*	2.3*a*	0.858*a*
ST	28.7*ab*	171.9*ab*	29.2*a*	2.0*a*	0.960*a*
2016					
CT	71.07*a*	174.6*ab*	33.4*a*	2.9*a*	1.533*a*
MW	50.00**b*	167.9*b*	35.7*a*	3.5*a*	1.400*a*
MC	38.66**b*	167.2**b*	35.9*a*	3.6*a*	1.307*a*
MM	36.36***b*	169.5*ab*	35.1*a*	3.6*a*	1.687*a*
MB	44.74**b*	172.4*ab*	32.7*a*	3.0*a*	1.143*a*
ST	52.78*ab*	176.5*a*	31.9*a*	2.9*a*	1.307*a*

Note: * – significant differences from the control treatment (CT) at $P < 0.05$, ** – at $P < 0.01$, *a*, *b*, … – values with different letters mean significant differences between treatments at a 95% probability level. The same as above.

Table 9

Correlation between investigated factors and sugar beet root yield and biochemical composition

Year	*X*	*Y*				
		yield (Mg ha^{-1})	sucrose (g kg^{-1})	K (mmol kg^{-1})	Na (mmol kg^{-1})	α-amino N (g kg^{-1})
2015 2016	weed dry biomass (Mg ha^{-1})	-0.726 -0.404	-0.329 -0.528	-0.514 0.449	0.595 0.529	-0.493 *n*
2015 2016	total inter-row plant dry biomass (Mg ha^{-1})	-0.878* -0.794	-0.552 -0.777	-0.450 0.748	0.699 0.912*	-0.820 0.479
2015 2016	P (mg kg^{-1})	*n* *n*	*n* -0.716	-0.684 0.817*	0.490 0.757	-0.556 0.348
2015 2016	K (mg kg^{-1})	0.431 *n*	0.559 -0.918**	-0.361 0.979**	*n* 0.857*	*n* 0.384
2015 2016	Mg (mg kg^{-1})	0.721 0.836*	0.658 0.368	0.377 *n*	-0.911* -0.509	0.853* *n*
2015 2016	S (mg kg^{-1})	0.337 *n*	0.623 0.394	*n* -0.386	*n* -0.307	*n* -0.445

Note: * – significant at $P < 0.05$, ** – at $P < 0.01$.

plants (weeds and living mulch) competed with the main crop (sugar beet) and negatively influenced its yield of roots and sucrose content (Table 9). At the beginning of this investigation (2015), inter-row plants had a negative impact on the potassium and alpha amino nitrogen content in sugar beet roots. Conversely, during the two years of this experiment, the above impact became positive or weak. Table 9 shows some correlations between soil chemical composition and sugar beet root biochemical properties, too. In many cases, two years of non-chemical weed control practice in sugar beet crop initiated a decrease in the phosphorus and sulfur content in the soil. A decrease in sulfur mainly depended on interactions between the inter-row plants, while less phosphorus affected the sugar beet yield. An increase in the soil content of potassium influenced the content of potassium in sugar beet roots. Sulfur in the soil had a negative *alebit* weak influence on sugar beet roots' chemical composition. The interaction between soil magnesium and sugar beet root chemical composition was stronger in the first year of investigation, but weaker at the end of the second plant growing season tested.

CONCLUSIONS

In 2015, the highest total biomass of inter-row plants was observed in the plots with Persian clover living mulch, and in 2016 - with white mustard and Persian clover. During two plant growing seasons, the accumulated biomass positively influenced the content of nitrogen, phosphorus and potassium in the soil, but decreased the content of magnesium and sulfur.

Inter-row loosening (control treatment) positively affected nearly all of the tested soil chemical properties (especially total nitrogen and magnesium), except the content of sulfur. Besides, the content of sulfur decreased in all the experimental plots. Inter-row cutting and mulching with weeds drastically decreased the content of phosphorus, but increased the concentration of potassium. The content of potassium was the highest in the whole experiment. Mulching with Persian clover improved only two characteristics of the soil: the content of total nitrogen and available potassium. However, this impact was common. Mulching with white mustard had a minor impact on the increase of total nitrogen, but significantly increased the content of potassium and magnesium. Similar results were found in the plots with spring barley living mulch. In steamed plots, due to the lack of plant residues, soil properties were not improved. A minor positive effect was noticed on the contents of total nitrogen and potassium, but the losses of phosphorus and magnesium were the highest in the experiment.

Different non-chemical weed control methods decreased yield and sucrose content in the sugar beet roots. The content of potassium, sodium and alpha amino nitrogen in the roots did not significantly depend on the methods of weed control.

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