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The Impact of Intercropping on Soil Fertility and Sugar Beet Productivity

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Abstract: There is a lack of research on the practice of intercropping sugar beet and the impact of such agrocenoses on soil and crop fertility, especially under organic farming conditions. For this reason, a three-year stationary field experiment was performed at Vytautas Magnus University, Agriculture Academy, Lithuania. Sugar beet was grown continuously with intercropped Persian clover (*Trifolium resupinatum* L., MC), white mustard (*Sinapis alba* L., MM) and spring barley (*Hordeum vulgare* L., MB) as a living mulch. Inter-row loosening (CT) and mulching with ambient weeds (MW) were used as comparative treatments. The results showed that, under minimal fertilization, CT and intercropping increased the average content of nitrogen, phosphorus and potassium in the soil. However, the average content of magnesium was reduced in single cases (MW, MB), and the average content of sulphur was reduced in all cases. Intercropping significantly decreased the yields of sugar beet root-crop, but was mainly neutral in quality terms. The meteorological conditions during experimentation had a weak impact on root-crop quantity and quality. Generally, the practice of sugar beet intercropping requires more detailed research on how to minimize the competition between the sugar beet, living mulch and weeds, and how to balance the nutrition conditions.

Keywords: chemical composition; *Beta vulgaris* L.; living mulch; Planosol; root-crop productivity and quality

1. Introduction

The ecological intensification of agriculture draws attention to the increase in agricultural production, as well as the optimal use of resources in harmony with the social and economic environment [1,2]. Organic farming promotes biodiversity, which is the main concern associated with ecological intensification in agriculture [3]. Intercrops, cover crops, catch crops, companion crops or living mulch crops, as components of alternative practices to conventional agriculture [4] and additional guardians of biodiversity, can increase the capacity of soil organic carbon [5], soil aggregate stability [6], water holding and infiltration [7]; reduce water erosion [8]; increase soil biological (enzymatic) activity [9]; regulate the emissions of CO_2 and N_2O from the soil [10]; and reduce the density of the pests and weeds in the crop [11–13]. Intercrops can also reduce nutrient leaching and increase their supply as well as the uptake of the current or the succeeding crop [2,4–8,14–18]. For example, in the experiment of Qian et al. [19], the total amount of organic carbon in the soil with white clover and crown vetch used as living mulch was 16–44% greater compared to non-mulched plots, while total nitrogen was 50% lower. Alexander et al. [20] found that Kura clover living mulch increased soil bioactivity, initiating an increase in the content of N by 300%. This was a result of the biomass of legumes stimulating microbial activity in the soil, which promotes organic matter decomposition [9]. In addition, legumes are characterized by nitrogen fixation.

During the vegetation period, the roots of catch crops produce excretion. Substances solubilize soil phosphorus and make it more available for crops. In this process, symbiotic mycorrhizal fungi play an important role [21]. Similarly, Deguchi et al. [22] showed that white clover living mulch enriched arbuscular mycorrhizal colonization and increased phosphorus uptake.

Intercropping systems promote balance and prevent competition between the main crop and the intercrops for light, moisture and nutrients [15,23] because the yield and the quality of the main crop depend on their competition. For example, wheat–subclover intercropping reduced grain yield by 15% on average compared to pure wheat due to competition between the intercropped species [24]. Similarly, Pfeiffer et al. [25] found lower yields of vegetables in plots with living mulch and a high-density weed seed bank. Afshar et al. [26] stated that barley living mulch increased the content of sucrose and decreased the content of sodium, potassium and, concentration of amino-N in the root-crops of sugar beet. They concluded that cultivation of sugar beet with barley living mulch can be an effective in providing ecosystem service without leading to a decrease in sucrose yield if it is terminated by applying glyphosate no later than by the V2 growth stage. In the experiment of Majkowska-Gadomska et al. [27], intercropping of carrot with dill also increased the quality of the root-crop, which was tested during the storage period. It may be concluded that the performance of living mulch depends on a range of factors, such as the crop, climate, time of sowing, range of development, nutrient consumption and others.

Among the Baltic States, white sugar is only produced in Lithuania, so sugar beet is an important crop in local industry. Sugar beet occupies about 14,700 hectares (or 0.7% of the total arable area), with an average yield of 70.95 tonnes per hectare (2019) [28]. Lithuania also produces about 4000 tonnes of organic sugar every year. Given that the production of organic sugar is projected to expand, more knowledge about growing organic sugar beet is needed. The effects of different agrotechnologies on soil properties, and the productivity and quality of sugar beet root-crop have been widely investigated in Lithuania [29–33] and worldwide [34]. However, the practices of sugar beet intercropping under organic farming conditions have not been sufficiently investigated and there is a need for more research. In addition, most organic farms in Lithuania use extensive mineral and organic fertilization systems, which decrease the proportion of nutrients in the soil and maintain the crop yields.

We hypothesise that mulched and decomposed intercrop' biomass will enrich the soil and compensate for the possible losses in sugar beet fertility and quality initiated by the intercrop and weed competition with the main crop. The aim of this study was to determine the influence of intercropping on (a) the soil chemical composition and (b) the quantitative and qualitative parameters of sugar beet cultivated continuously for three years under organic farming conditions.

2. Materials and Methods

A three-year (2015–2018) stationary field experiment was performed at the Experimental Station of Aleksandras Stulginskis University (since 2019, the Vytautas Magnus University, Agriculture Academy), Lithuania. The experimental station was located 6 km from Kaunas city, on the left side of the river Nemunas. This massif belongs to a region of sandy and dusty loams.

Sugar beet was intercropped with Persian clover (*Trifolium resupinatum* L., MC), white mustard (*Sinapis alba* L., MM) and spring barley (*Hordeum vulgare* L., MB) as a living mulch. In our pilot short-term investigations, these intercrops had a positive effect on weed suppression and a neutral effect on the yield and quality of sugar beet [30,31]. White mustard and spring barley develop fast, effectively controlling weeds before the first cutting and mulching, and then mainly die, so they do not compete with sugar beet for space, nutrients and solar radiation later on. Persian clover, as a leguminous plant, improves the soil N balance and leads to a high amount of biomass (up to 0.5 kg of DM per m^2 per vegetative season). The development of this crop is slow during the first stages of vegetation but, after cutting of inter-rows of sugar beet, Persian clover regrows very fast and must be cut at least three times per vegetation. Persian clover competes with the main crop, but effectively suppresses weeds [35]. However, a high biomass of Persian clover at the end of vegetation complicates harvesting of the sugar beet root-crops.

Inter-row loosening (CT) was applied as a comparative control treatment. Inter-row mulching with ambient weeds (MW) was applied as a "natural farming" system. According to Yagioka et al. [36], MW simulates no-tillage with weed cover mulching.

The experiment was performed with four replications, and a randomized complete block design (RCBD) was used. The size of each experimental plot was 24 m^2 (3 × 8 m), replication—96 m^2 (Figure 1a). Red lines on the map separate each experimental plot. The black area shows protection zones between blocks (replications) of the experiment. The matrix of treatment randomization was as follows.

(**a**) (**b**)

Figure 1. Map of the experimental site: (**a**) actual, experimental blocks with plots presented; (**b**) electrical conductivity of the soil (0–30 cm soil layer). Coordinates: 54°52′57″ N latitude and 23°50′51″ E longitude.

Replications	Treatments					
						1—inter-row loosening;
Rep. 4	3	1	5	2	4	2—inter-row cutting and mulching with ambient weeds;
Rep. 3	2	3	1	4	5	3—inter-row cutting and mulching with Persian clover;
Rep. 2	4	5	2	3	1	4—inter-row cutting and mulching with white mustard;
Rep. 1	1	4	5	2	3	5—inter-row cutting and mulching with spring barley.

The precrop of sugar beet was spring barley. During the three years of experimentation, sugar beet was continuously cultivated in order to determine the cumulative effect of intercropping.

The agrotechnical operations applied in the experiment are shown in Table 1.

Table 1. The agrotechnical operations of the experiment (according to Romaneckas et al. [36]).

Agrotechnical Operation	Timing and the Stage of Sugar Beet Development (BBCH Stage)
Presowing soil tillage in spring	End of April, at the time of soil physical maturity (BBCH 00)
Sugar beet sowing	Right after presowing soil tillage (BBCH 00)
Inter-row loosening	Mid-May, after the emergence of sugar beet seedlings (BBCH 09–11)
Sowing of intercrops	After the spread of weeds (BBCH 14–15)
Inter-row loosening, cutting and mulching	2–3 times before the sugar beet leaves come into contact between the rows (BBCH 19–22, 30–32, 36–38)
Harvesting	Beginning of October (BBCH 49–50)

After the precrop harvesting, the soil was loosened with a Väderstad Carrier 300 disc harrow (Väderstad AB, Väderstad, Sweden) to a depth of 12–15 cm. A John Deere 6620 tractor (Deere and Company, Moline, IL, USA) was used in the experiments. In October, the soil was ploughed with a Gamega PP-3-43 plough (Gamega Ltd., Garliava, Lithuania) with semi-helical shell-boards. In spring, the experimental site was shallowly cultivated with a Laumetris KLG-3.6 cultivator (Laumetris Ltd., Keleriškės village, Kėdainiai reg., Lithuania) to a depth of 2–3 cm. Seeds were sown with a Kverneland Accord mechanic drill (Kverneland Group, Klepp Stasjon, Norway). The width of the sugar beet inter-row space was 45 cm, and the distance between the sugar beet seeds was 16 cm. Intercropping plants for living mulch purposes (white mustard and Persian clover) were sown at a seed rate of 10 kg ha^{-1}, while spring barley was sown at a seed rate of 200 kg ha^{-1} after sugar beet germination by a hand machine for greenhouses. Intercropped plants and weeds (MW) were cut and disseminated on the soil surface 2–3 times per vegetation with a hand-operated Stihl FS–550 bush cutter (Sweden). Since the experiment was conducted according to organic farming guidelines, pesticides and basic organic fertilization were not used. During each vegetative period, the crop was treated with a NAGRO universal (Russian Federation) leaf bioorganic fertilizer (1 L ha^{-1} + 200 L ha^{-1} water). This fertilizer is certified for use in organic farming and consists of fulvic and humic acids (105.8 mg L^{-1}), N (1.2%), P (0.01%), K (0.23%), Mg (0.04%), 10 microelements, organic matter (6.21 g L^{-1}) and C_{org} (2.26 g L^{-1}).

The soil at the experimental site is a silt loam Planosol [37] with an average composition of 46% sand, 42% silt and 12% clay. The variance of the soil texture was high and correlated with the soil electrical conductivity, as shown in the map (Figure 1b).

The electrical conductivity was measured before the beginning of the experimentation in the autumn of 2014 with a Veris 3150 MSP mobile machine (USA). The machine was able to test the electrical conductivity of the soil up to a depth of 90 cm and was equipped with a GPS system. Mapping of the electrical conductivity was performed with the computer program SMS Advanced (USA). Based on the information from this map, we corrected the sampling places in the experiment. Soil samples were taken from the same coloured sampling spots of the experimental plot. At least 10 soil samples were taken from each experimental plot in spots with a similar colour (conductivity). Composite samples were formed. The sampling depth was 0–25 cm. Soil samples were then tested at the laboratories of the Lithuanian Research Centre for Agriculture and Forestry.

Negiş and Şeker [38] found that, out of 15 chemical characteristics, P_{avail}, N_{total}, pH, K and Mg were the best representatives of soil fertility. Therefore, more attention was paid to these parameters in our experiment. The total nitrogen content in the soil was tested according to the ISO 11261:1995 standard, available phosphorus and potassium by the Egner-Riehm-Domingo (A-L) method (LVP D-07:2016), available magnesium by LVP D-13:2016, and soil pH_{KCl} by the potentiometric method determined in 1 M KCl (soil and solution ratio 1:2.5) (ISO 10390:2005—Soil quality and Determination of pH).

Sugar beet root-crop chemical indices (content of Na, K, alpha-amino N and sucrose) were determined at the sugar factory laboratory of a joint stock company Nordic Sugar Lietuva (Kėdainiai, Lithuania). The sucrose content was determined by applying the cold digestion method, the content of soluble ash (Na, K) by applying the conductometric method, and the content of alpha amino nitrogen by applying the spectrometric method. At least eight root-crop samples were taken per plot in an area of 0.45 m^2. Then, the average sample per experimental plot was formed and tested.

The meteorological conditions during the three vegetative periods are presented in Table 2. Long-term averages were considered for the temperature and precipitation from 1974.

The vegetative periods were quite different in terms of temperature, precipitation and solar radiation. In 2015, the weather was colder than the long-term average, except for April, August and September, and the precipitation rates were lower than the average, except for April. In 2016, July, August and September were slightly colder than the long-term average and the distribution of precipitation was uneven. July and August were exceptionally humid; on the contrary, May and September lacked humidity. For most of 2017, the temperature was lower than or similar to the long-term average, and the precipitation, as in 2016, was distributed unevenly. April and September were exceptionally humid, May and August were exceptionally dry, and the humidity in June and July was similar to the long-term average. Due to such vegetative conditions, the germination and development of sugar beet, intercrops and weeds was different every year, but not strongly correlated with the quantitative and qualitative parameters of the root-crop.

Table 2. Meteorological conditions during the sugar beet vegetative periods, Kaunas Meteorological Station.

Year/Month	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
2017	5.6	12.9	15.4	16.8	17.5	13.4
Long-term average	6.9	13.2	16.1	18.7	17.3	13.6
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
2017	73.7	10.5	80.2	79.6	55.0	87.1
Long-term average	41.3	61.7	76.9	96.6	88.9	60.0
Duration of sunlight (h)						
2015	158	192	269	228	326	132
2016	123	308	275	165	175	157
2017	118	279	193	210	207	135
Long-term average	181	263	258	255	242	163

The experimental data were statistically processed by applying single-factor analysis of variance (ANOVA). Significant differences among the studied intercropping treatments were determined by calculating the least significant difference at the 95% and 99% level of significance ($p < 0.05$ and $p < 0.01$). A dispersion analysis was performed, using Fisher's LSD test to identify significant differences between the means. The results were checked by calculating numerical values to test accuracy, and we established that the results were precise (with an accuracy value of $p < 0.05$ or $p < 0.01$). The values within columns marked with the same letter (a, b, c, etc.) are not significantly different, using a single factor (A) analysis of variance with a confidence level of 95%. The averaged data (2015–2017) of sugar beet root-crop yield and qualitative parameters were tested in the case of year x treatment interaction. A correlation analysis was performed with STAT software. The analysis matrix included data of meteorological conditions, soil fertility parameters, sugar beet root-crop yield and qualitative parameters.

3. Results

3.1. Soil Chemical Composition

3.1.1. Soil pH, Nitrogen and Phosphorus

At the beginning of the experiment in 2015, the soil tests showed that the soil background pH was 7.3–7.6, N_{total} 1.10–1.18 g kg^{-1} and P_2O_5 210.8–248.2 mg kg^{-1}. Variations depended on the differences in soil texture and physical properties. During the three years of experimentation, the soil pH changed, except in the MB plots. In the plots intercropped with Persian clover (MC), the soil pH decreased significantly compared with the CT and MW plots (Table 3).

Table 3. The effect of intercropping on the change of pH, nitrogen and phosphorus in the soil, 2015–2017.

Treatment	pH_{KCl}	N_{total} ($g\ kg^{-1}$)	P_2O_5 ($mg\ kg^{-1}$)
Inter-row loosening (control treatment, CT)	+0.1a	+0.13a	+31.5b
Inter-row cutting and mulching with ambient weeds (MW)	+0.1a	+0.14a	+30.2b
Inter-row cutting and mulching with Persian clover (MC)	−0.2b	+0.18a	+13.8b
Inter-row cutting and mulching with white mustard (MM)	−0.1ab	+0.24a	+17.2b
Inter-row cutting and mulching with spring barley (MB)	0.0ab	+0.10a	+84.1 * a

* Significant differences from the control treatment (CT) at $p < 0.05$. Values within the columns with different letters indicate significant differences between the treatments at the 95% confidence level.

The content of total nitrogen increased in all the experimental plots (Table 3). The averaged data showed no significant differences between the treatments, but a higher increase in the content of nitrogen was found in MC and MM.

The content of phosphorus increased in all the experimental plots. In CT plots without intercropping, the amount of phosphorus also increased by 31.5 mg kg^{-1}. The larger amount of sugar beet residues (up to 40 tonnes per ha) compared with other treatments could account for this increase. However, the largest increase was found in MB plots.

3.1.2. Soil Potassium, Magnesium and Sulphur

In 2015, at the beginning of the experiment, the background content of K_2O varied from 86.5 to 98.8 mg kg^{-1}, MgO from 618.5 to 664.0 mg kg^{-1} and sulphur from 2.4 to 2.7 mg kg^{-1}. At the end of the experiment, the content of potassium increased in all the plots, but the differences between the treatments were not significant (Table 4). Despite that, the highest increase (83.0 mg kg^{-1}) was found in MW plots.

Table 4. The effect of intercropping on the change of soil potassium, magnesium and sulphur, 2015–2017.

Treatment	K_2O ($mg\ kg^{-1}$)	MgO ($mg\ kg^{-1}$)	S ($mg\ kg^{-1}$)
Inter-row loosening (control treatment, CT)	+72.3a	+25.7a	−0.2a
Inter-row cutting and mulching with ambient weeds (MW)	+83.0a	−18.3ab	−0.2a
Inter-row cutting and mulching with Persian clover (MC)	+71.5a	+15.8ab	−0.6ab
Inter-row cutting and mulching with white mustard (MM)	+61.3a	+8.2ab	−0.9 * b
Inter-row cutting and mulching with spring barley (MB)	+66.8a	−58.7b	−0.4ab

* Significant differences from the control treatment (CT) at $p < 0.05$. Values within the columns with different letters indicate significant differences between the treatments at the 95% confidence level.

During the three-year experimentation, the content of magnesium changed more (Table 4). The lowest content of magnesium was found in MB plots. A decrease also occurred in MW plots.

The soil at the experimental site had a very low amount of sulphur. During the three vegetative periods of continuous sugar beet cultivation, the proportion of sulphur decreased in all the plots. A more significant decrease was observed in the MM and MC plots (Table 4).

To summarize, under minimal fertilization, intercropping of living mulch plants without incorporation still positively influenced the content of nitrogen, phosphorus and potassium in the soil and reduced the content of magnesium in single cases (MV, MB) and the content of sulphur in all cases. In control plots (CT), due to the elimination of competitors (weeds and intercrops), the proportion of macro-elements in the soil increased, except for sulphur.

3.2. Sugar Beet Root-Crop Yield

In Lithuania, in a traditional farming system, the sugar beet yield was, on average, 55.82 (2017) and 57.21 (2018) tonnes per ha. In our experiment, the yield of sugar beet root-crop varied from 13.73 to

40.57 tonnes ha^{-1} in 2015, from 36.36 to 71.07 tonnes ha^{-1} in 2016 and from 30.46 to 54.17 tonnes ha^{-1} in 2017. Intercropping with living mulch plants and weeds as competitors [35] had a significantly negative effect on the yield of sugar beet root-crop (Table 5).

Table 5. The effect of intercropping on the yield and the chemical content of sugar beet root-crop, 2015–2017.

Treatment	Yield (t ha^{-1})	Sucrose (g kg^{-1})	K (mmol kg^{-1})	Na (mmol kg^{-1})	α-Amino N (g kg^{-1})
			2015		
CT	40.57a	173.2a	28.7a	2.1a	0.918a
MW	13.73 * b	166.2ab	27.4a	2.6a	0.815a
MC	17.46 * b	166.6ab	28.2a	2.7a	0.735a
MM	18.05 * b	163.2 * b	28.9a	2.6a	0.808a
MB	18.23ab	164.4ab	28.8a	2.3a	0.858a
			2016		
CT	71.07a	174.6a	33.4a	2.9a	1.533a
MW	50.00 * b	167.9ab	35.7a	3.5a	1.400a
MC	38.66 ** b	167.2 * b	35.9a	3.6a	1.307a
MM	36.36 ** b	169.5ab	35.1a	3.6a	1.687a
MB	44.74 * b	172.4ab	32.7a	3.0a	1.143a
			2017		
CT	54.17a	154.8b	42.6a	3.4a	1.727a
MW	36.58 * bc	162.6 * a	42.0a	3.4a	1.347 * b
MC	37.92abc	159.7ab	44.5a	3.4a	1.597ab
MM	50.65ab	157.2ab	43.7a	3.7a	1.660ab
MB	30.46 * c	163.4 * a	42.8a	3.3a	1.523ab
			2015–2017 average		
CT	55.27a	167.5a	34.9a	2.8b	1.393a
MW	33.44 * b	165.6a	35.0a	3.2 * a	1.187a
MC	31.35 * b	164.5a	36.2a	3.2 * a	1.213a
MM	35.02 * b	163.3a	35.9a	3.3 ** a	1.385a
MB	31.14 * b	166.7a	34.8a	2.9b	1.175a
F_{YxT}	**	**	**	**	**

* Significant differences from the control treatment (CT) at $p < 0.05$, ** at $p < 0.05$. F_{YxT}—year and treatment interaction. Values with different letters indicate significant differences between the treatments at the 95% confidence level. CT—inter-row loosening (control treatment); MW—inter-row cutting and mulching with ambient weeds; MC—inter-row cutting and mulching with Persian clover; MM—inter-row cutting and mulching with white mustard; MB—inter-row cutting and mulching with spring barley.

Yields in the inter-cropped plots were on average more than 20 tonnes per hectare lower than under CT conditions. However, due to the positive effect of intercropped biomass on soil fertility, the differences between the intercropped and the control plots decreased every year. In 2015, the differences from CT were 55–66%, in 2016 30–49% and in 2017 6.5–44%.

The 2015–2016 experimental data showed a strong negative correlations between the biomass of intercropped plants and the yield of sugar beet [36]. In 2015–2017, the yield of sugar beet root-crop mainly depended on soil total nitrogen (r = 0.482) and magnesium (r = 0.804). Moreover, we found a significant ($p < 0.01$) interaction between experimental years and treatments (Table 5); however, the correlation between air temperature, precipitation rate and solar radiation during the three vegetative seasons and sugar beet root-crop yield was weak.

3.3. Sugar Beet Root-Crop Chemical Composition

Sugar beet root-crop chemical composition mainly depends on the meteorological conditions during the vegetation, especially the precipitation rates, air temperature and solar radiation [30,31]. However, in our experiment, air temperature and precipitation rate during the vegetative seasons was not correlated with root-crop sucrose and K contents. There were also weak correlations between the precipitation rate and contents of Na and α-amino N. Conditions of solar radiation (duration of sunlight) had no effect on sugar beet root-crop content. The chemical content of root-crop varied significantly over the years: we found significant year x treatment interactions (Table 5). The content of sucrose varied from 173.2 to 163.2 in 2015, from 174.6 to 167.2 in 2016 and from 154.8 to 163.4 g kg^{-1} in 2017. The amount of potassium varied between 27.4–28.9, 32.7–35.9 and 42.0–44.5 mmol kg^{-1}; for sodium it was 2.1–2.7, 2.9–3.6 and 3.3–3.7 mmol kg^{-1}; and for α-amino nitrogen it was 0.735–0.918, 1.143–1.687 and 1.347–1.727 g kg^{-1}. The averaged data from the three years of experimentation showed that the sugar beet root-crop qualitative parameters were not significantly different, except the content of Na, which was significantly lower in MW, MC and MM plots compared to CT (Table 5).

In addition to meteorological vegetation conditions, the effect of soil chemical content on the composition of sugar beet root-crop was also determined (Table 6). Total nitrogen in the soil affected the rise in sugar beet root-crop yield and the proportion of negative impurities (K, Na, α-amino N). Similarly, the excess amount of magnesium in the soil slightly increased the content of negative impurities (K, Na, α-amino N) in the sugar beet root-crop (Table 6). This is a warning that salinization of the soil could negatively affect the quality of sugar beet root-crop.

Table 6. Correlation between the final variance (from 2015 to 2017) of soil chemical composition (x), root-crop yield and chemical composition in the last year (2017) of investigations.

Soil Chemical Composition (*x*)	Sugar Beet Root-Crop Chemical Composition (*Y*)				
	Yield (Mg ha^{-1})	Sucrose (g kg^{-1})	K (mmol kg^{-1})	Na (mmol kg^{-1})	α-Amino N (g kg^{-1})
N	0.482	−0.428	0.617	0.927 *	0.327
P (mg kg^{-1})	−0.572	0.561	−0.432	−0.600	n
K (mg kg^{-1})	n	n	−0.561	−0.511	−0.668
Mg (mg kg^{-1})	0.804	−0.858	0.393	0.458	0.608
S (mg kg^{-1})	n	n	−0.766	-0.767	−0.365

n—weak correlation. *—significant at $p < 0.05$

Strong correlations were found between the productivity of sugar beet root-crop and the content of sucrose at root-crop (r = −0.964 **), the content of sodium (r = 0.618), the content of α-amino nitrogen (r = 0.739), the content of sucrose at root-crop and the content of α-amino nitrogen (r = −0.859). During the experimentation, the soil pH changed only slightly, and this change would have no effect on sugar beet productivity and production quality.

4. Discussion

4.1. Soil Chemical Composition

In our experiment, background soil chemical proportion varied between plots because of differences in soil texture and physical properties. During the three years of experimentation, soil pH became more even, but when intercropped with Persian clover plots (MC), it decreased significantly compared with CT and MW plots (Table 3). Meanwhile, Orzech and Załuski [39] found no significant decrease in soil pH in potato, spring wheat and spring barley cultivations with red clover companion crop during seven years of experimentation. It is unclear why soil pH decreased in MC compared to the CT and MT plots.

During the three years, the content of total nitrogen increased in all the experimental plots (Table 3). The averaged data showed that the highest increase in nitrogen content was found in the MC and MM plots, because Persian clover and white mustard grew the largest fresh biomass [35]. Moreover, *Fabaceae* catch crops contain a high amount of nitrogen and quickly decompose in the soil [21]. Similar to our experiment, Marinari et al. [40] noted that mulching with white mustard was effective for accumulating nutrient nitrogen. In the experiment of Den Hollander et al. [23], a positive correlation between the quantities of clover catch crop biomass and nitrogen accumulation was found. Piotrowska-Długosz and Wilczewski [9] found that the content of total nitrogen was significantly higher in catch crop treatments, while the concentration of available phosphorus was the opposite. Similarly, Adamavičienė et al. [41] found a positive correlation between the volume of living mulch (spring barley, summer oilseed rape, white mustard, Persian clover, red clover, annual ryegrass) biomass and the content of soil total nitrogen, potassium and phosphorus in maize cultivation, continuously intercropped for three years. Topsoil pH increased, on average, by 4%, total nitrogen content by 62%, phosphorus by 18% and potassium by 22%. Conversely, Alvarez et al. [42] indicated that the proportion of nitrates in the soil decreased by 30% after the cover crops, regardless of whether the cover crop was a legume.

During the three vegetative seasons, the content of phosphorus in the soil increased in all the experimental plots (Table 3), including in CT plots without intercropping. This could be due to larger amount of sugar beet residues (up to 40 tonnes per ha) in CT compared with other intercropped treatments. The largest increase was found in MB plots. Similarly, Liu et al. [43] established that catch crops effectively increased the proportion of phosphorus in the soil. Furthermore, Wanic et al. [21] pointed that the content of available phosphorus in the soil depended on the species of catch, the rate of mineralization and the P cycle.

During continuous sugar beet intercropping, the potassium content in the soil increased in all the plots, but not significantly (Table 4). The highest increase was found in MW (mulching with ambient weeds) plots. Similarly, Lumbanraja et al. [44] found that weeds used as cover plants improved the total C, total N, available P and exchangeable (ex.) Mg in the soil of coffee fields.

Barley (MB) and ambient weed (MW) intercropping initiated a higher decrease in soil magnesium; however, the amount of sulphur decreased in all experimental plots (Table 4). The highest decrease in sulphur was observed in the plots with mustard and Persian clover intercrops. Similarly, Eriksen et al. [45] found that the legume catch crop sequestrated 10–12 kg ha^{-1} of sulphur, but the rate of S-mineralization after incorporation was slow. Moreover, the methods of intercrop (living mulch) suppression and residue incorporation have a strong influence on the biomass decomposition rate, nutrient supply and storage in the soil. If such systems could be better utilized and managed, the results could demonstrate agronomic benefits [20].

4.2. Sugar Beet Root-Crop Yield and Quality Parameters

Sugar beet root-crop yields in weeded plots and those without intercrops (CT) were, on average, more than 20 tonnes per hectare higher; however, the decomposed biomass of intercrops increased soil fertility, and the differences between the CT and intercropped plots decreased every year (Table 5). The yield of sugar beet root-crop mainly depended on the differences in soil total nitrogen and magnesium (Table 6) because the correlation between air temperature, precipitation rate and solar radiation during vegetative seasons and sugar beet root-crop yield was weak. Marchetti and Castelli [46] also stated that nitrogen is the nutrient that most strongly influences the production of sugar beet root-crop.

The experimental data from the previous study at the same site showed strong negative correlations between the biomass of intercropped plants and the yield of sugar beet [35] because intercrops competed for space, solar radiation and nutrients. In our pilot short-term investigations, white mustard and spring barley developed fast, effectively controlling weeds before the first cutting and mulching, and did not regrow and compete with sugar beet [30,31]. Persian clover (legume crop) improved the soil N balance and grew a high volume of biomass. The complication of this intercrop was slow development in the first stages of vegetation and with fast regrowth later. Due to the fast regrowth, Persian clover effectively suppressed weeds but competed with the main crop [35]. Moreover, the high biomass volume of Persian clover at the end of vegetation disturbs the harvesting of sugar beet root-crops. There is a lack of information about the effect of sugar beet intercropping; however, conversely to our findings, Götze et al. [47] found a positive effect of alfalfa (legume crop) integration in crop rotation on the yields of sugar beet root-crop and amount of white sugar. A positive effect of intercropping was also established in the cultivation of other crops. For example, Munkholm and Hansen [15] showed that the yield of spring barley was the highest with fodder radish grown as a catch crop. In the experiment of Hong et al. [48], under semiarid vegetative conditions, yields of maize intercropped with legumes increased from 1.3 to 2.3 tonnes ha^{-1}. Similar conclusions were drawn by Deguchi et al. [49] after experimenting with white clover living mulch and by Ren et al. [50] after experimenting with mustard. In other experiments (with broccoli rabe, cauliflower, maize, wheat, barley, oats, etc.), living mulch was proven to control weeds without competing with crops [11,51,52]. Conversely, Dyer's woad and perennial ryegrass had a negative effect due to competition with the main crop, late uptake of nitrogen and slow release of nitrogen from the residues. In our earlier experiments, annual ryegrass was quite aggressive towards the main crop (sugar beet, maize) [30,31,53], which is why it was not included in the treatment list in the experiments.

According to the averaged data, the sugar beet root-crop qualitative parameters were not significantly different between treatments, except the content of Na, which was significantly lower in the MW, MC and MM plots compared to CT (Table 5). In our earlier investigations at different sites in Lithuania, density of sugar beet crop is the main factor that caused changes in sugar beet chemical content [31]. However, Majkowska-Gadomska et al. [27] found that intercropping of carrot with dill increased the quality of root-crop tested during the storage period.

Sugar beet root-crop chemical composition often depends on the moisture, air temperature and solar radiation conditions during the vegetative season [54]. Conversely, in our experiment, meteorological conditions had a weak impact on the sugar beet root-crop chemical composition. Soil chemical composition was the main factor that led to differences in the sugar beet root-crop content (Table 6). An increase in the soil total nitrogen raised the proportion of negative impurities (K, Na, α-amino N). The amount of impurities also depended on the amount of magnesium in the soil. This is a warning because most fertile (suitable for sugar beet cultivation) Lithuanian soils have surplus contents of magnesium.

To summarize, the hypothesis was partially confirmed. In fact, most of the intercrops raised the concentration of chemical elements in the soil, but an increase was found in CT plots as well. The chemical composition of sugar beet root-crops was similar in all the treatments during the three years of continuous intercropping. However, as a result of competition with intercrops ($r = -0.565$) and weeds ($r = -0.836$) [36], due to ineffective inter-row cutting and mulching equipment and imbalanced crop nutrition, the yields of root-crop in intercropped sugar beet cultivation decreased significantly. However, soil tillage (inter-row loosening in CT plots) has a negative ecological footprint for soil physical and biological properties. From an ecological and economic point of view, intercropping treatments could be a suitable practice for organic sugar beet growing if the suppression technique of intercrops and weeds and the balance of nutrients were correctly implemented. Similarly, Hiltbrunner et al. [55] concluded that legume cover crops were an available alternative for weed control under the conditions of organic farming, but their negative impact on the growth and yield of the main crop should be minimized.

5. Conclusions

Under the conditions of minimal fertilization, inter-row loosening (CT) and intercropping had an overall positive effect on the content of nitrogen, phosphorus and potassium in the soil. In some cases, they reduced the content of magnesium (MV, MB), and in all cases they reduced the content of sulphur. Inter-row mulching with grown weeds (MW) initiated an increase in available phosphorus and the concentration of potassium in the soil; intercropping with Persian clover (MC) increased the total nitrogen, potassium and magnesium; intercropping with white mustard (MM) increased the total nitrogen and magnesium; and spring barley (MB) increased the phosphorus.

Intercropping significantly decreased the yields of sugar beet root-crop, but was mainly neutral in quality terms. The meteorological conditions during experimentation had a weak impact on root-crop quantity and quality.

Generally, the practice of sugar beet intercropping requires more detailed research on how to minimize the competition between sugar beet, living mulch and weeds, and how to balance the nutrition conditions.

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References

1. Hochman, Z.; Carberry, P.; Robertson, M.; Gaydon, D.; Bell, L.; McIntosh, P. Prospects for ecological intensification of Australian agriculture. *Eur. J. Agron.* **2013**, *44*, 109–123. [CrossRef]
2. Doltra, J.; Olesen, J.E. The role of catch crops in the ecological intensification of spring cereals in organic farming under Nordic climate. *Eur. J. Agron.* **2013**, *44*, 98–108. [CrossRef]
3. Doré, T.; Makowski, D.; Malézieux, E.; Munier-Jolain, N.; Tchamitchian, S.; Tittonell, P. Facing up to the paradigm of ecological intensification in agronomy: Revisiting methods, concepts and knowledge. *Eur. J. Agron.* **2011**, *34*, 197–210. [CrossRef]
4. Daryanto, S.; Fu, B.; Wang, L.; Jacinthe, P.-A.; Zhao, W. Quantitative synthesis on the ecosystem services of cover crops. *Earth-Sci. Rev.* **2018**, *185*, 357–373. [CrossRef]
5. Poeplau, C.; Aronsson, H.; Åsa, M.; Kätterer, T. Effect of perennial ryegrass cover crop on soil organic carbon stocks in southern Sweden. *Geoderma Reg.* **2015**, *4*, 126–133. [CrossRef]
6. Rücknagel, J.; Götze, P.; Koblenz, B.; Bachmann, N.; Löbner, S.; Lindner, S.; Bischoff, J.; Christen, O. Impact on soil physical properties of using large-grain legumes for catch crop cultivation under different tillage conditions. *Eur. J. Agron.* **2016**, *77*, 28–37. [CrossRef]
7. Wick, A.; Berti, M.; Lawley, Y.; Liebig, M. Integration of Annual and Perennial Cover Crops for Improving Soil Health. In *Soil Health and Intensification of Agroecosytems*; Elsevier BV: Amsterdam, The Netherlands, 2017; pp. 127–150.
8. Prosdocimi, M.; Tarolli, P.; Cerdà, A. Mulching practices for reducing soil water erosion: A review. *Earth-Sci. Rev.* **2016**, *161*, 191–203. [CrossRef]
9. Piotrowska-Długosz, A.; Wilczewski, E. Effects of catch crops cultivated for green manure and mineral nitrogen fertilization on soil enzyme activities and chemical properties. *Geoderma* **2012**, 72–80. [CrossRef]
10. Muhammad, I.; Sainju, U.M.; Zhao, F.; Khan, A.; Ghimire, R.; Fu, X.; Wang, J. Regulation of soil CO2 and N2O emissions by cover crops: A meta-analysis. *Soil Tillage Res.* **2019**, *192*, 103–112. [CrossRef]
11. Fracchiolla, M.; Renna, M.; D'Imperio, M.; Lasorella, C.; Santamaria, P.; Cazzato, E. Living mulch and organic fertilization to improve weed management, yield and quality of broccoli raab in organic farming. *Plants* **2020**, *9*, 177. [CrossRef]
12. Kolota, E.; Adamczewska-Sowinska, K. Living mulches in vegetable crops production: Perspectives and limitations (a review). *Acta Sci. Pol. Hortorum Cultus* **2013**, *12*, 127–142.
13. El-Fakharany, S.; Samy, M.; Ahmed, S.; Khattab, M. Effect of intercropping of maize, bean, cabbage and toxicants on the population levels of some insect pests and associated predators in sugar beet plantations. *J. Basic Appl. Zool.* **2012**, *65*, 21–28. [CrossRef]
14. Thorup-Kristensen, K.; Dresbøll, D.B. Incorporation time of nitrogen catch crops influences the N effect for the succeeding crop. *Soil Use Manag.* **2010**, *26*, 27–35. [CrossRef]
15. Munkholm, L.J.; Hansen, E.M. Catch crop biomass production, nitrogen uptake and root development under different tillage systems. *Soil Use Manag.* **2012**, *28*, 517–529. [CrossRef]
16. Lorin, M.; Jeuffroy, M.-H.; Butier, A.; Valantin-Morison, M. Undersowing winter oilseed rape with frost-sensitive legume living mulch: Consequences for cash crop nitrogen nutrition. *Field Crop. Res.* **2016**, *193*, 24–33. [CrossRef]
17. Norberg, L.; Aronsson, H. Effects of cover crops sown in autumn on N and P leaching. *Soil Use Manag.* **2020**, *36*, 200–211. [CrossRef]
18. Zhang, H.; Hu, K.; Zhang, L.; Ji, Y.; Qin, W. Exploring optimal catch crops for reducing nitrate leaching in vegetable greenhouse in North China. *Agric. Water Manag.* **2019**, *212*, 273–282. [CrossRef]
19. Qian, X.; Gu, J.; Pan, H.-J.; Zhang, K.-Y.; Sun, W.; Wang, X.; Gao, H. Effects of living mulches on the soil nutrient contents, enzyme activities, and bacterial community diversities of apple orchard soils. *Eur. J. Soil Boil.* **2015**, *70*, 23–30. [CrossRef]
20. Alexander, J.; Venterea, R.T.; Baker, J.M.; Coulter, J.A. Kura clover living mulch: Spring management effects on nitrogen. *Agronomy* **2019**, *9*, 69. [CrossRef]

21. Wanic, M.; Żuk-Gołaszewska, K.; Orzech, K. Catch crops and the soil environment—A review of the literature. *J. Elem.* **2019**, *24*, 31–45. [CrossRef]
22. Deguchi, S.; Uozumi, S.; Touno, E.; Kaneko, M.; Tawaraya, K. Arbuscular mycorrhizal colonization increases phosphorus uptake and growth of corn in a white clover living mulch system. *Soil Sci. Plant Nutr.* **2012**, *58*, 169–172. [CrossRef]
23. Hollander, N.D.; Bastiaans, L.; Kropff, M. Clover as a cover crop for weed suppression in an intercropping design. *Eur. J. Agron.* **2007**, *26*, 92–103. [CrossRef]
24. Radicetti, E.; Baresel, J.; El-Haddoury, E.; Finckh, M.R.; Mancinelli, R.; Schmidt, J.; Alami, I.T.; Udupa, S.; Van Der Heijden, M.; Wittwer, R.; et al. Wheat performance with subclover living mulch in different agro-environmental conditions depends on crop management. *Eur. J. Agron.* **2018**, *94*, 36–45. [CrossRef]
25. Pfeiffer, A.; Silva, E.; Colquhoun, J. Living mulch cover crops for weed control in small-scale applications. *Renew. Agric. Food Syst.* **2015**, *31*, 309–317. [CrossRef]
26. Afshar, R.K.; Chen, C.; Eckhoff, J.; Flynn, C. Impact of a living mulch cover crop on sugar beet establishment, root yield and sucrose purity. *Field Crops Res.* **2018**, *223*, 150–154. [CrossRef]
27. Majkowska-Gadomska, J.; Dobrowolski, A.; Mikulewicz, E.; Jadwisieńczak, K. Yield and mineral composition of storage roots of carrots (*Daucus carota* L.) protected with biological methods. *J. Elem.* **2017**, *22*, 1131–1139. [CrossRef]
28. Organic Europe. 2018. Available online: https://www.organic-europe.net/home-europe.html (accessed on 25 May 2020).
29. Romaneckas, K.; Romaneckienė, R.; Šarauskis, E.; Pilipavičius, V.; Sakalauskas, A. The effect of conservation primary and zero tillage on soil bulk density, water content, sugar beet growth and weed infestation. *Agron. Res.* **2009**, *7*, 73–86.
30. Romaneckas, K.; Romaneckienė, R.; Pilipavičius, V. Non-chemical weed control in sugar beet crop under intensive and conservation soil tillage: I. Crop weediness. *Agron. Res.* **2009**, *7*, 457–464.
31. Adamavičienė, A.; Romaneckas, K.; Šarauskis, E.; Pilipavičius, V. Non-chemical weed control in sugar beet crop under an intensive and conservation soil tillage pattern: II. Crop productivity. *Agron. Res.* **2009**, *7*, 143–148.
32. Romaneckas, K.; Pilipavičius, V.; Šarauskis, E. Impact of seedbed density on sugar beet (*Beta vulgaris* L.) seed germination, yield and quality of roots. *J. Food Agric. Environ.* **2010**, *8*, 599–601.
33. Šarauskis, E.; Romaneckas, K.; Kumhála, F.; Kriaučiūnienė, Z. Energy use and carbon emission of conventional and organic sugar beet farming. *J. Clean. Prod.* **2018**, *201*, 428–438. [CrossRef]
34. Boyd, D.A.; Tinker, P.B.H.; Draycott, A.P.; Last, P.J. Nitrogen requirement of sugar beet grown on mineral soils. *J. Agric. Sci.* **1970**, *74*, 37–46. [CrossRef]
35. Marks, M.; Romaneckas, K.; Šarauskis, E.; Adamavičienė, A.; Eimutyte, E.; Čekanauskas, S.; Kimbirauskiene, R.; Pupaliene, R. Impact of non-chemical weed control methods on the soil and sugar beet root chemical composition. *J. Elem.* **2018**, *23*, 1215–1227. [CrossRef]
36. Yagioka, A.; Komatsuzaki, M.; Kaneko, N.; Ueno, H. Effect of no-tillage with weed cover mulching versus conventional tillage on global warming potential and nitrate leaching. *Agric. Ecosyst. Environ.* **2015**, *200*, 42–53. [CrossRef]
37. IUSS working group WRB. *World Reference Base for Soil Resources*, 3rd ed.; World Soil Resources Reports No. 106; FAO: Rome, Italy, 2014. Available online: http://www.fao.org/3/i3794en/I3794en.pdf (accessed on 3 April 2020).
38. Negiş, H.; Şeker, C. Estimation of Soil Quality of under Long Term Sugar Beet-wheat Cropping System by Factor Analysis. *Commun. Soil Sci. Plant Anal.* **2020**, *51*, 440–455. [CrossRef]
39. Orzech, K.; Załuski, D. Effect of companion crops and crop rotation systems on some chemical properties of soil. *J. Elem.* **2020**, *25*, 931–949. [CrossRef]
40. Marinari, S.; Mancinelli, R.; Brunetti, P.; Campiglia, E. Soil quality, microbial functions and tomato yield under cover crop mulching in the Mediterranean environment. *Soil Tillage Res.* **2015**, *145*, 20–28. [CrossRef]
41. Adamavičienė, A.; Romaneckas, K.; Pilipavičius, V.; Avižienytė, D.; Šarauskis, E.; Sakalauskas, A. Interaction of maize and living mulch: Soil chemical properties and bioactivity. *J. Food Agric. Environ.* **2012**, *10*, 1219–1223.
42. Alvarez, R.; Steinbach, H.S.; De Paepe, J.L. Cover crop effects on soils and subsequent crops in the pampas: A meta-analysis. *Soil Tillage Res.* **2017**, *170*, 53–65. [CrossRef]

43. Liu, J.; Bergkvist, G.; Ulén, B. Biomass production and phosphorus retention by catch crops on clayey soils in southern and central Sweden. *Field Crop. Res.* **2015**, *171*, 130–137. [CrossRef]
44. Lumbanraja, J.; Adachi, T.; Oki, Y.; Senge, M.; Watanabe, A. Effect of weed management in coffee plantation on soil chemical properties. *Nutr. Cycl. Agroecosys.* **2004**, *69*, 1–4. [CrossRef]
45. Eriksen, J.; Thorup-Kristensen, K.; Askegaard, M. Plant availability of catch crop sulfur following spring incorporation. *J. Plant Nutr. Soil Sci.* **2004**, *167*, 609–615. [CrossRef]
46. Marchetti, R.; Castelli, F. Mineral nitrogen dynamics in soil during sugar beet and winter wheat crop growth. *Eur. J. Agron.* **2011**, *35*, 13–21. [CrossRef]
47. Götze, P.; Rücknagel, J.; Wensch-Dorendorf, M.; Märländer, B.; Christen, O. Crop rotation effects on yield, technological quality and yield stability of sugar beet after 45 trial years. *Eur. J. Agron.* **2017**, *82*, 50–59. [CrossRef]
48. Hong, Z.; Mkonda, M.Y.; He, X.-H. conservation agriculture for environmental sustainability in a semiarid agroecological zone under climate change scenarios. *Sustainability* **2018**, *10*, 1430. [CrossRef]
49. Deguchi, S.; Uozumi, S.; Touno, E.; Uchino, H.; Kaneko, M.; Tawaraya, K. White clover living mulch reduces the need for phosphorus fertilizer application to corn. *Eur. J. Agron.* **2017**, *86*, 87–92. [CrossRef]
50. Ren, L.; Nest, T.V.; Ruysschaert, G.; D'Hose, T.; Cornelis, W.M. Short-term effects of cover crops and tillage methods on soil physical properties and maize growth in a sandy loam soil. *Soil Tillage Res.* **2019**, *192*, 76–86. [CrossRef]
51. Canali, S.; Campanelli, G.; Ciaccia, C.; Diacono, M.; Leteo, F.; Fiore, A.; Montemurro, F. Living mulch strategy for organic cauliflower (*Brassica oleracea* L.) production in central and southern Italy. *Ital. J. Agron.* **2015**, *10*, 90. [CrossRef]
52. Verret, V.; Gardarin, A.; Pelzer, E.; Médiène, S.; Makowski, D.; Valantin-Morison, M. Can legume companion plants control weeds without decreasing crop yield? A meta-analysis. *Field Crop. Res.* **2017**, *204*, 158–168. [CrossRef]
53. Romaneckas, K.; Adamavičienė, A.; Pilipavičius, V.; Šarauskis, E.; Avižienytė, D.; Buragienė, S. Interaction of maize and living mulch: Crop weediness and productivity. *Žemdirb. Agric.* **2012**, *99*, 23–30.
54. Romaneckas, K. The Influence of reduced primary soil tillage on soil physical properties, weed infestation, sugar beet yield and quality. *Agron. Vēstis* **2005**, *8*, 232–236.
55. Hiltbrunner, J.; Liedgens, M.; Bloch, L.; Stamp, P.; Streit, B. Legume cover crops as living mulches for winter wheat: Components of biomass and the control of weeds. *Eur. J. Agron.* **2007**, *26*, 21–29. [CrossRef]