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Effect of Soil Regenerative Practice on Selected Soil Physical Properties and Eggplant (*Solanum melongena* L.) Yield

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Abstract: Living mulches can play a crucial role in the protection of the soil against erosion, as well as biological and chemical degradation. Soil fertility and its physical properties, including soil structure, are of special importance to crops. Soil physical properties are affected, among other factors, by the type of tillage. In order to determine the effect of regenerative practice (living mulches) on soil physical properties, a two-factorial experiment was conducted. The first factor involved white clover and perennial ryegrass as an intercropping of eggplant. The second factor was the living mulches sowing term: three weeks before eggplant planting, at the time of planting and three weeks after eggplant planting. Covering eggplant inter-rows with living mulches reduced eggplant yield and was beneficial to soil structure and improved water resistance of soil aggregates. Perennial ryegrass had a slightly more advantageous effect on yield and improvement of soil physical properties, as compared to white clover. The greater eggplant fruit yield was obtained from vegetable grown without companion plants. The application of living mulches (especially *Trifolium repens* L.) caused a non-significant decrease in eggplant fruit yield. It was found that limiting the growth of seedlings sown on the first date result in a decrease in marketable fruit yield (on average 14%). A similar result occurred when living mulches were sown on the planting date of eggplants and difference between the yields was 4.3%. The first term of sowing living mulches—three weeks before eggplant planting—no significantly affected the mean weighted diameter of soil aggregate (MWDg), the water stability index (ΔMWD), the index of waterproof index (Wod) and the soil structure index (W). Later sowing terms resulted in the improvement of the majority of the parameters; however, this was not confirmed statistically. Soil with periodic mechanical treatment of inter-rows showed the 3–4% lower values of soil porosity, 3–16% increased compactness, as well as 28–30% lower indices soil structure and 28–30% for water resistance of soil aggregates compared to the living mulches system.

Keywords: *Solanum melongena* L.; living mulches; soil structure indices; water resistance of soil aggregates; regenerative cultivation methods

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1. Introduction

The protection of soil structure is a key requirement for sustainable soil use. The appropriate aggregates structure combines many soil properties and determines its fertility, biodiversity, nutrient cycle and carbon sequestration and regulates (both quantitatively and qualitatively) the water cycle [1–3]. The quality of soil results from a number of its morphological, biological, chemical and physical properties, which are dependent, among other factors, on the type of tillage [4–7]. Currently, when sustainable agriculture is being introduced, special attention is being paid to the improvement of soil fertility and soil physical properties [3]. The optimal structure guarantees the most advantageous physical condition of soil—its loosening and impact on capillary pores, which is important for water retention, as well as the number of macropores, which provides for air permeability [1,8].

Use of cover crops, and improvement of soil physical properties has been proposed as an alternative methods of food production called regenerative agriculture [9]. Stable and water resistant soil aggregates, which determine soil physical properties, improve the water and air conditions of soil and protect it against forming a soil crust and water erosion [10–14].

One of the factors which improves yield and soil physical properties, especially its structure and water resistance of aggregates, is organic fertilisation [15]. Intercropping and living mulches can provide important nutrients to support crop yield in the event shortages of organic fertilizer [16]. The latter factor has been gaining increasing and more interest, especially in horticulture, since intercropping can contribute to the reduction of weed infestation [16–18] and in pest occurrence [16,19]. Living mulches should also be considered as an important element in the protection of the soil environment against erosion [17,20], as well as a factor reducing the leaching out of nutrients to deeper soil layers and ground waters [21–23]. Some authors believe that living mulches can increase or at least maintain the current level of organic matter content in soil [24–26]. Living mulches are also a valuable as a secondary source of macro- and microelements in soil [16,27,28]. Blanco-Moure et al. [14] and Lu et al. [27] point to the beneficial effect of cover plants on soil properties, while Rasse et al. [29] and Romaneckas et al. [30] report that cover crops generally improve the soil structure indices.

The eggplant is a vegetable of great worldwide economic importance, especially in tropical and subtropical countries [31]. It is also grown in the south of Europe and in the Mediterranean zone, where eggplant ranks among the top five most important vegetable crops [32,33]. Climate change and the increases in temperature as well as the extension of the growing season are having an impact on an extension of range of eggplants cultivation also under temperate climate conditions [34]. The literature data on the influence of living mulches as a regenerative cultivation method on soil physical properties on eggplant plant are limited. Leary et al. [17] and Adamczewska-Sowińska and Kołota [35] tested different cover crops as living mulches for eggplants cultivation. The eggplant is well adapted to the environmental conditions of Central Europe, and such crop characteristics such as the length of the growing season and wide row spacing between plants provide for cultivation in the living mulch system.

Therefore, the aim of this research was the assessment of the effect of living mulches species, used in eggplant cultivation, and the different lengths of their growing periods, on yield of eggplant yield, living mulches biomass and especially selected physical properties of soil.

2. Methods and Materials

2.1. Field Experiment Layout

The two-factorial experiment was conducted in the years 2010–2012, at the Research Station belonging to the Department of Horticulture, Wroclaw University of Environmental and Life Sciences. The experiment was established according to the split-plot method, in three replications. The first factor was the effect of living mulches species, used in eggplant cultivation (white clover—*Trifolium repens* L. Grasslands Huia variety, and perennial ryegrass—*Lolium perenne* L. 'Więcławski variety). The second factor involved the comparison of their different sowing times and living mulch management. The field experiment assessed the effect of treatments on living mulches biomass, eggplant yielding and soil physical properties. The field experimental design is presented in Figure 1A.

Living mulches were sown 3 weeks before planting eggplants, on the day of planting and 3 weeks after planting. At selected sites, the growth of living mulches was reduced by mowing or spraying with herbicide. The white clover and perennial ryegrass seeds were sown in 20-centimetre strips between eggplant rows, in the amount of 5 g m^{-2}. The living mulches were sown on 6.05, 27.05 and 17.06 in 2010; on 02.05, 20.05 and 10.06 in 2011; and on 04.05, 25.05 and 15.06 in 2012. Before eggplant transplanting applied triple superphosphate (100 kg P_2O_5 ha^{-1}), potassium sulphate (180 kg K_2O ha^{-1}), and ammonium nitrate (150 kg N ha^{-1}). Additional nitrogen dosses (ammonium nitrate—50 kg N ha^{-1}) applied

5 weeks after eggplant planting. Once sufficient biomass had been produced to cover the soil surface, the mulches were mowed with a brushcutter, 3 times during the growth period. A reduced dose of the preparation containing glyphosate (720 g ha^{-1}) was applied to inhibit the growth of the plants and this only partially killed them. Spraying with the herbicide was introduced when living mulches produced a biomass yield sufficient to form a good covering of soil surface mulch.

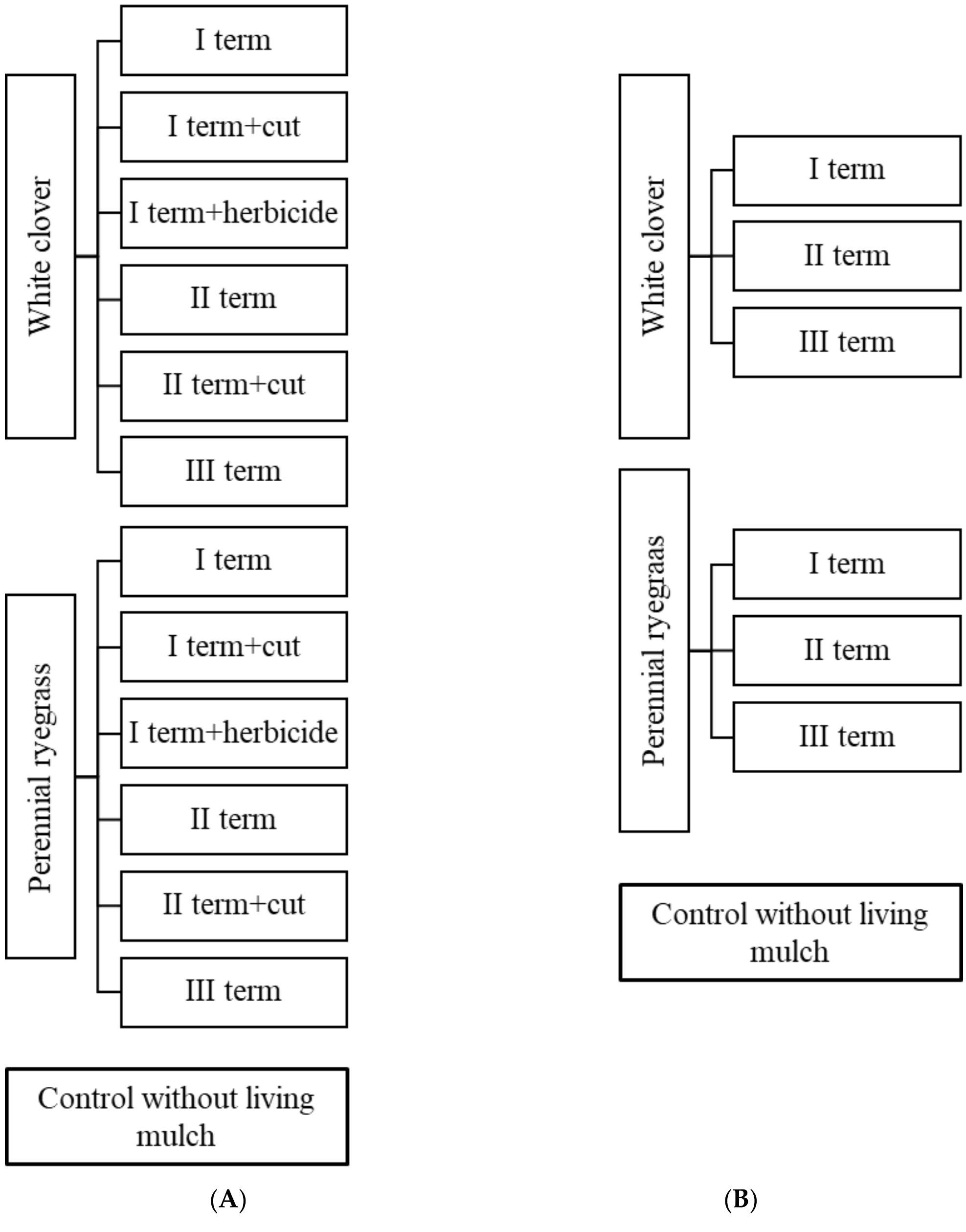

Figure 1. Experiment design. (**A**)—field experiment layout for living mulches management and eggplant yielding. (**B**)—field experiment layout for soil physical parameters.

The most favourable weather conditions for eggplant production were noted in 2012 year (Table 1). In the period from eggplant transplanting until the final crops harvest, the average temperature remained at a level of 17.6 °C, the rainfall was evenly distributed and the total amount was 241.3 mm during the growing season. The average temperature and rainfall in 2011 were similar to those in 2012. In June, directly after transplanting eggplants, the average temperature was 19.1 °C, but the rainfall was 3.6 times lower than average for June. Very high rainfall was recorded in July (153.2 mm) exceeding the monthly average from years 1970–2000 by 62.2 mm. The effect of weather conditions and living mulches on eggplant yielding in Central Europe is presented in Adamczewska-Sowińska et al. 2016 [34].

Table 1. Mean air temperature and sum of rainfall during the eggplant growing period in 2010–2012.

Months	2010		2011		2012	
	Mean	Deviation *	Mean	Deviation *	Mean	Deviation *
			Temperature (°C)			
May	13.3	−0.2	14.9	1.4	15.9	2.4
June	17.5	1.2	19.1	2.8	17.2	0.9
July	21.0	2.9	18.2	0.1	20.1	2.0
August	18.8	1.0	19.4	1.6	19.7	1.9
September	12.5	−1.1	15.9	2.3	14.8	1.2
			Rainfall (mm)			
May	134.5	77.5	41.4	−15.6	20.5	−36.5
June	24.8	−54.2	21.9	−57.1	77.1	−1.9
July	79.1	−11.9	153.2	62.2	70.8	−20.2
August	74.0	10.0	22.7	−41.3	48.4	−15.6
September	88.8	37.8	21.8	−29.2	45.0	−6.0

* Deviation from mean monthly temperature and rainfall from the years 1971–2000.

The experiment was conducted on chernozems with a calcic level (FAO-WRB Gleyic Calcic Chernozems) on medium clay, belonging to medium soil (class III), of pH 7.8 and salinity of 113.1 $\mu s \cdot cm^{-1}$ [36]. The plot size was 4 m^2 (2 × 2 m). Eggplants were strip planted at a spacing of 80 × 50 × 120 cm. Mowing of mulches was performed on 24.06, 20.07 and 19.08 in 2010; 22.06, 26.07 and 16.08 in 2011 and 05.07, 24.07 and 21.08 in 2012. The herbicide was used on 20.07.2010, 11.07.2011 and 24.07.2012. The control consisted of plots without living mulches. Living mulch biomass was collected from each plot from an area of 0.1 m^2 and living mulches biomass yield presented in fresh matter. Eggplant fruits were harvested every 7 days: 9 times between 14.07. and 14.09. in 2010; 9 times between 6.07. and 13.09. in 2011 and 12 times between 29.06. and 14.09. in 2012. The study evaluated fresh eggplant yield in tonnes per hectare and the fresh weight of 1 fruit (g). Certain variants of the experiment described above and marked in Figure 1B were selected for the study of soil physical properties.

2.2. Methods for Assesment of Soil Selected Physical Properties

The study involved the assessment of soil properties during the eggplant growing period, in mid-August. Soil moisture, bulk density, as well as total and capillary porosity were determined in 5–10 cm and 15–20 cm layers, in two replications in the plot, with the use of 100 cm^3-capacity cylinders. Soil compaction for 0–10 cm and 10–20 cm layers was determined on site in 12 replications using a soil compaction tester. The assessment of soil aggregates stability was performed for 0–10 cm and 10–20 cm layers, using the method of dry and wet separation in a Bakszajew apparatus manufactured by Wroclaw University of Science and Technology. Soil samples from each plot, after drying, were sieved using a sieve set of 0.25-, 0.5-, 1-, 3-, 5-, 7- and 10-mm mesh diameter, and then the percentage share of each aggregate fraction was estimated. On the basis of the obtained results, the following parameters were calculated: the soil cloddiness index (B—Equation (1)), the soil structure index (W—Equation (2)) and the mean weighted diameter of aggregates, measured using the dry method (MWDa—Equation (3)).

$$B = \frac{\%\text{ by weight of aggregates } > 10\text{ mm}}{\%\text{ by weight of aggregates } < 10\text{ mm}} \quad (1)$$

$$W = \frac{\%\text{ by weight of aggregates 1–10 mm}}{\%\text{ by weight of aggregates } > 10\text{ mm} + \%\text{ by weight of aggregates } < 0.25\text{ mm}} \quad (2)$$

$$\text{MWDa} = \frac{\sum_{i=1}^{n}(\text{x}_{\text{ia}} \times \text{w}_{\text{ia}})}{\sum_{i=1}^{n} \text{w}_{\text{ia}}} \tag{3}$$

w_{ia}—weights of soil fraction *i* obtained using dry method;
x_{ia}—value of soil fraction *i* obtained using dry method.

The water resistance of aggregates was assessed using the Bakszajew apparatus by sieving the soil samples while wet through the sieves of 0.25-, 0.5-, 1-, 3-, 5-, 7- and 10-mm mesh diameters. Then, the mean weighted diameter of aggregates (MWDg—Equation (4)) was measured, using the wet method, and the water stability index (ΔMWD—Equation (5)) as well as the index of waterproof (Wod—Equation (6)) were calculated.

$$\text{MWDg} = \frac{\sum_{i=1}^{n}(\text{x}_{\text{ig}} \times \text{w}_{\text{ig}})}{\sum_{i=1}^{n} \text{w}_{\text{ig}}} \tag{4}$$

w_{ig}—weights of soil fraction *i* obtained using wet method;
x_{ig}—value of of soil fraction *i* obtained using wet method.

$$\Delta\text{MWD} = \text{MWDa} - \text{MWDg} \tag{5}$$

$$\text{Wod} = \frac{\text{MWDg}}{\text{MWDa}} \times 100 \tag{6}$$

2.3. Statistical Analysis

Living mulches biomass, eggplant yield and fruit biomass were statistically elaborated by two-way analysis of variance (ANOVA), using Statistica software version 13.1 StatSoft (Krakow, Poland). Mean values were compared using the Tukeya test for the level of significance α = 0.05.

The living mulches species and their sowing term and management methods were entered as a fixed effect in the analysis and replications and year were considered as random effects.

The research results for physical soil properties were subject to statistical analysis; the calculation involved confidence intervals according to the Tukey test for the significance level α = 0.05. The statistical analysis was performed for two different procedures: 8 combinations (including control)—with three replications—for cultivation methods and for 6 combinations (without control)—with three replications—for comparison of living mulches species and sowing terms.

3. Results and Discussion

The yield of live mulch biomass evaluated on completion of eggplant vegetation significantly depended on the experimental factors (Figure 2). An analysis of averages of the study years showed that the earliest date of sowing—3 weeks before planting the eggplants transplants—was optimal for the development of the biomass of live mulches. The yield of live mulches was then on average more than twice as high as the yield from the other periods. Moreover, the average yield of white clover biomass was 43% higher than that of perennial ryegrass. Antichi et al. [37] emphasized the importance of the use of live mulches during the growth of the crop species; this results from the need to reduce competition.

Cutting or herbicide treatment of living mulches sown at the earliest term resulted in a significant reduction in their yield, 45.3% on average. The longer vegetation period of the living mulches sown in term I contributed to the production of at greater biomass before the first mowing and their more intensive growth compared to the living mulches sown in term II. In contrast moving did not result in at significant reduction in the yield of living mulches sown at the second date (by 27.9% on average).

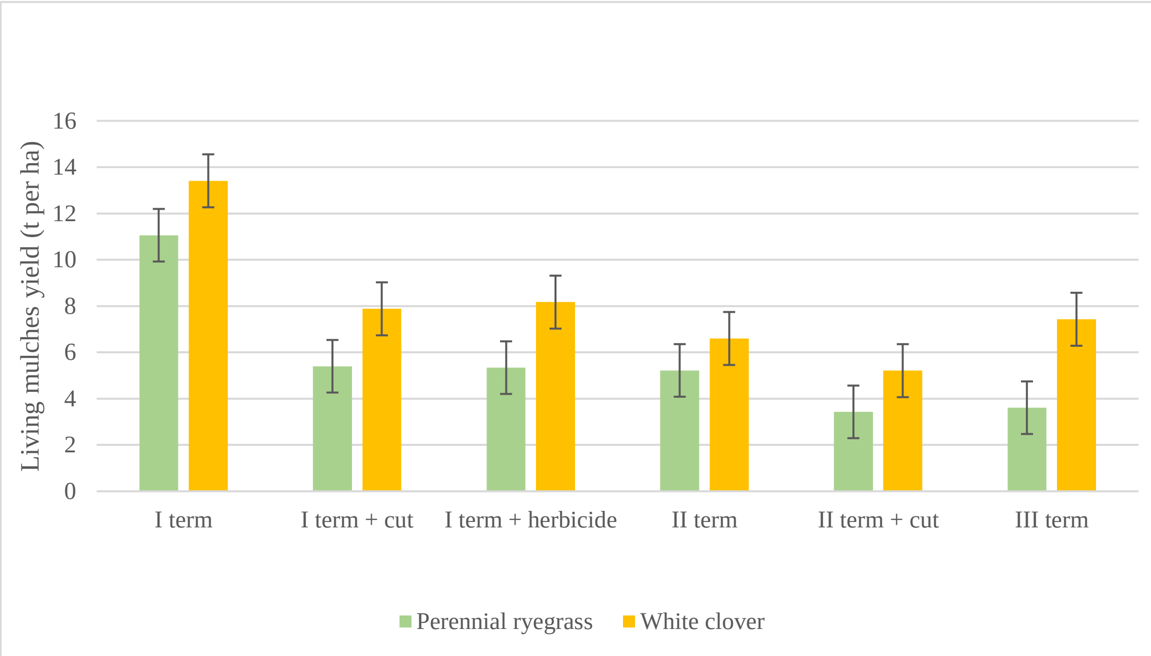

Figure 2. Living mulches biomass dependence on living mulches species, sowing term and management [t·ha^{-1}]. I term—living mulches sowed 3 weeks before planting eggplants; II term—living mulches sowed on the day of eggplants planting; III term—living mulches sowed 3 weeks after eggplants planting.

In our studies, the marketable yield of eggplant fruit depended on the sowing term of live mulch and the method of reduction of its growth (Figure 3). The greater yield was obtained from eggplants grown without companion plants. The yield of plants grown with live mulches sown on the day of transplanting and 3 weeks later remained at the same level of significance. Eggplants yield grown with living mulches sown three weeks before planting significantly decreased yield (on average by 30%). It was found that limiting the growth of seedlings sown on the first date (by mowing or herbicide application) did not result in an increase in marketable eggplants fruit yield. A statistically unconfirmed tendency to its decrease (on average 14%) was observed. A similar phenomenon occurred when moving living mulches were sown on the planting date of eggplants. However, the difference between the yields was much smaller (4.3%).

Similar relationships have been found in other studies [38]. The application of living mulches (*Trifolium repens* L.) and their mowing caused a non-significant decrease in eggplants yield. While the inhibition of seedling growth by application of a flame burner caused a significant decrease in eggplant fruit yield [38].

Considering the average results for the three years of the study, it was proven that clearly the greater fruit unit weight was achieved by sowing the living mulches on the planting date of eggplants or three weeks later (224–229 g) (Figure 4). In a previous study, neither live mulch sowing date nor mulch type had a significant effect on the unit weight of eggplant fruits [35].

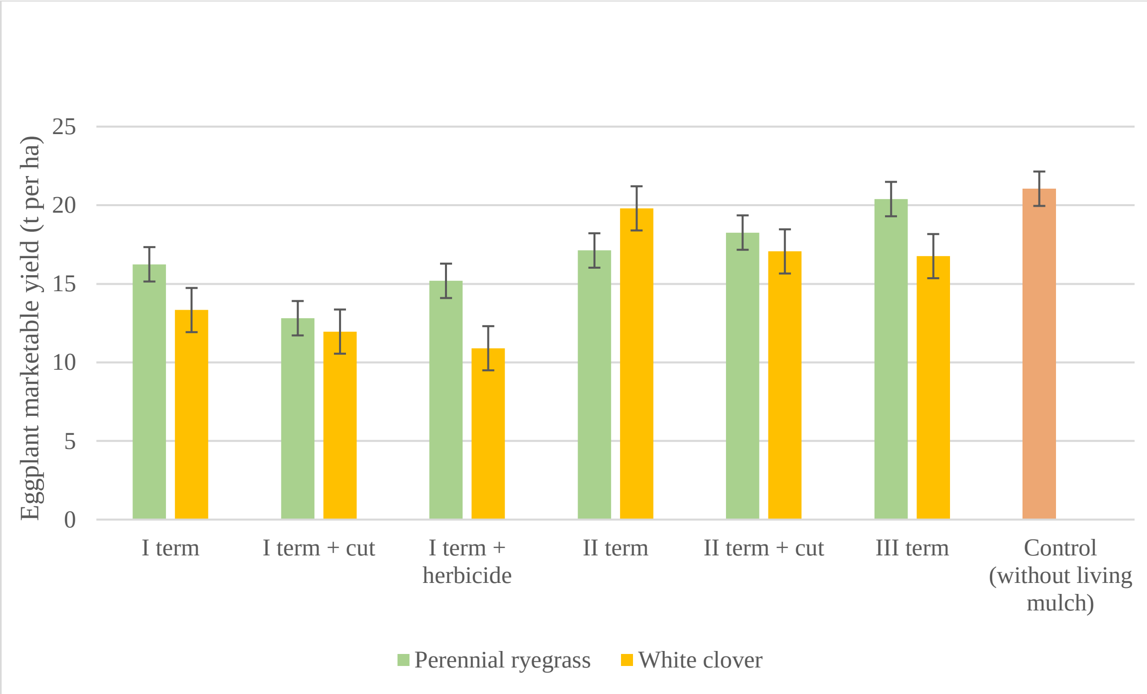

Figure 3. The effect of living mulches species, sowing term and living mulches management on eggplant marketable yield [t·ha^{-1}].

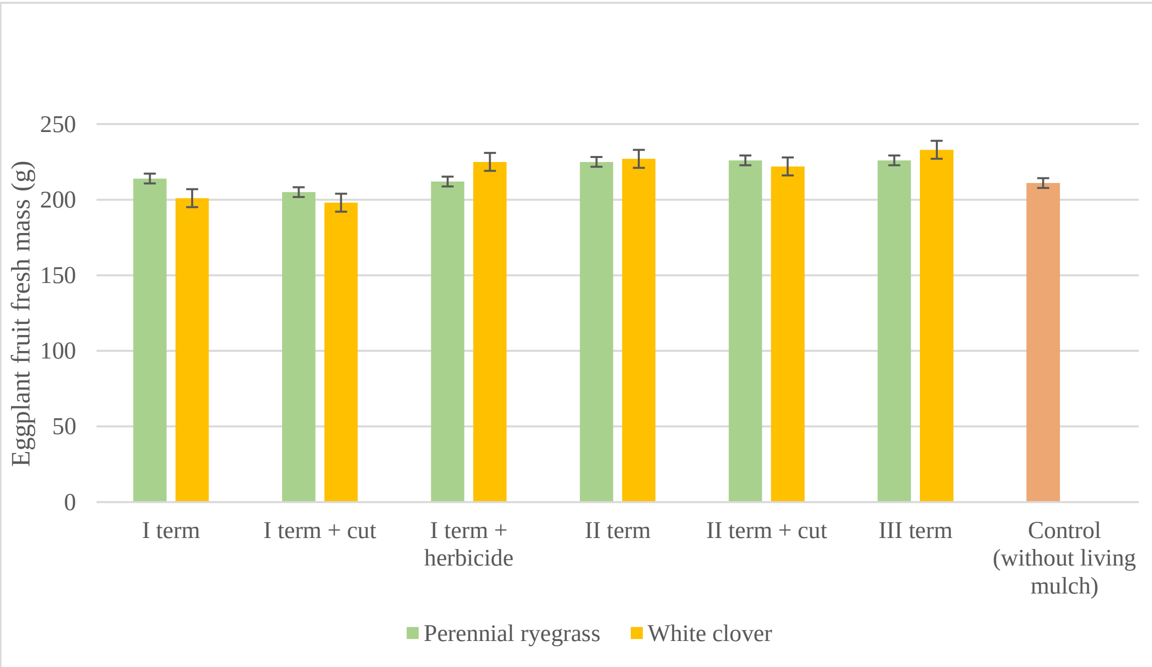

Figure 4. Eggplant fruit fresh mass was dependent on living mulches species, sowing term and management [g].

Some authors [1,14,39] report that changes in soil structure are significantly affected by such cultivation technology elements as crop rotation, plant fertilisation or the effect of crop roots, especially those of legumes and grasses. This thesis was confirmed by the author's research, which proved the beneficial effect of living mulches on soil structure (Table 2). Both white clover and perennial ryegrass did considerably improve this property, which was most evident when the plants were sown at the earliest date. The greater soil structure index value (W) was recorded when the soil in inter-rows was covered by perennial ryegrass, sown before eggplant planting. This index was slightly higher than in the case of white clover sown at the same time. Any later sowing of living mulches (than that before eggplant planting) caused at worsening of that soil property. However, a decreased soil structure index value was statistically proved only at those places where perennial ryegrass was sown three weeks after eggplant planting (on average 21.2% lower), as well as in the site with introduced mechanical treatment of inter-rows (on average 25% lower). Similarly, Hernanz et al. [40] confirmed a highly beneficial effect of legumes on the structure of fallow land. These authors stated that legume species had a greater impact on the improvement of soil structure indices than other species [40].

Table 2. Index of cloddiness of the soil, index of soil structure and mean weighted diameter of aggregates (dry) depending on the type and sowing term of living mulch, mean for 2010–2012.

Type and Sowing Term of Living Mulch	B	W	MWDa
white clover I term	0.35	1.59	3.08
white clover II term	0.38	1.52	3.08
white clover III term	0.39	1.49	2.98
mean	**0.37**	**1.53 b**	**3.04**
perennial ryegrass I term	0.29	1.67	2.74
perennial ryegrass II term	0.32	1.60	3.13
perennial ryegrass III term	0.37	1.23	2.97
mean	**0.33**	**1.50 b**	**2.95**
mean for sowing term I term	0.32	1.63	2.91
II term	0.35	1.56	3.10
III term	0.38	1.36	2.98
Control without living mulch	0.50	1.17 a	2.77
LSDα = 0.05 for:			
type of living mulch	n.s.	n.s.	n.s.
sowing term of living mulch	n.s.	n.s,	n.s.
cultivation method	n.s.	*	n.s.

Sowing terms of living mulch: I term—3 weeks before eggplants planting; II term—in the term of eggplants planting; III term—3 weeks after eggplants planting. B—index of cloddiness of the soil; W—index of soil structure; MWDa—mean weighted diameter of aggregates (dry). Significance level: * 0.05, n.s. not significant. Means followed by similar letter within each column and columns that do not contain letters indicate no significance differences between treatments.

No statistically significant influence of living mulches was confirmed on the mean weighted diameter of soil aggregate (dry) (MWDa). It was noticed, however, that, in comparison to other sites, slightly larger aggregates occurred in soil covered with white clover and just slightly smaller ones were noted after mechanical treatment of inter-rows. Delayed sowing of living mulches resulted in the insignificant crushing of soil aggregates. Covering of fallow land with a mixture of legumes and grasses improved fallow land for supporting soil health and productivity [41].

The effect of the type of treatment of inter-rows on soil cloddiness was not statistically proved, yet it was recorded that mechanical treatment of inter-rows did contribute to an increase in the soil cloddiness index (B). In the examined tillage conditions, this was 47.1% higher than after destroying living mulches with a herbicide, on average by 51.5% than in the case of introducing perennial ryegrass, and 35.1% higher than in the case of white clover. It was noticed that delayed sowing of living mulches slightly increased soil cloddiness. Sowing living mulches (white clover and perennial ryegrass) in inter-rows reduced soil cloddiness. This fact is very important for the development of crops, as inner parts of large aggregates, especially clods > 10 mm, contain few plant roots. A positive effect of plant mulch on the soil cloddiness index was also shown by [42].

Living mulches, especially those sown at the earliest time point, had a highly beneficial, statistically confirmed influence on the water resistance of soil aggregates (Table 3). In comparison to other treatments, a significantly higher mean weighted diameter value for the aggregate, measured wet (MWDg) was obtained in site with perennial ryegrass and white clover sown three weeks before eggplant planting, as well as in the case of white clover sown at the time of eggplant planting. Sowing living mulches later led to a decrease in that index, on average by 10%, while in the control this index was on average 19.4% lower. The water stability index (ΔMWD) showed the greater value when living mulches were sown in the first two periods. Sowing which took place three weeks after eggplant planting and eggplant cultivation with the mulch did considerably contribute to at decrease in this parameter, on average by 8.8%. In cultivation without living mulches, the ΔMWD index value was by 24.9% lower. Similar research results were reported by [43,44] and macropores formed in the soil by plant roots have a positive effect on soil physical properties. After cultivation, deep tap rooted crops increase soil aeration, water infiltration and nutrients access deeper into soil.

Table 3. The effect of type and sowing term of living mulch on indicators describing wet soil structure status in eggplant cultivation, mean for 2010–2012.

Type and Sowing Term of Living Mulch	MWDg (mm)	ΔMWD	Wod
white clover I term	1.18	2.29	31.5
white clover II term	1.19	2.23	27.9
white clover III term	1.06	2.06	27.3
mean	**1.14 b**	**2.19 b**	**28.9 b**
perennial ryegrass I term	1.22	2.30	32.9
perennial ryegrass II term	1.09	2.29	30.7
perennial ryegrass III term	1.09	2.11	28.3
mean	**1.13 b**	**2.23 b**	**30.6 b**
mean for sowing term I term	1.20	2.30	32.2
II term	1.14	2.26	29.3
III term	1.07	2.08	27.8
Control without living mulch	0.96 a	1.71 a	26.8 a
LSDα = 0.05 for:			
type of living mulch	n.s.	n.s.	n.s.
sowing term of living mulch	n.s.	n.s.	n.s.
cultivation method	*	*	*

MWDg—mean weighted diameter of aggregates (-wet); ΔMWD—water stability index; Wod—index of waterproof. Significance level: * 0.05, n.s. not significant. Means followed by similar letter within each column and columns that do not contain letters indicate no significance differences between treatments.

Soil moisture was not significantly modified by living mulch species and the effect of the amount of biomass covering the soil surface was observed only in the 5–10 cm soil layer (Table 4). Each type of treatment of inter-rows without soil loosening, that is by covering them either with living mulch or mulch, caused better soil moistening. However, the improvement in soil moisture in that layer was statistically proved mainly for white clover cover. The time of sowing living mulches did not influence the above-mentioned soil property. Similarly, [11,17] showed at increase in soil moistening in cultivation with living mulches. Montague and Kjelgren [45] and Chalker-Scott [46] explained that living mulches competing for basic resources f.ex. moisture-influenced soil temperature.

Our research results proved that the waterproof index (Wod) in those sites where perennial ryegrass was applied as living mulch was significantly higher, 5.9%; so, to provide a comparison, the cultivation with white clover was determined. The greater waterproof index value was obtained for site where the two species were sown at the earliest time. Delaying the sowing of white clover by 3 and 6 weeks resulted in a decreased Wod value, on average by 12.4%, while in the case of perennial ryegrass this reduction was 6.7% and 14%, respectively. The same significance level of Wod ratio was recorded for locations with mulch and those mechanically treated. The beneficial effect of living mulches on the waterproof index, as proved by our research results, can be of considerable ecological importance, since, according to [12,41], low water resistance of soil aggregates shows soil susceptibility to water erosion. Refs. [14,47] proved the beneficial effect of a no-tillage system in the case of soil covered with plants on an increase in the water stability of soil aggregates.

Table 4. The effect of type and sowing term of living mulch on soil moisture, total and capillary porosity of soil in eggplant cultivation, mean for 2010–2012 (cm^3 100 cm^{-3}).

Type and Sowing Term of Living Mulch	Soil Moisture		Total Porosity		Capillary Porosity	
	Soil Layer (cm)					
	5–10	15–20	5–10	15–20	5–10	15–20
white clover I term	18.8	18.6	40.4	41.0	31.2	32.5
white clover II term	18.8	18.7	41.3	40.7	31.2	32.1
white clover III term	19.0	19.0	39.9	40.5	31.6	33.6
mean	**18.9**	**18.8**	**40.5 b**	**40.7**	**31.3 b**	**32.7 b**
perennial ryegrass I term	18.1	18.8	41.0	41.1	31.9	33.0
perennial ryegrass II term	18.5	18.7	40.0	40.0	31.2	32.4
perennial ryegrass III term	19.0	19.1	40.4	39.7	31.5	32.2
mean	**18.5**	**18.9**	**40.5 b**	**40.3**	**31.5 b**	**32.5 b**
mean for sowing term I term	18.5	18.7	40.7	41.1	31.5	32.8
II term	18.6	18.7	40.5	40.4	31.2	32.2
III term	19.0	19.0	40.1	40.1	31.5	32.9
Control without living mulch	17.7	19.1	38.9 a	39.1	29.3 a	30.2 a
LSDα = 0.05 for:						
type of living mulch	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
sowing term of living mulch	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
cultivation method	n.s.	n.s.	**	n.s.	**	**

Significance level: ** 0.01, n.s. not significant. Means followed by similar letter within each column and columns that do not contain letters indicate no significance differences between treatments.

These inconsistencies in findings can be partially explained by the research results obtained by White [48], who proved a considerable dependence of soil physical properties, including soil moisture and weather conditions, mainly the amount of rainfall, on waterproofing.

Living mulches and also biomass mulch had a positive effect on total and capillary soil porosity (Table 4). These properties, under the above-mentioned conditions of cultivation, were significantly higher than the values obtained in the case of mechanical tillage without living mulches. The greater total soil porosity value was observed in the plots with inter-rows of perennial ryegrass sown at the earliest time point and white clover sown in term I and II. That value was, on average, 4.1% higher in the 5–10 cm soil layer and 5.0% in a deeper layer, as compared to the control. The capillary porosity reached its greater value in the cultivation with white clover sown at the earliest point, and this was higher by 13.3% and 11.3%, respectively, as compared to the value obtained in the case of mechanical tillage. The capillary porosity in the 15–20 cm soil layer was, on average, 7.9% higher than the value obtained in the case of mechanical tillage. Gajda et al. [49] proved that soil porosity is a good indicator of soil physical quality. Janušauskaite et al. [50] pointed to an increase in total porosity in a no-tillage system, as compared to the conventional one. Borowy [51] stated that different methods of tillage, including the simplified one with living mulches, did not affect soil porosity.

Living mulches advantageously influenced soil loosening (Table 5). The lower bulk density value in the 5–10 cm layer was recorded for the places where living mulches were sown in the first two terms. Other tillage methods caused an increase in the parameter, on average by 3.5%. In the 15–20 cm soil layer, the positive effect of living mulches was observed at sites where white clover was sown three weeks before eggplant planting and where inter-rows were sown with perennial ryegrass. There bulk density was by 2.5% lower than in the remaining locations. However, Borowy [51] proved that living mulch did not affect the bulk density of soil. On the other hand, Janušauskaite et al. [50] stated that conventional tillage caused a higher bulk density than with no-tillage and moderate-tillage systems. It was possible to state that the influence of living mulches on arable soil properties depended on the choice of mulching plant species.

Table 5. The effect of type and sowing term of living mulch on bulk density and soil compaction in eggplant cultivation, mean for 2010–2012 (Mg m^{-3}).

Type and Sowing Term of Living Mulch	Bulk Density		Soil Compaction	
	Soil Layer (cm)			
	5–10	15–20	0–10	10–20
white clover I term	1.58	1.59	2.74	4.86
white clover II term	1.59	1.62	2.96	5.25
white clover III term	1.66	1.62	3.27	6.11
mean	**1.61 a**	**1.61 a**	**2.99 b**	**5.41 b**
perennial ryegrass I term	1.58	1.61	2.51	4.29
perennial ryegrass II term	1.61	1.60	2.50	5.01
perennial ryegrass III term	1.63	1.61	2.84	4.99
mean	**1.61 a**	**1.61 a**	**2.62 a**	**4.77 a**
mean for sowing term I term	1.58I	1.60	2.63	4.58 a
II term	1.60I	1.61	2.73	5.13 ab
III term	1.65II	1.62	3.05	5.55 b
Control without living mulch	1.64 b	1.66 b	3.09	5.31
LSDα = 0.05 for:				
type of living mulch	n.s.	n.s.	*	**
sowing term of living mulch	***	n.s.	n.s.	**
cultivation method	*	**	n.s.	n.s.

Significance level: * 0.05, ** 0.01, *** 0.001, n.s. not significant. Means followed by similar letter within each column and columns that do not contain letters indicate no significance differences between treatments.

4. Conclusions

Cultivation of white clover and perennial ryegrass in the eggplants inter-rows affected the yield of the cultivated species and had a positive effect on the soil structure index and soil aggregate water resistance index. Living mulches especially sown in first term decreased eggplant yield. This was due to the competitiveness of white clover and perennial ryegrass biomass produced in this term for growing space, water, nutrients and light. A slightly better improvement of soil physical properties was observed in the case of perennial ryegrass.

Repeated mechanical tillage between rows during eggplant growth resulted in the lower porosity value, increased soil compactness and decreased soil structure and water resistance indices for soil aggregates, thus leading to a deterioration of soil physical properties in comparison with the regeneration system using live mulches.

In the future, sustainable agriculture should pay particular attention to improving soil fertility and implementing regenerative practices. It would be reasonable to undertake research on the reduction of competition, between crops and living mulches. One of the methods is to select living mulches species for intercropping and at the same time to pay attention to morphological features of living mulches that favour soil regenerative practice.

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