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Usefulness of Living Mulch in Rows in a Dwarf Pear, *Pyrus communis* L., Orchard

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Abstract: The key problem in the cultivation of densely planted dwarf orchards is the removal of weeds—trees' competitors for habitat resources. There is an urgent need to look for ecological methods of weed control as an alternative to herbicides that are harmful to the environment. The use of living mulch (LM) in tree rows additionally improves soil quality but usually weakens tree growth and may reduce yield. The aim of this 11-year experiment was to assess the impact of the use of two different LMs in rows (*Trifolium repens*—*Tr* and *Agrostis capillaris*—*Ac*) on the growth, yield, and fruit quality of three pear cultivars on Quince S_1 rootstock compared to herbicide fallow. The presence of LM did not significantly affect tree growth. There was no significant effect of either mulch on the cumulative yield. However, for the first 4–6 years, the yield was clearly lower than in the control, which changed in the later years of the experiment. When LMs were used, pear trees showed a significantly lower tendency to alternate fruiting. The average fruit weight was significantly lower in *Tr*, but the other parameters of external fruit quality did not differ significantly. Furthermore, a smaller share of ultra-small fruit was found with LM compared to the control. The LM did not significantly affect such parameters as the content of soluble solids, vitamin C, Ca, Mg, and P. The use of *Ac* in dwarf pear orchards with sowing in tree rows is recommended in the 2nd or 3rd year after planting at the earliest.

Keywords: orchard floor management; cover crop; Quince rootstock; growth; yield; fruit quality; nutrient concentration; 'Winter Forelle'; 'Harrow Sweet'; 'Dolores'

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1. Introduction

Today, the concept of sustainable development is a recognised idea for thinking about the future and is found in many documents and declarations of politicians. One of its necessary conditions is ensuring a non-toxic environment, which in agricultural practice means a reduction in the use of chemicals, including herbicides [1]. Orchard floor management is a pre-harvest factor that can influence on growth and fruit quality, including biologically active compounds, e.g., phenolic groups [2,3]. Among the alternatives to herbicide use are ecological methods of weed control, including living mulch (LM), which have been studied quite intensively in recent decades [4–6]. The concept of LMs in orchards is the introduction of additional herbaceous perennial species into the tree rows, which accompany them throughout the growing season and protect the soil surface against nutrient leaching and spontaneous colonisation by weeds [2]. LMs seem to be effective in controlling weed growth, although they do not completely stop them [7–10]. The advantages of this method, emphasised by some authors, include the natural supplementation of the soil with nutrients due to the decomposition of cover plant tissues [11,12] and the improvement in the soil structure by cover plant roots, which creates a favourable environment for soil microorganisms [13]. Meta-analysis of data from Chinese orchards [14] showed that grass cover increased the microbial biomass carbon as well as abundances of bacteria, fungi, and actinobacteria by 47–78.7%, compared with orchards without grass cover. Increased activities of extracellular hydrolitic enzymes that decompose organic compounds (invertase, urease, and cellulase) were also documented. Thus, living mulches help maintain the biological balance in the soil. They promote the development of fungi that enzymatically break down cellulose and hemicellulose into forms that can be absorbed by plants [15].

Disadvantages include competition for water and nutrients with tree roots, which usually affect tree growth and, in some cases, reduce the yield [4,11,16,17]. In the presence of LMs, an increase in the population of rodents that damages the trunks and roots of fruit trees has been observed in some orchards [18]. For these reasons, mixes of different species are still being tested to identify those that are the least competitive for trees [5] and unattractive for rodents [18,19].

Herbicides in orchard rows can also be replaced with other types of mulch, either organic or synthetic. Numerous studies have demonstrated that they do not compete with cultivated trees for water and nutrients, but they have other disadvantages limiting their usefulness or widespread use in large-scale orchards [16,20–27]. Thus, the search for the best alternative to herbicide use is an extremely topical issue—especially now, when the withdrawal of Glyphosate use, the most common active ingredient of herbicides, seems to be sure in the near future [28].

The problem of removing weeds, i.e., competitors for habitat resources, is particularly important in intensive orchards, which, thanks to the use of dwarf rootstocks, are characterised by a high density of trees per area unit. In such orchards, trees usually bear fruit early, abundantly, and every year [29,30]. However, due to a rather weak root system, they require soil rich in nutrients and water [31]. It is therefore reasonable to determine whether the use of LMs sown directly under the trees in dwarf orchards can be an acceptable alternative to herbicide fallow. Will the supposed deeper weakening of the growth of trees on the dwarf rootstock caused by the presence of competing cover plants significantly deteriorate the yield and quality of the harvested fruit? In the literature, this problem is still quite poorly recognised, and the results of the research conducted thus far do not provide a clear answer [16,32–34]. Another issue that still needs to be investigated is determining the optimal time to sow LM in tree rows. According to some researchers [5,11,17,35], each year of delay can reduce their competition.

After apple, pear is the second most important fruit in temperate zones [30], and its production in Central Europe has recently increased as a result of climatic changes and a lack of frozen winters. One can expect a further increase in the pear orchards' area in that zone. The most popular pear cultivar in Europe is 'Conference' [36]. European countries usually use different clones of Quince rootstocks to establish high-density commercial orchards [37]. Therefore, the problem of ecological orchard floor management in a dwarf pear orchard and the potential impact of the methods used on fruit quality are current issues. The quality of fruit is key to commercial success nowadays [38]. Dense planting of spindle trees suppresses their vegetative growth and enables high yields, but simultaneously, it tends to impair their quality in terms of fruit average mass, size, and colouration [39]. A wire support combined with a multiple-leader system enables even stronger canopy shape modification. The most popular V-shaped canopy systems, recommended as an alternative for orchards with high tree densities, are the Güttingen-V system and the Y system (Tatura) [40–42].

The main goal of the experiment presented was to evaluate the long-term effects (11 years) of the use of two LMs in rows on the yield, tree growth, fruit quality, and mineral status of three pear cultivars on a Polish dwarf rootstock Quince S_1 in comparison with herbicide fallow. This study is an attempt to solve the question defined above about whether this non-chemical method of orchard floor management can be an alternative to the most commonly used herbicide fallow in intensive orchards with dwarf trees. This study also increases our present knowledge of the Quince rootstock/pear cultivar relationship, which is estimated as still insufficient [30]. It should be emphasised that the research covers three lesser-known pear cultivars with different harvest ripeness times. One of them, 'Harrow Sweet', shows genetic resistance to fire blight—the most dangerous disease of this species [43,44].

2. Materials and Methods

This experiment was conducted from 2006 to 2016 at the Fruit Experimental Station located in Samotwór near Wrocław (51°06′12″ N; 16°49′52″ E) in SW Poland. That area is located in a mid-latitude, temperate, transitional (maritime–continental) climate zone characterised by a high frequency of polar air masses and a dominating western flow. The mean annual temperature is about 9 °C, and the average sum of precipitation is slightly less than 600 mm. The rainfall regime is dominated by continental features, with maxima occurring in July [45]. The orchard was located on the haplic luvisol derived from silty light loam and represented the 3rd class of the Polish economic soil classification.

This research was carried out on one-year-old trees of three pear cultivars (cvs) of *Pyrus communis* L. budded on dwarf rootstock Quince S_1: 'Dolores' and 'Harrow Sweet'—autumn cvs of Polish and Canadian origin, respectively [43,46], and 'Winter Forelle'—winter cv of German origin [47].

The trees were planted in one-row system with a spacing of 3.5 × 1.2 m (2381 trees ha^{-1}) and formed as a spindle crown. Before planting the trees at the end of March 2006, in October 2005, the field was thoroughly weeded of persistent weeds (3.7 L/ha Glyphosate + 2 L/ha MCPA) and fertilised with phosphorus and potassium at a dose of 120 kg K_2O and P_2O_5. Deep ploughing was performed only once before the winter in November 2005.

The planting pattern followed a randomised split-plot design with 4 replications and 3 trees per plot. The trees were pruned annually soon after flowering, starting in the fourth year after orchard establishment. No irrigation was applied, and the fruitlets were not thinned. The orchard floor management system consisted of herbicide fallow (3.7 L/ha Glyphosate + 2 L/ha MCPA) in the tree rows (control) and sward in the alleyways, both introduced in the year of tree planting. LMs of white clover *Trifolium repens* L. (*Tr*) and common bent *Agrostis capillaris* L. (*Ac*) were sown in tree rows at the end of June 2007. They were not mowed throughout the time of the experiment. Chemical protection was carried out according to the up-to-date recommendations of the Orchard Protection Programme for commercial orchards. An annual dose of 50 kg N ha^{-1} in the form of ammonium nitrate was applied, starting from the 3rd year following orchard establishment. The soil was limed in 2011 with 750 kg CaO ha^{-1}, and fertilisation with potassium salt equivalent to 80 kg K_2O ha^{-1} was performed in the early spring of 2009 and 2013. No additional fertilisation was applied to trees in rows with LM.

In the 11 years of evaluation, tree growth and fruit yield per tree, as well as mean fruit weight, size, and skin colouration, were assessed annually. Each year in mid-October, the extent of vegetative growth was assessed by measuring trunk circumference 30 cm above bud union and calculating the cross-sectional area of the tree trunk (TCSA) values, as well as their two-year increments. In autumn 2016, tree height and canopy width in two directions were recorded. The volume of the canopy was calculated using the formula for cone volume. The last set of TCSA (a), together with the 2007–2016 fruit yield sums (b), were used to calculate the crop efficiency index (CEI), which was obtained at the end of the study, CEI = b:a. For data collection, each cultivar was harvested following a single-picking schedule, and the fruit from each tree was collected in separate boxes. To determine external crop quality, a sample of 20 fruits per tree was collected, and from each experimental treatment, 3 boxes of pears were randomly selected for grading. This was followed by weighting the fruit, and in 2012–2016, the fruit diameter and skin colouration were recorded. Annual harvests were used to calculate alternate bearing indexes. The yield variability of fruit trees was assessed using the L index according to Szczepański [48].

In 2016, 4–5 pieces of fruit were randomly collected from each replication for chemical analysis of the biological value of the fruit. In juice of fresh fruit, immediately after harvest, the soluble solid content was determined using an Abbe refractometer, and the vitamin C content was determined using the titration method [49]. The concentrations of some macronutrients were determined in dry mass using the P-colourimetric method with ammonium molybdate, Mg-titanium yellow (universal method developed by Nowosielski), K, and the Ca-flame photometric method. The detailed courses of all analyses were previously described by Komosa [50]. The units used to present the values of these parameters are given in tables with appropriate data.

The leaf samples were collected in the second half of July 2016 for analysis of macronutrients and total chlorophyll in three replications. A sample of 100 leaves from the middle part of the long shoots (3–4 leaves each) was collected from all trees in one replication. The total chlorophyll content in the fresh leaf extract was determined via spectrophotometry. The leaves were then dried at 60 °C and ground and mineralised using the microwave method. The concentrations of macronutrients in the leaves were determined with the use of the same methods as in the fruit.

In this study, the published results were based on data obtained during 11 years of research. The collected experimental data were subjected to statistical analysis based on the analysis of variance (ANOVA) approach, involving a model appropriate for the split-plot design. Significant differences at the $\alpha \leq 0.05$ level were obtained using Duncan's multiple range test and Statgraphics software 18. In the case of percentage data pertaining to fruit quality, an angular transformation according to the Bliss function was applied prior to the ANOVA.

3. Results and Discussion

3.1. Vegetative Growth Parameters

After 11 years of evaluation, the TCSA was smaller in *Tr* compared to the control, while it was higher in *Ac* (Table 1). Differences in the values of this parameter between mulches were statistically significant, but in relation to the control, they were not significant. Therefore, it can be assumed that the use of mulches in a dwarf orchard on Quince S_1 rootstock did not significantly reduce tree growth as measured by this parameter. Just after the first two years of this experiment, researchers [32] reported no significant effect of LMs on the vegetative growth of pear trees of the cvs 'Harrow Sweet' and 'Winter Forelle'. However, in an 11-year-old pear orchard on a Caucasian pear rootstock, there was a significant increase in the TCSA of trees growing in *Tr* [51]. A differential effect of LMs on the growth of apple tree trunks, depending on the botanical composition of the mulches, was observed [2]. The presence of grass mulch (*Secale cereale* L. cv Wheeler) had a comparable effect to the control (bare ground), while in the mulch of *Tr*, the increments were significantly greater.

The cultivars examined differed in this parameter (Table 1). The 'Dolores' pear tree had the thickest trunks, and 'Harrow Sweet' had the thinnest trunks. The latter cv differed significantly from the others in terms of trunk thickness, while the differences between 'Dolores' and 'Winter Forelle' were not significant.

In both mulches, the two-year increase in trunk thickness was smaller than in the control, but only in trees growing in *Tr* was there a significant difference. Therefore, this mulch showed a limiting effect on tree growth in the last two years of the study. The same result was obtained when the same LMs were tested in a pear orchard on a Caucasian pear rootstock [51]. Therefore, the presence of white clover mulch sown in rows in the second year after planting may have a limiting effect on the growth of fruit trees, even in older orchards. Different conclusions have been presented by Baluszynska et al. [6]. In their opinion, the presence of grass mulch significantly weakened the growth of young apple trees, while in an older orchard, this trend was no longer significant. According to some authors [11,35], grassy LMs limit the growth of apple trees continuously, regardless of the age of the orchard.

Table 1. Vegetative growth of three pear cultivars on Quince S_1 depending on in-row living mulch.

Treatment		Trunk Cross-Sectional Area (cm^2) Autumn 2007	Autumn 2016	Increase 2014–2016	Canopy Volume (m^3) Autumn 2016	Alternate Bearing Index (0–1)
'Dolores'	*Trifolium repens*	5.2 [a]	33.5 [a]	4.0 [a]	2.2 [a]	0.33 [a]
	Agrostis capillaris	5.6 [a]	35.3 [a]	4.5 [a]	2.6 [a]	0.42 [a]
	herbicide fallow	4.6 [a]	38.0 [a]	4.4 [a]	2.0 [a]	0.49 [a]
'Harrow Sweet'	*Trifolium repens*	3.2 [a]	14.2 [a]	2.1 [a]	1.3 [a]	0.14 [a]
	Agrostis capillaris	4.3 [a]	19.0 [a]	2.4 [a]	1.5 [a]	0.16 [a]
	herbicide fallow	3.4 [a]	13.3 [a]	2.4 [a]	0.8 [a]	0.31 [a]
'Winter Forelle'	*Trifolium repens*	4.6 [a]	25.7 [a]	3.7 [a]	1.7 [a]	0.17 [a]
	Agrostis capillaris	5.9 [a]	37.6 [a]	6.2 [a]	2.6 [a]	0.20 [a]
	herbicide fallow	4.8 [a]	33.7 [a]	7.9 [a]	2.1 [a]	0.28 [a]
Mean for orchard floor management (A)						
Trifolium repens		4.3 [a]	24.4 [a]	3.2 [a]	1.7 [ab]	0.21 [a]
Agrostis capillaris		5.3 [b]	30.6 [b]	4.4 [ab]	2.2 [b]	0.26 [a]
herbicide fallow—control		4.3 [a]	28.3 [ab]	4.9 [b]	1.6 [a]	0.36 [b]
Mean for cultivar (B)						
'Dolores'		5.1 [b]	35.6 [b]	4.3 [b]	2.3 [b]	0.41 [b]
'Harrow Sweet'		3.6 [a]	15.5 [a]	2.3 [a]	1.2 [a]	0.20 [a]
'Winter Forelle'		5.1 [b]	32.3 [b]	5.9 [b]	2.1 [b]	0.22 [a]

[a,b] Means marked by the same letter within the column for orchard floor management (A), cultivar (B), or their interaction (A × B) do not significantly differ at $p \leq 0.05$ according to Duncan's multiple *t*-test.

The trunks of the 'Winter Forelle' pear tree increased most intensively, while other cvs showed smaller growth. Significantly, the lowest values of this growth parameter were found for the 'Harrow Sweet' variety.

In the rows with *Ac*, the volume of pear tree crowns was larger than in the other variants, and in relation to the control, this difference was statistically significant (Table 1). The trees of the tested pear cultivars differed in size. Significantly smaller crowns were found in the 'Harrow Sweet' cv, which was characterised by the weakest growth. For all measured vegetative growth parameters, no differences were found in the interaction between the tested cultivars and the method of orchard floor management. A different effect of the presence of grass mulch on the volume of tree crowns was noted by Sosna and Fudali [51] in a pear orchard with the 'Alfa' cv on a Caucasian pear rootstock. The authors found a reduction in crown volume in tree rows growing in that LM, which was also observed by Tahir et al. [17] in an apple orchard.

In the studies published thus far, the question of whether the presence of LMs affects the alternate fruiting index in pear orchards was not analysed, although that information is important for producers. The presented research showed that the use of LMs in tree rows had a significant impact on this index (Table 1); in both variants, it was significantly lower than in the control. Therefore, it can be assumed that when LMs are used, pear trees on dwarf Quince S_1 rootstock show a significantly lower tendency to alternate fruiting, which, in practice, means a more even yield every year. This is a great advantage of these mulches, which were documented for the first time in the present research. The two tested cultivars, 'Harrow Sweet' and 'Winter Forelle', were characterised by a relatively low value for this indicator. In turn, the 'Dolores' pear tree showed a significantly greater tendency to yield crops every other year.

3.2. Quantity and Quality of Yield and Crop Efficiency Index

The use of LMs in tree rows did not have a significant impact on their yield, although individual variants of orchard floor management differed in this respect (Table 2). Pear trees growing in *Ac* had the best yields, while those growing in *Tr* had the lowest yields.

This is different than in an 11-year-old pear orchard established on a Caucasian pear rootstock, in which the presence of the same LMs resulted in a significant decrease in the cumulative yield, at the level of 20–22%, depending on the variety [51]. However, with a different composition of LMs (multi-species mixtures of grasses and legumes), the reduction in the yield of 'Williams' pear on the Quince MA rootstock in a 4-year experiment was statistically insignificant compared to the herbicide fallow [5]. Similar varied tree responses to the presence of LMs were recorded in apple orchards. A decrease in yield has been repeatedly confirmed, especially in grassy mulches [2,6,11,14,16]. However, ref. [7] found no significant effect on the yield of mulch consisting of various legume species.

Table 2. Quantity and quality of yield and crop efficiency index (CEI) of three pear cultivars on Quince S_1 depending on in-row living mulch (year of tree planting—spring 2006).

Treatment		Cumulative Yield (kg·Tree^{-1}) 2007–2016	Fruit Quality			CEI (kg·cm^{-2}) 2006–2016
			Mean Fruit Mass (g) 2007–2016	% of Fruit with Diameter >7 cm	% of Fruit with Blush over ½	
'Dolores'	*Trifolium repens*	52.4 ^{a}	197 ^{a}	23.1 ^{b}	3.7 ^{a}	1.56 ^{a}
	Agrostis capillaris	50.0 ^{a}	191 ^{a}	26.3 ^{b}	3.6 ^{a}	1.42 ^{a}
	herbicide fallow	39.6 ^{a}	196 ^{a}	6.9 ^{a}	26.0 ^{b}	1.04 ^{a}
'Harrow Sweet'	*Trifolium repens*	36.0 ^{a}	139 ^{a}	13.9 ^{a}	10.6 ^{a}	2.54 ^{a}
	Agrostis capillaris	51.7 ^{a}	153 ^{b}	20.7 ^{a}	10.1 ^{a}	2.72 ^{a}
	herbicide fallow	38.0 ^{a}	144 ^{a}	9.4 ^{a}	12.8 ^{a}	2.86 ^{a}
'Winter Forelle'	*Trifolium repens*	40.7 ^{a}	206 ^{a}	73.0 ^{a}	59.8 ^{a}	1.58 ^{a}
	Agrostis capillaris	57.6 ^{a}	218 ^{b}	80.6 ^{a}	56.8 ^{a}	1.53 ^{a}
	herbicide fallow	54.8 ^{a}	229 ^{c}	76.4 ^{a}	48.2 ^{a}	1.63 ^{a}
Mean for orchard floor management (A)						
Trifolium repens		43.0 ^{a}	181 ^{a}	36.7 ^{a}	24.7 ^{a}	1.89 ^{a}
Agrostis capillaris		53.1 ^{a}	187 ^{b}	42.5 ^{a}	23.5 ^{a}	1.89 ^{a}
herbicide fallow—control		44.1 ^{a}	190 ^{b}	30.9 ^{a}	29.0 ^{a}	1.84 ^{a}
Mean for cultivar (B)						
'Dolores'		47.3 ^{a}	195 ^{b}	18.8 ^{a}	11.1 ^{a}	1.34 ^{a}
'Harrow Sweet'		41.9 ^{a}	145 ^{a}	14.7 ^{a}	11.2 ^{a}	2.71 ^{b}
'Winter Forelle'		51.0 ^{a}	218 ^{c}	76.7 ^{b}	54.9 ^{b}	1.58 ^{a}

$^{a–c}$ Means marked by the same letter within the columns for orchard floor management (A), cultivar (B), or their interaction (A × B) do not significantly differ at $p \leq 0.05$ according to Duncan's multiple *t*-test.

In the first 4 years of the presented experiment, the yield obtained from trees growing in LMs was up to two times lower than that of the control, regardless of the variety or type of mulch (Figure 1a–c). This trend was reversed in the 5-year-old orchard in the case of the 'Dolores' cv growing in *Tr* and lasted for the next 5 years, while in the grass mulch, a higher yield in this cultivar appeared a year later and persisted for another 4 years. In the 'Harrow Sweet' cv, only in the 6th year of the orchard's operation did the presence of *Ac* mulch result in a higher yield, and this tendency continued until the end of the experiment. In the *Tr* variant, higher yields than the control (but lower than in the grass) appeared in a 7-year-old orchard of this cultivar, and this tendency turned out to be continuous. For the 'Winter Forelle' cv, only in the 7th year of the orchard's operation were higher yields recorded in the variant with *Ac* mulch, and this tendency continued until the end of the experiment.

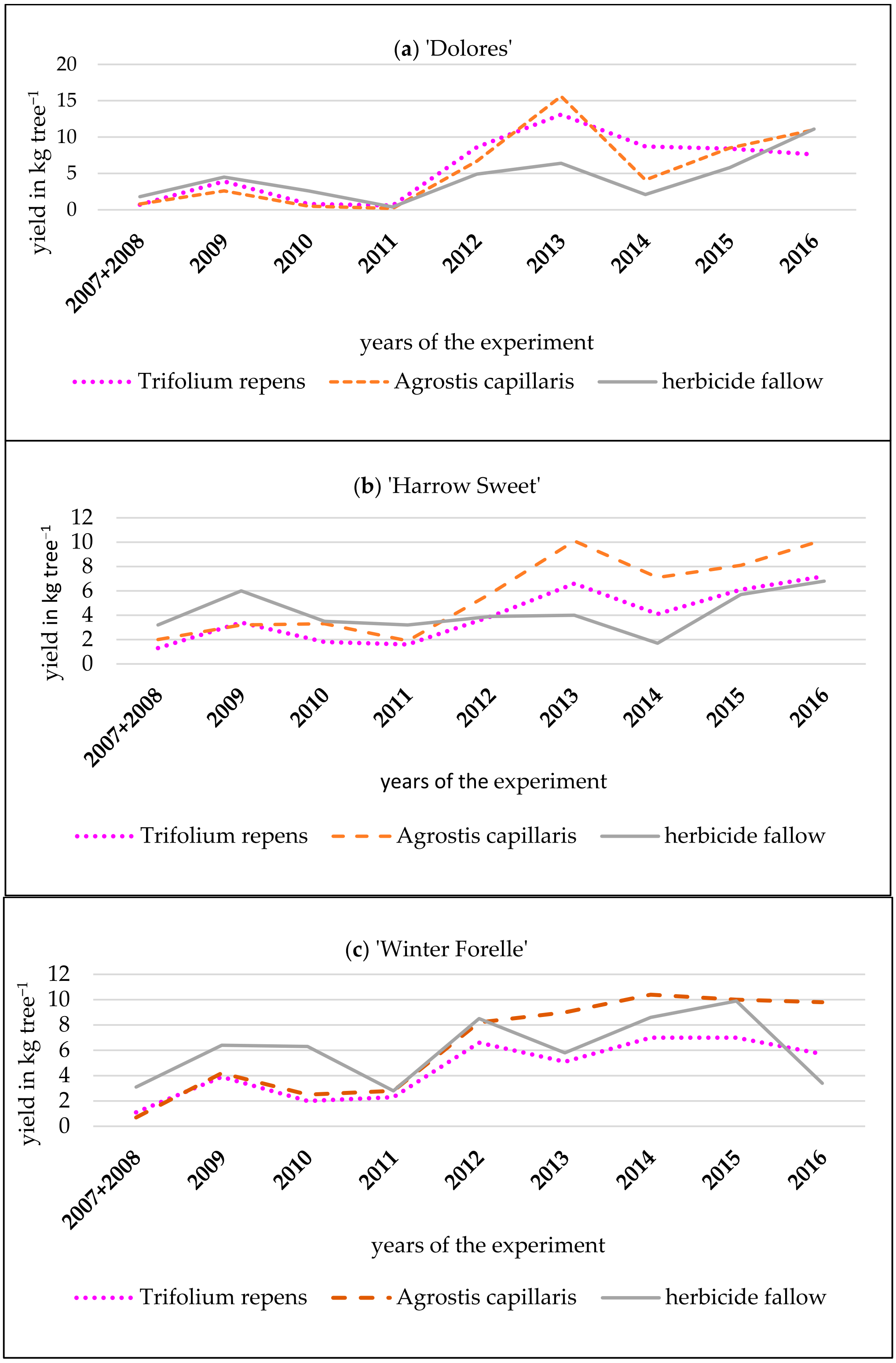

Figure 1. Yield of three pear cultivars (kg per tree) depending on orchard floor management in tree rows.

The best-yielding cultivar was 'Winter Forelle', while the least fruit was collected from the smallest trees of the 'Harrow Sweet' cv. However, these differences were not statistically significant. The observed differences in the impact of the presence of LMs on yield, depending on the age of the orchard, are consistent with the observations of other authors. Baluszynska et al. [6] found that the decline in the yield of apple tree cv 'Sampion' growing in grass mulch was significant only in young orchards. In their opinion, when the trees reach full fruiting, the influence of orchard floor management on fruiting is much smaller. According to Żelazny and Licznar-Małańczuk [11], the reduction in apple yield in the presence of LMs is continuous and applies to both young and older orchards. Research by Slatnar et al. [3] has shown that the decrease in yield (which persisted throughout the 7 years of the experiment) depends on the age of the apple orchard to which LMs are introduced. The highest was recorded in the earliest variant of sowing mulch, i.e., in the second year after planting the trees. However, postponing LM sowing until the 4th and 5th year after the orchard planting limited yield loss to only 5–20%.

The introduction of *Tr* mulch into the tree rows resulted in a significant reduction in the average fruit weight compared to the other tested orchard floor management variants (Table 2). In the presence of *Ac* mulch, the average fruit weight was lower than in the control, but in this case, the difference was not significant. For comparison, in an 11-year-old pear orchard established on a Caucasian pear rootstock, the presence of the same LMs did not result in a significant reduction in fruit weight [51]. Research [25] has shown that in an apple orchard of cv 'Gold Chief', the fruit weight from trees growing in the 5-year-old mulch of *Miscanthus* spp. was 5.6% higher than in other variants of orchard floor management, including herbicide fallow.

In both LM variants tested, a higher percentage of large fruit (over 7 cm in diameter) was recorded, but in relation to the control, these differences were not statistically significant (Figure 2). In the presence of mulch, the percentage of the smallest fruit (less than 6 cm in diameter) was significantly lower than in the herbicide-treated fallow in the case of two varieties—'Dolores' and 'Winter Forelle'. Similar results were reported by Baluszynska et al. [6] for apple cv 'Sampion' growing in *Festuca ovina* mulch. Stern and Doron [38] pointed out that the size of pear fruit was a critical market factor, as consumers prefer large fruit. Therefore, the lower share of ultra-fine fruit found in the LMs compared to the control should be considered an advantage of this method of orchard floor management.

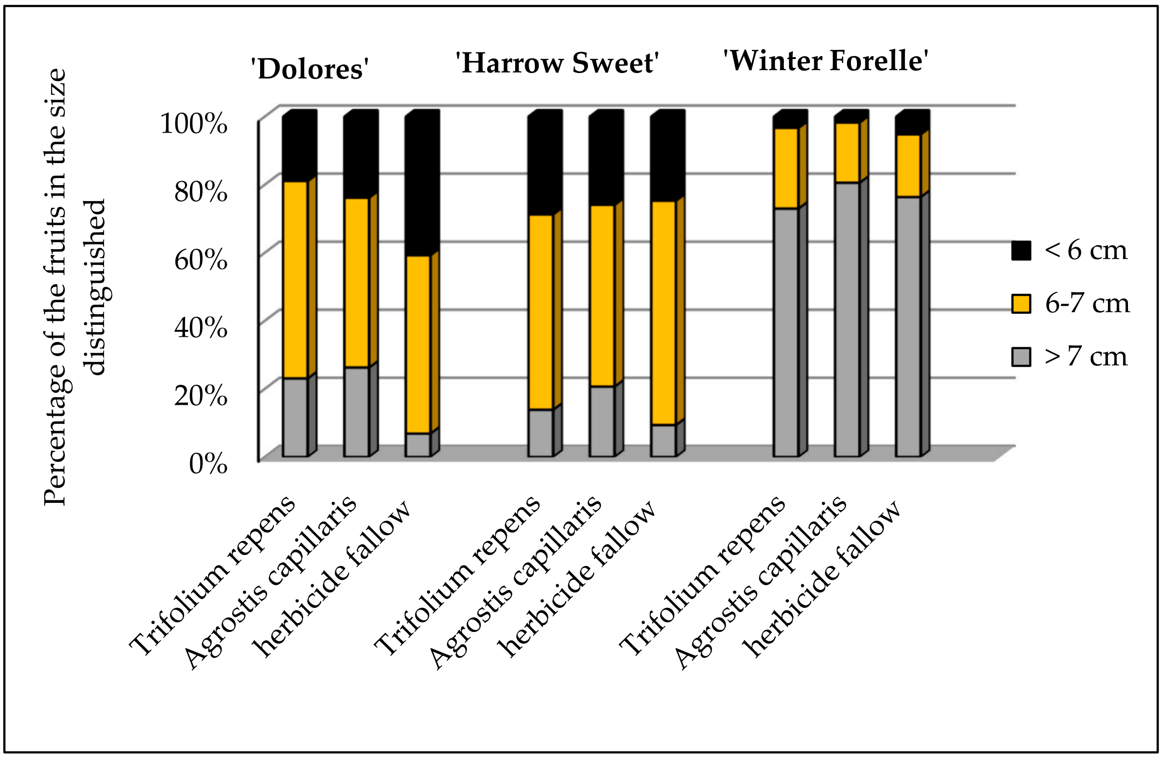

Figure 2. Influence of orchard floor management on the fruit size of three pear cultivars (mean for 2012–2016).

In general, the presence of mulch resulted in weaker fruit colouration (Table 2). However, this regularity was significant only in the case of cv 'Dolores' (Table 2; Figure 3).

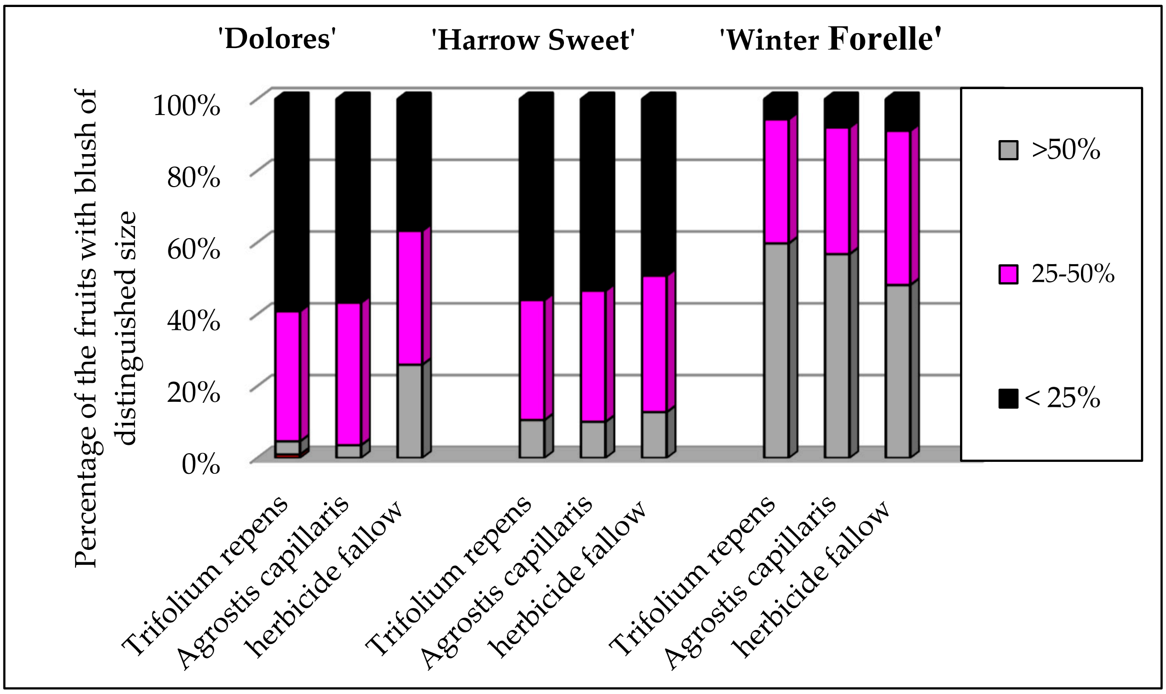

Figure 3. Influence of orchard floor management on the fruit colouring of three pear cultivars (mean for 2012–2016).

The tested pear cvs differed significantly in terms of average fruit weight (Table 2). The lightest came from 'Harrow Sweet' trees and the heaviest from 'Winter Forelle' trees. The latter variety was distinguished by a significantly higher percentage of large fruit and those with a blush covering more than 50% of the fruit skin surface. Previous reports on the impact of LMs in tree rows on the external quality parameters of fruit differ. In an 11-year-old pear orchard established on a Caucasian pear rootstock, the presence of *Ac* mulch resulted in a significant increase in the percentage of large fruit in two tested cvs—'Amfora' and 'Dolores' [51]. Additionally, in apple orchards growing in *Festuca ovina* mulch, an increase in the share of very large fruit, by up to 40% in one year, has been observed [35]. However, in the cultivation of apple trees growing in legume mulch (*Phacelia tanacetifolia* and *Ornithopus sativus*), an increased share of small fruit has been found [32]. Several authors have reported a significant increase in the number of well-coloured fruit in apple trees in various mulches [17,32,35]. In [6], a relationship between the availability of nitrogen for trees and the colour of the fruit skin is indicated. In these authors' opinions, grass mulches absorb excess nitrogen in the soil, which interferes with the synthesis of anthocyanins responsible for the blush on the fruit.

LMs in rows had no significant effect on the calculated CEI (Table 2). However, the tested cvs showed significant differences in this parameter; its highest value was found for the slowest-growing tree, 'Harrow Sweet'. In the first years of fruiting, a lower CEI was observed for pear trees of the 'Harrow Sweet' and 'Winter Forelle' cvs on a Quince S_1 growing in mulches *Ac* and *Tr*, compared to herbicide fallow, which was related to the inhibition of their growth [32]. This is not surprising, as Quince is a dwarf rootstock with a weak root system; thus, LMs sown in rows are effective competitors for water and nutrients for tree roots. In the older apple orchard, the long-term presence of LMs had no significant effect on this factor [3].

3.3. Content of Chlorophyll and Macronutrients in Leaves

Compared to the herbicide fallow, the presence of *Tr* mulch significantly reduced the chlorophyll concentration in the leaves (Table 3). Leaves of trees growing in *Ac* mulch also showed a lower content of this pigment, but this difference was not statistically significant.

Table 3. Content of chlorophyll and macronutrients in the leaves of three pear cultivars on Quince S_1 depending on in-row living mulch (2016).

Treatment		Total Chlorophyll (mg·100 g^{-1} f.m.)	Macronutrients (g·kg^{-1} d.m.)			
			K	Ca	Mg	P
'Dolores'	*Trifolium repens*	121.2 ^{a}	7.71 ^{a}	7.38 ^{a}	2.00 ^{a}	0.90 ^{a}
	Agrostis capillaris	143.1 ^{a}	10.04 ^{a}	9.32 ^{a}	2.07 ^{a}	0.74 ^{a}
	herbicide fallow	113.4 ^{a}	9.08 ^{a}	8.25 ^{a}	2.70 ^{b}	0.87 ^{a}
'Harrow Sweet'	*Trifolium repens*	115.5 ^{a}	9.33 ^{a}	5.63 ^{a}	1.85 ^{a}	0.76 ^{a}
	Agrostis capillaris	142.9 ^{ab}	9.75 ^{a}	7.46 ^{a}	2.05 ^{a}	0.65 ^{a}
	herbicide fallow	183.3 ^{b}	13.83 ^{b}	6.25 ^{a}	1.98 ^{a}	1.07 ^{a}
'Winter Forelle'	*Trifolium repens*	103.9 ^{a}	10.38 ^{a}	6.42 ^{a}	1.87 ^{a}	0.75 ^{a}
	Agrostis capillaris	114.6 ^{a}	11.92 ^{ab}	7.83 ^{a}	2.00 ^{a}	0.95 ^{a}
	herbicide fallow	136.7 ^{a}	14.67 ^{b}	5.83 ^{a}	1.87 ^{a}	0.81 ^{a}
Mean for orchard floor management (A)						
Trifolium repens		113.5 ^{a}	9.14 ^{a}	6.48 ^{a}	1.91 ^{a}	0.81 ^{a}
Agrostis capillaris		133.5 ^{ab}	10.57 ^{a}	8.21 ^{b}	2.04 ^{a}	0.78 ^{a}
herbicide fallow—control		144.5 ^{b}	12.53 ^{b}	6.78 ^{a}	2.18 ^{a}	0.92 ^{a}
Mean for cultivar (B)						
'Dolores'		125.9 ^{a}	8.95 ^{a}	8.32 ^{b}	2.26 ^{a}	0.84 ^{a}
'Harrow Sweet'		147.2 ^{a}	10.97 ^{b}	6.45 ^{a}	1.96 ^{a}	0.83 ^{a}
'Winter Forelle'		118.4 ^{a}	12.32 ^{b}	6.69 ^{a}	1.91 ^{a}	0.84 ^{a}

^{a,b} Means marked by the same letter within the columns for orchard floor management (A), cultivar (B), or their interaction (A × B) do not significantly differ at $p \leq 0.05$ according to Duncan's multiple *t*-test.

The pear cvs tested were characterised by a similar content of total chlorophyll. The obtained results are consistent with other studies in which grassy mulches caused a decrease in the chlorophyll content in apple leaves compared to herbicide fallow [11,16].

Both mulch variants showed significantly lower K concentrations in the leaves of the tested pear cvs than in the control. The examined pear cvs also differed insignificantly in this parameter (Table 3). The lowest amount of this macronutrient was found in the leaves of trees growing in rows with *Tr*. Significantly less K was recorded in the leaves of the 'Harrow Sweet' and 'Winter Forelle' cvs compared to the control. Among the cultivars tested, 'Dolores' pear leaves contained the least K. Regarding the Ca content in the leaves, a significantly higher content of this macronutrient was found in the leaves of trees growing in *Ac* mulch. In the remaining orchard floor-management variants, the values of this parameter were very similar. The Ca content in the leaves of 'Winter Forelle' and 'Harrow Sweet' was very similar but significantly lower than that of the 'Dolores' cv. Compared to herbicide fallow, trees growing in rows covered with LMs were characterised by similar Mg and P content in the leaves. The pear cvs tested also did not differ significantly in the concentration of these elements. In summary, compared to the control, the significant impact of the presence of LMs on the mineral composition of leaves mainly concerned reduced K availability. In a 3-year-old pear orchard with cv 'Winter Forelle' on the Quince S_1 rootstock, the presence of LMs had no significant effect on the macronutrient content in the leaves, and the concentrations of Mg and K were assessed as high compared to the values described for pear leaves [33]. However, in a 10-year-old dwarf apple orchard, similar to the research presented, a significant decrease in K was found in the leaves of trees growing in *Lolium perenne* L. and *Poa pratensis* L. mulches compared to the herbicide control [16]. Another experiment showed no significant effect of the presence of *Coronilla varia* L. mulch on the content of K, P, Ca and Mg in apple leaves [52].

3.4. Biological Value of Fruit

The presence of mulches did not significantly affect the extract (soluble solids) content in fruit compared to herbicide fallow (Table 4), although the values obtained were slightly higher than in the control, which indicates that fruit from trees growing in LMs may be slightly sweeter. In relation to the control, the LMs used in the tree rows did not have a significant effect on the vitamin C content, although slight differences in this parameter were noted between the tested mulches. More of this vitamin was found in fruit from trees growing in *Tr*. Therefore, it seems that *Tr* mulch may increase the fruit's consumption value in terms of the content of soluble solids and vitamin C. A significantly positive effect of this mulch on the soluble solids content in fruit was demonstrated in pear orchards established on a strongly growing Caucasian pear rootstock [51]. The obtained results are consistent with the conclusions of Slatnar et al. [3], who showed no significant effect of grassy mulch (with the use of *Festuca ovina* L.) on the soluble sugar content in apples compared to herbicide fallow. However, these results differ slightly from those reported by Muscas et al. [53], who showed that mulch consisting of several grass species increased the extract content in vine berries, while the mixture of legumes had no significant impact on this parameter. As the cited studies show, the proper selection of cover crops can improve fruit taste. In this context, the introduction of white clover mulch may be beneficial due to the increased content of soluble solids and vitamin C in pear fruit. However, maintaining this mulch in a monoculture is difficult because, after a few years, it becomes heavily infested with weeds [13].

Table 4. Biological value of the fruit of three pear cultivars depending on in-row living mulch (2016).

Treatment		Soluble Solids (Brix)	Vitamin C (mg·100 g^{-1} f.m.)	Macronutrients (g·kg^{-1} d.m.)			
				K	Ca	Mg	P
'Dolores'	*Trifolium repens*	16.37 ^{a}	16.37 ^{a}	5.42 ^{a}	1.52 ^{b}	0.35 ^{a}	0.40 ^{a}
	Agrostis capillaris	15.97 ^{a}	14.67 ^{a}	6.46 ^{a}	1.18 ^{a}	0.20 ^{a}	0.41 ^{a}
	herbicide fallow	14.57 ^{a}	13.53 ^{a}	5.69 ^{a}	1.52 ^{b}	0.25 ^{a}	0.48 ^{a}
'Harrow Sweet'	*Trifolium repens*	15.17 ^{a}	11.17 ^{a}	4.42 ^{ab}	1.23 ^{a}	0.33 ^{a}	0.35 ^{a}
	Agrostis capillaris	14.47 ^{a}	11.53 ^{a}	4.25 ^{a}	1.33 ^{a}	0.22 ^{a}	0.26 ^{a}
	herbicide fallow	13.37 ^{a}	13.63 ^{a}	5.46 ^{b}	1.29 ^{a}	0.33 ^{a}	0.25 ^{a}
'Winter Forelle'	*Trifolium repens*	8.43 ^{a}	17.60 ^{a}	5.67 ^{a}	1.78 ^{a}	0.67 ^{a}	0.83 ^{a}
	Agrostis capillaris	8.80 ^{a}	15.83 ^{a}	6.60 ^{a}	1.63 ^{a}	0.67 ^{a}	0.82 ^{a}
	herbicide fallow	8.27 ^{a}	16.17 ^{a}	6.81 ^{a}	1.58 ^{a}	0.75 ^{a}	0.75 ^{a}
Mean for orchard floor management (A)							
Trifolium repens		13.32 ^{a}	15.04 ^{a}	5.17 ^{a}	1.51 ^{a}	0.45 ^{a}	0.53 ^{a}
Agrostis capillaris		13.04 ^{a}	14.01 ^{a}	5.77 ^{ab}	1.38 ^{a}	0.36 ^{a}	0.50 ^{a}
herbicide fallow—control		12.17 ^{a}	14.44 ^{a}	5.99 ^{b}	1.47 ^{a}	0.44 ^{a}	0.49 ^{a}
Mean for cultivar (B)							
'Dolores'		15.63 ^{b}	14.86 ^{ab}	5.86 ^{b}	1.41 ^{ab}	0.27 ^{a}	0.43 ^{a}
'Harrow Sweet'		14.30 ^{b}	12.11 ^{a}	4.71 ^{a}	1.29 ^{a}	0.29 ^{a}	0.29 ^{a}
'Winter Forelle'		8.50 ^{a}	16.53 ^{b}	6.36 ^{b}	1.67 ^{b}	0.69 ^{a}	0.80 ^{b}

[a,b] Means marked by the same letter within the columns for orchard floor management (A), cultivar (B), or their interaction (A × B) do not significantly differ at $p \leq 0.05$ according to Duncan's multiple *t*-test.

Additionally, it is attractive to rodents, which increases the risk of damage to the roots and bark of cultivated trees [54]. Grassy mulch did not show a significant effect on the content of soluble solids or vitamin C, but as some research suggests, it is better suited to creating long-term living covers in a pear orchard on a Quince rootstock than herbs or legumes. In a pear orchard of the 'Williams' cv on the Quince MA rootstock, mulch consisting of various grass species showed a high level of cover maintained over the years and a small decline in yield in the orchards [5].

The K content in fruit was the highest with herbicide fallow and significantly the lowest with *Tr* mulch. These results correspond to the lower K content found in the leaves of trees growing in mulch compared to the control and suggest that the presence of mulch reduces the K supply for trees. However, the analyses of the content of Ca, Mg, and P in the fruit allowed us to conclude that the method of orchard floor management did not have a significant impact on the content of these macronutrients. Therefore, the presence of mulches did not deteriorate the internal quality of the fruit. The influence of LMs on the mineral composition of fruit has rarely been analysed in the literature. A study by Tahir et al. [17] showed that the K:Ca ratio in apple fruit growing in the presence of a mixture of grasses (*Lolium perenne* and *Poa pratensis*) with a 5% admixture of legume *Tr* was significantly lower than in the case of mechanical cultivation or the use of a natural herbicide, confirming the reduction in K availability for trees. Preliminary studies [33,55] showed that *Tr* and *Ac* mulches had no effect on the content of K, Ca, Mg, and P in fruit from a young pear orchard. However, in fruit from 11-year-old trees (on Caucasian pear rootstock) growing in the same mulches, a higher Ca content and a lower P content were found in comparison to those grown in herbicide-treated fallow [51].

The tested pear cvs differed significantly in terms of the soluble solids content; the highest concentration was found in the fruit of the 'Dolores' pear (at the 'Harrow Sweet' level), and the lowest in 'Winter Forelle'. There was also a clear difference in the vitamin C content of the fruit between the cvs. The highest values were found for cv 'Winter Forelle' and the lowest for cv 'Harrow Sweet'. The difference between these cvs was significant. The fruit of the 'Harrow Sweet' cv was characterised by a significantly lower K and Ca content (but at the level of cv 'Dolores'). In turn, cv 'Winter Forelle' pear fruit was the richest in P. The tested cvs did not differ from each other in terms of Mg content in the fruit. As for the interaction of the orchard floor management system and the pear tree cv, an unfavourable effect of grass mulch on the K content in cv 'Harrow Sweet' and Ca in cv 'Dolores' was noted.

4. Conclusions

The presented results showed that, compared to the commonly used method of floor management in the rows of a commercial orchard, i.e., herbicide fallow, the use of living mulches (LMs) in a pear orchard on a dwarf Quince S_1 rootstock did not significantly reduce tree growth. It also did not have a significant impact on the amount of cumulative yield. The LMs did not significantly affect the content of vitamin C. Replacing herbicides with LMs is therefore not generally associated with a significant decrease in fruit production in these orchards. Moreover, as shown, the presence of LMs in the tree rows promoted the formation of a larger number of medium and large fruit in relation to the herbicide fallow and had a significant impact on the fruiting alternation index. In both variants of living mulch used, it was significantly lower than in the control, which in practice means a more even yield every year. Less fruit each year can have a significant impact on their quality, which is a priority nowadays when the trick is to sell profitably, not just to produce.

These are the reasons for recommending living mulches as an alternative to the use of herbicides in large-scale dwarf orchards. Due to the problems reported in the literature related to the long-term maintenance of white clover (*Trifolium repens*) mulch and its attractiveness to rodents, it seems more justified to introduce grass (*Agrostis capillaris*) mulch. We recommend the simplest method of LM cultivation—single sowing without additional agrotechnical procedures.

However, the presence of LMs in a young orchard had a clearly inhibiting effect on the yield, and this tendency was reversed only in the 4th–6th year of the orchard's operation. Further research should aim to determine whether the postponed introduction of living mulch into the tree rows, e.g., in the 4th–5th year of growth of a dwarf pear orchard, will eliminate the problem of the initial reduction in yield.

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References

1. COM/2019/640 Final. The European Green Deal. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. 2019. Available online: https://www.eumonitor.eu/9353000/1/j9vvik7m1c3gyxp/vl4cnhyp1ort (accessed on 18 October 2023).
2. Granatstein, D.; Mullinix, K. Mulching Options for Northwest Organic and Conventional Orchards. *Hortic. Sci.* **2008**, *43*, 45–50. [CrossRef]
3. Slatnar, A.; Kwiecińska, I.; Licznar-Małańczuk, M.; Veberic, R. The Effect of Green Cover Within Rows on the Qualitative and Quantitative Fruit Parameters of Full-Cropping Apple Trees. *Hortic. Environ. Biotechnol.* **2020**, *61*, 41–49. [CrossRef]
4. Mia, M.J.; Massetani, F.; Murri, G.; Neri, D. Sustainable Alternatives to Chemicals For Weed Control In the Orchard—A Review. *Hortic. Sci.* **2020**, *47*, 1–12. [CrossRef]
5. Paušič, A.; Tojnko, S.; Lešnik, M. Permanent, Undisturbed, In-Row Living Mulch: A Realistic Option to Replace Glyphosate-Dominated Chemical Weed Control in Intensive Pear Orchards. *Agric. Ecosyst. Environ.* **2021**, *318*, 107502. [CrossRef]
6. Baluszynska, U.B.; Licznar-Malanczuk, M.; Medic, A.; Veberic, R.; Grohar, M.C. Influence of Living Mulch and Nitrogen Dose on Yield and Fruit Quality Parameters of Malus domestica Borkh. Cv. 'Sampion'. *Agriculture* **2023**, *13*, 921. [CrossRef]
7. Tzortzi, M.; Roberts, H.; Tatnell, L.V.; Atwood, J. The Suppression of Weeds by Cover Crops Grown as Living Mulches in Perennial Fruit Crops. *Asp. Appl. Biol.* **2015**, *129*, 57–64.
8. Hammermeister, A.M. Organic Weed Management in Perennial Fruits. *Sci. Hortic.* **2016**, *208*, 28–42. [CrossRef]
9. Licznar-Małańczuk, M. Occurrence of Weeds in an Orchard Due to Cultivation of Long-Term Perennial Lving Mulches. *Acta Agrobot.* **2020**, *73*, 7326. [CrossRef]
10. Singhal, V.; Ghosh, J.; Jinger, D. Cover Crop Technology—A Way Towards Conservation Agriculture: A Review. *Indian J. Agric. Sci.* **2020**, *90*, 2275–2284. [CrossRef]
11. Żelazny, W.R.; Licznar-Małańczuk, M. Soil Quality and Tree Status in a Twelve-Year-Old Apple Orchard under Three Mulch-Based Floor Management Systems. *Soil Tillage Res.* **2018**, *180*, 250–258. [CrossRef]
12. Przybyłko, S.; Szpadzik, E.; Marszał, J.; Kowalczyk, W.; Wrona, D. Different Floor Management Systems Affect Soil Properties and Initial Development of Apple Tree (*Malus x domestica* Borkh.) in an Orchard. *Agriculture* **2022**, *12*, 2070. [CrossRef]
13. Hoagland, L.; Carpenter-Boggs, L.; Granatstein, D.; Mazzola, M.; Smith, J.; Peryea, F.; Reganold, J.P. Orchard Floor Management Effects on Nitrogen Fertility and Soil Biological Activity in a Newly Established Organic Apple Orchard. *Biol. Fertil. Soils* **2008**, *45*, 11–18. [CrossRef]
14. Xiang, Y.; Chang, S.X.; Shen, Y.; Chen, G.; Liu, Y.; Yao, B.; Xue, J.; Li, Y. Grass Cover Increases Soil Microbial Abundance And Diversity And Extracellular Enzyme Activities In Orchards: A Synthesis Across China. *Appl. Soil Ecol.* **2023**, *182*, 104720. [CrossRef]
15. Wiesnerová, L.; Hřebečková, T.; Jablonský, I.; Koudela, M. Effect of Different Water Contents In the Substrate On Cultivation of Pleurotus ostreatus Jacq. P. Kumm. *Folia Hortic.* **2023**, *35*, 25–31. [CrossRef]
16. Zhang, Y.; Xie, Y.-S.; Hao, M.-D.; She, X.-Y. Effects of Different Patterns Surface Mulching on Soil Properties and Fruit Trees Growth and Yield in an Apple Orchard. *Chin. J. Appl. Ecol.* **2010**, *21*, 279–286.
17. Tahir, I.I.; Svensson, S.-E.; Hansson, D. Floor Management Systems in an Organic Apple Orchard Affect Fruit Quality and Storage Life. *HortScience* **2015**, *50*, 434–441. [CrossRef]
18. Sullivan, T.P.; Sullivan, D.S.; Granatstein, D.M. Influence of Living Mulches On Vole Populations and Feeding Damage to Apple Trees. *Crop Prot.* **2018**, *108*, 78–86. [CrossRef]
19. Wiman, M.R.; Kirby, E.M.; Granatstein, D.M.; Sullivan, T.P. Cover Crops Influence Meadow Vole Presence in Organic Orchards. *HortTechnology* **2009**, *19*, 558–562. [CrossRef]
20. Neilsen, G.; Forge, T.; Angers, D.; Neilsen, D.; Hogue, E. Suitable Orchard Floor Management Strategies in Organic Apple Orchards That Augment Soil Organic Matter and Maintain Tree Performance. *Plant Soil* **2014**, *378*, 325–335. [CrossRef]
21. Lisek, J.; Buler, Z. Growth and Yield of Plum Trees in Response to In-Row Orchard Floor Management. *Turk. J. Agric. For.* **2018**, *42*, 97–102. [CrossRef]

22. Kiprijanovski, M.; Tanaskovic, V.; Bojkovska, S. The Influence of Tree Row Strip Mulching in Pear Orchard on Soil Temperature and Moisture, Growth and Yield of the Trees. *Contrib. Sec. Nat. Math. Biotech. Sci. MASA* **2019**, *40*, 219–228.
23. Hussain, S.; Sharma, M.K.; Rasheed War, A.; Hussain, B. Weed Management in Apple cv. Royal Delicious by Using Different Orchard Floor Management Practices. *Int. J. Fruit Sci.* **2020**, *20*, 891–921. [CrossRef]
24. Iqbal, R.; Raza, M.A.S.; Valipour, M.; Saleem, M.F.; Zaheer, M.S.; Ahmad, S.; Toleikiene, M.; Haider, I.; Aslam, M.U.; Nazar, M.A. Potential Agricultural and Environmental Benefits of Mulches—A review. *Bull. Nati. Res. Cen.* **2020**, *44*, 75. [CrossRef]
25. Bokszczanin, K.Ł.; Wrona, D.; Przybyłko, S. Influence of an Alternative Soil Management System to Herbicide Use on Tree Vigor, Yield, and Quality of Apple Fruit. *Agronomy* **2021**, *11*, 58. [CrossRef]
26. Lisek, J.; Stępień, T. Macroelements Concentration in Plum Tree Leaves and Soil in Response to Orchard Floor Management. *Acta Sci. Pol. Hortorum Cultus* **2021**, *20*, 115–124. [CrossRef]
27. Rutkowski, K.; Łysiak, G.P. Influence of Mulching on Replantation Disease in Sour Cherry Orchard. *Agriculture* **2023**, *13*, 1587. [CrossRef]
28. Fogliatto, S.; Ferrero, A.; Vidotto, F. Current and Fucture Scenarios of Glyphosate Use in Europe: Are there Alternatives? *Adv. Agron.* **2020**, *163*, 219–278. [CrossRef]
29. Mészáros, M.; Lañar, L.; Kosina, J.; Náměstek, J. Aspects Influencing the Rootstock-Scion performance During Long Term Evaluation in Pear Orchard. *Hortic. Sci.* **2019**, *46*, 1–8. [CrossRef]
30. Kurt, T.; Őztürk, A.; Faizi, Z.A.; Őztürk, B. Impact of Quince Clonal Rootstocks on Yield and Fruit Quality Characteristics of European pear (*Pyrus communis* L.) Cultivars. *Erwerbs-Obstbau* **2023**, *65*, 1321–1329. [CrossRef]
31. North, M.; de Kock, K.; Booyse, M. Effect of Rootstock on ‘Forelle’ Pear (*Pyrus communis* L.) Growth and Production. *S. Afr. J. Plant Soil* **2015**, *32*, 65–70. [CrossRef]
32. Sosna, I.; Licznar-Małańczuk, M.; Czaplicka, M. The Influence of Living Mulches on the Growth and Fruiting of Pear and Apple Trees—Preliminary Results. *Zesz. Probl. Post. Nauk Roln.* **2009**, *536*, 197–203. (In Polish)
33. Janoszek, B.; Czaplicka, M.; Kortylewska, D. Assessment of the Effect of Living Mulches On the Content of Macronutrients in the Fruits and Leaves of ’Winter Forelle’ Pear. In *Book of Abstracts. 1st National Conference of Doctoral Students ’Multidirectional Research in Agriculture and Forestry’*; Agricultural University in Krakow: Krakow, Poland, 2012; pp. 481–487.
34. Sosna, I.; Czaplicka-Pędzich, M. Growth and Fruiting of Trees on Six Pear Cultivars Depending on Applied Rootstock. *Episteme* **2013**, *19*, 441–451. (In Polish)
35. Licznar-Małańczuk, M. Suitability of Blue Fescue (*Festuca ovina* L.) as Living Mulch in an Apple Orchard—Preliminary Evaluation. *Acta Sci. Pol. Hortorum Cultus* **2015**, *14*, 163–174.
36. Massai, R.; Loreti, F.; Fei, C. Growth and Yield of ‘Conference’ Pears Grafted On Quince and Pear Rootstocks. *Acta Hortic.* **2008**, *800*, 617–624. [CrossRef]
37. Musacchi, S.; Iglesias, I.; Neri, D. Training Systems and Sustainable Orchard Management for European Pear (*Pyrus communis* L.) in the Mediterranean Area: A Review. *Agronomy* **2021**, *11*, 1765. [CrossRef]
38. Stern, R.A.; Doron, I. Performance of ‘Coscia’ Pear (Pyrus communis) On Nine Rootstocks in the North of Israel. *Sci. Hortic.* **2009**, *119*, 252–256. [CrossRef]
39. Lordan, J.; Alegre, S.; Montserrat, R.; Asin, L. Yield and Profitability of ‘Conference’ Pear In Five Training Systems in North East of Spain. *Spanish J. Agric. Res.* **2017**, *15*, e0904–e0909. [CrossRef]
40. Kwon, Y.H.; Park, Y.S.; Park, J.E. Changes of Fruit Characteristics by Fruit Load Control in ‘Niitaka’ and ‘Whangkeumbae’ Pear Trees on Y-trellis Training System. *Korean J. Hort. Sci. Technol.* **2011**, *29*, 523–530.
41. Jajo, A.; Rahim, M.d.A.; Serra, S.; Gagliardi, F.; Jajo, N.K.; Musacchi, S.; Costa, G.; Bonghi, C.; Trainotti, L. Impact of Tree Training System, Branch Type and Position In the Canopy On the Ripening Homogeneity of ‘Abbé Fétel’ Pear Fruit. *Tree Genet. Genomes* **2014**, *10*, 1477–1488. [CrossRef]
42. Choi, J.J.; Gu, M.; Choi, J.H.; Han, J.H.; Yim, S.H.; Kim, Y.K.; Jung, S.K.; Choi, H.S. Growth and Fruit Production of Asian Pear Trees Grown on Y-, T-, and Vase-training Systems. *Hort. Environ. Biotechnol.* **2014**, *55*, 1–8. [CrossRef]
43. Hunter, D.M.; Pinsonneault, P.; Kappel, F.; Quamme, H.A.; Bonn, W.G.; Layne, R.E.C. ‘Harrow Sweet’ Pear. *HortScience* **1992**, *27*, 1331–1334. [CrossRef]
44. Erfani, J.; Abdollahi, H.; Ebadi, A.; Fatahi, R. Evaluation of Resistance to Fire Blight in Pear Cultivars. In Proceedings of the 2nd Symposium on Horticulture in Europe, Angers, France, 1–5 July 2012; p. 170.
45. Szymanowski, M.; Wieczorek, M.; Namyślak, M.; Kryza, M.; Migała, K. Spatio-Temporal Changes in Atmospheric Presipitation Over South-Western Poland Between the Periods 1891–1930 and 1981–2010. *Theor. Appl. Climatol.* **2019**, *135*, 505–518. [CrossRef]
46. Lisek, A.; Rozpara, E. Identification of Pear Cultivars With RAPID and ISSR Markers. *J. Fruit Ornam. Plant Res.* **2010**, *18*, 17–22.
47. Jacobs, J.N.; Cook, N.C. The Effect of Rootstock Cultivar On the Yield and Fruit Quality of ‘Packham’s Triumph’, Doyenne du Comice’, ‘Forelle’, ‘Flamingo’ and ‘Rosemarie’ Pears. *S. Afric. J. Plant Soil* **2003**, *20*, 25–30. [CrossRef]
48. Szczepański, K.; Rejman, S. *Methodology of Fruit Growth Research*; PWRiL: Warsaw, Poland, 1987. (In Polish)
49. *Polish Standard PN-90/A-75101/11*; Fruit and Vegetable Preserves. Sample Preparation and Methods of Physicochemical Research. Determination of Vitamin C Content. Polish Quality Committee: Warsaw, Poland, 1990; pp. 1–5. (In Polish)
50. Komosa, A. *Fertilization of Garden Plants. Part. I. Diagnostics of Fertilization Needs*; Scripts of the Agricultural University in Poznań: Poznań, Poland, 1992. (In Polish)

51. Sosna, I.; Fudali, E. Living Mulches In-Rows As an Alternative For Herbicide Fallow In a Pear *Pyrus communis* L. Orchard. *Hort. Sci.* 2024, 2, *in press*.
52. Merwin, I.A.; Stiles, W.C. Orchard groundcover management impacts on apple tree growth and yield, and nutrient availability and uptake. *J. Am. Soc. Hortic. Sci.* **1994**, *119*, 209–215. [CrossRef]
53. Muscas, E.; Cocco, A.; Mercenaro, L.; Cabras, M.; Lentini, A.; Porqueddu, C.; Nieddu, G. Effects of Vineyard Floor Cover Crops On Grapevine Vigor, Yield And Fruit Quality, And the Development of the Vine Mealybug Under a Mediterranean Climate. *Agric. Ecosyst. Environ.* **2017**, *237*, 203–212. [CrossRef]
54. Hogue, E.J.; Cline, J.A.; Neilsen, G.; Neilsen, D. Growth and Yield Responses to Mulches and Cover Crops Under Low Potassium Conditions in Drip-Irrigated Apple Orchards On Coarse Soils. *HortScience* **2010**, *45*, 1866–1871. [CrossRef]
55. Czaplicka-Pędzich, M.; Sosna, I. Application of Living Mulch With Clover And Grass In Pear Orchard—Impact On the Yield and Fruit Quality. In Proceedings of the 2nd International Conference and Workshop, Plant—The Source of Research Material, Lublin, Poland, 18–20 October 2012; p. 131. (In Polish)