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ORIGINAL RESEARCH PAPER in HERBOLOGY

Grass Species as Living Mulches – Comparison of Weed Populations and Their Biodiversity in Apple Tree Rows and Tractor Alleys

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Abstract

The durability of four grass living mulches, population of annual and perennial weeds, and their biodiversity in tree rows and tractor alleys were evaluated in the first 4 years after cover crop sowing. The experiment was established in a young semi-dwarf apple orchard 1 year after the planting of the tree 'Chopin' cv. Soil coverage was satisfactory for the three cover crops: red fescue, Kentucky bluegrass, and perennial ryegrass. The sods of the grasses exhibited 100% soil surface cover in the tree rows and drive alleys, starting from 1 year after sowing to the end of the study period. Only the maintenance of the blue fescue resulted in low average soil development.

Annual and perennial weed populations were lower in the tree rows than in the drive alleys. It was determined meticulous and manual soil preparation prior to all grass sowing under tree crowns, followed by precise mowing of grasses and nitrogen fertilization in subsequent years. The highest soil surface cover by the total annual taxa was observed immediately after the emergence of the living mulch. Total perennial weed populations increased in the following vegetation seasons. *Trifolium repens* L. and *Taraxacum offcinale* (L.) Web. dominated all the grass living mulches evaluated. Only the red fescue sod effectively limited the infestation of perennial weed after 4 years of living mulch maintenance in the tree row. More than half of the annual and perennial weed taxa occurred sporadically in all living mulches. In both the tree rows and tractor alleys, the soil surface cover was not more than 1%, and these species contributed to the increase in orchard biodiversity.

Keywords
apple orchard; cover crop; fescue; Kentucky bluegrass; ryegrass

1. Introduction

Grasses occur in natural and anthropogenic plant communities where they perform diverse functions (Karbivska et al., 2020; Kozłowski et al., 2000). In apple tree cultivation, the maintenance of perennial grasses between tree rows is a standard practice (Merwin, 2003). Similar to legumes and other broadleaf plants, Poaceae species can be used as a living mulch beneath tree canopies. In this way, they can replace herbicides used in tree rows. Grass sods suppress weeds, build soil organic matter, and prevent soil erosion and nutrient losses in orchards (Hammermeister, 2016). Based on research works and literature reviews, Merwin (2003) reported the characteristics of several perennial grasses, which are most often kept on the apple orchard floor in tractor alleys. The best value: a low growth and a low water use, a very good establishment and a high durability by *Festuca rubra* L., ahead of *Festuca duriuscula* L. and the more vigorous *Festuca arundinacea* Schreb. Prończuk et al.

(2003) reported that there are high variabilities in sod density, re-growth, overwintering, and tolerance to diseases among different grasses. *Festuca rubra* ssp. *cummutata* Gaud. (clump form), *F. rubra* ssp. *trichophylla* Gaud., and *F. duriuscula* L. were recognized as the best candidates for long-term sod maintenance. In addition to *Festuca* spp., Merwin (2003) described two other species, *Poa pratensis* L. and *Lolium perenne* L., which are useful for orchards. Compared to *F. rubra*, both grasses had higher water requirements and a stronger growth rate, but their growth rates were not as high as *F. arundinacea*. Compared to that of *P. pratensis*, the tillering of *L. perenne* was faster, and the grass quickly covered the soil surface (Newenhouse & Dana, 1989), because some of these grass cultivars can rapidly develop numerous vegetative shoots (Domański & Golińska, 2003) and longer roots (Gawryluk, 2019; Harkot & Gawryluk, 2010) after sowing. However, the durability of *L. perenne* is lower than that of other grasses, as described by Merwin (2003).

Festuca rubra, *P. pratensis*, and *L. perenne* mix have long been recommended for tractor alleys in commercial orchards (Mika, 2010). The use of herbicide in tree rows can be avoided by employing a single grass species (Harrington et al., 2002; Licznar-Małańczuk, 2020; Tworkoski & Glenn, 2012) or their mixes or their mix with dicotyledon plants (Paušič et al., 2021). Their application does not eliminate weed infestation in an orchard. Annual and perennial weeds germinate during the first few weeks of cover crop development. Annual species decline in subsequent years, whereas perennial species increases (Harrington et al., 2002; Licznar-Małańczuk, 2020). The use of living mulch for soil covering in the following years can protect the soil surface against seed germination and weed seedling emergence; however, it is not effective against established perennial weeds (Bound & Grundy, 2001).

The aim of weed control is to maintain a balance between crops and weeds (Bond & Grundy, 2001). Similar, living mulch and weed dominance need to be balanced if a perennial cover crop is employed. The abandonment of conventional and herbicide-based floor management fosters species diversity in fruit tree cultivation (Lisek & Sas-Paszt, 2015; Tasseva, 2005) and such desirable outcomes are also expected in orchards with living mulches. However, grass sods are suppressed by excessive abundance of certain perennial taxa (Licznar-Małańczuk, 2020).

With the growing popularity of apples in nutrition, food, and drug industries, they have become one of the most consumed fruits worldwide (Gundogdu et al., 2018; Konopacka et al., 2010). Therefore, apple cultivation requires careful selection of production technologies. The present study evaluated the persistence of four grass living mulches in young apple orchard, and the occurrence, variability, and biodiversity of weed taxa in the grass sods in tree rows and tractor alleys.

2. Material and Methods

Weed infestation and durability of four grass living mulch sods in an apple orchard were determined at the Fruit Experimental Station of the Wrocław University of Environmental and Life Sciences in Wrocław (Poland), in Samotwór (51° 06′ 12″ N, 16° 49′ 52″ E), in 2017–2020. Two-year-old apple trees (*Malus domestica* Borkh.) 'Chopin' cv. grafted on a semi-dwarf MM106 rootstock was planted in spring 2016 on haplic luvisol. The chosen spacing was 3.6 m between tree rows and the distance between the trees in a row was 1.2 m. The trees were trained into the slender spindle form of the canopy. Since the second year after orchard establishment, each tree was fertilized with ammonium nitrate (15 g N in 2017–2018 and 20 g N in 2019–2020). The tree plants were cut and protected in accordance with the current commercial orchard recommendations.

The experiment was established following a randomized block design with four replicates: Four perennial grass living mulches were sown in spring 2017. The cover crops were the blue fescue (*F. ovina* L.) of the 'Noni' cv., red fescue (*F. rubra* L.) of the 'Adio' cv., Kentucky bluegrass (*P. pratensis* L.) of the 'Niweta' cv., and perennial ryegrass (*L. perenne* L.) of the 'Info' cv. Each grass was sown separately at the rate of 50 kg seeds per ha in the tree rows and in the adjacent tractor alleys on the eastern side of each row. The glyphosate herbicide was applied at the rate of 2,450 g ha^{-1} in the tree rows 1 month before the grasses were sown. The soil was hoed three weeks later, and the main remaining perennial weeds were hand-picked. The tree-row soil was leveled with a rake. At the end of May, the experimental grass seeds were scattered by hand and raked into the soil, after which the floor was rolled with a hand roll. Tractor alleys were performed 1 month before the living mulches were sown into the soil, and weeds were destroyed between the rows. The floor was leveled 3 weeks later with a cultivator. Similar to the tree rows, the grass seeds in the tractor alleys were scattered by hand at the end of May, but subsequent cultivation was limited to rolling with a roll pulled by a tractor. From the beginning of the summer of the year of living mulch sowing, the grass sods in the tractor alleys were mowed with the lawn mower several times per year in accordance with the orchard commercial recommendation (Mika, 2010). In contrast, the grass sods in the tree rows were mowed manually, twice or thrice per year with a string trimmer.

The main plot area for each estimated grass was 17.28 m^2 (3.6 m × 4.8 m) and contained four apple trees. In the middle part of the main plot area, two sub-plot areas were designated for the assessment of living mulch sods and weed infestation in the tree row (1.80 m^2) and tractor alley (4.68 m^2). Whole-plot evaluation was not performed, to avoid the occurrence of non-representative weed communities at the edges of the investigated grass living mulches. The degree of coverage by the four grass living mulches and each separate weed species was assessed as the percentage of both separate surface areas in the years 2017–2020. A non-invasive method of separate plant estimation was used, following the methodology of Lipecki and Janisz (2000). The original share of the scale was modified by splitting the range of over 0% to 20% into two separate groups, and as a final result, each taxon was expressed using a discrete percentage scale: 0%, 1%, 20%, 40%, 60%, 80%, and 100%. The estimation was performed separately for each species and for the genus of the weeds in some cases. It was impossible to express the relationship between the total shares of all weed populations on a scale of 100%, because the share of each species was assessed independently. Therefore, additional estimations of the total annual and total perennial weed populations were performed. The first evaluation of weed cover was conducted in July 2017. From 2018 to 2020, weeds were estimated twice per year, in spring (the end of April) and at the beginning of summer (July). The nomenclature of the vascular plants was based on the taxonomy described by Erhardt et al. (2008).

The discrete data of the degree of the soil cover by the grass sod (only the first two assessments) and total annual and total perennial weed population cover and the continuous data of the number of weed species were evaluated statistically. One-way analysis of variance was used for the randomized block design. The statistical analysis considered a value related to weed abundance, including over 5% coverage by the separate weed species of the surface plot area. Additionally, in order to fulfill the assumptions of analysis of variance, at least approximately, angularly (by the Bliss function) or exponential transformations were applied to some of the data. Multiple comparisons were performed at a 5% significance level using Duncan's multiple range test.

3. Results

Tree planting (2016) and living mulch sowing (2017) coincided with the 2 coolest years of the experiment (Table 1). Water conditions were similar in the first 2 years after orchard establishment (2016–2017), in which annual precipitation sums of above 600 mm were recorded. The 2 following years were warm and dry, but the year 2020 was very wet, with a total precipitation sum of over 800 mm.

Table 1 Mean temperatures and total precipitations at the Wrocław-Strachowice Station (51°06′14″ N, 16°52′55″ E) in the years 2016–2020.

Specification	Year after tree planting				
	1st (2016)	2nd (2017)	3rd (2018)	4th (2019)	5th (2020)
Mean temperature (°C)	10.0	9.8	10.8	11.0	10.6
Total precipitation (mm)	643.1	619.3	441.4	430.8	808.4

Table 2 Mean percentage of soil surface under living mulch sod cover in the years 2017–2020.

Living mulch	Year and season						
	2017	2018		2019		2020	
	Summer	Spring	Summer	Spring	Summer	Spring	Summer
Tree row							
Blue fescue	6 a	35 a	65	75	90	90	100
Red fescue	25 b	95 b	100	100	100	100	100
Kentucky blue grass	25 b	55 a	100	100	100	100	100
Perennial ryegrass	65 c	100 b	100	100	100	100	100
Tractor alley							
Blue fescue	10 a	20 a	40	60	70	85	80
Red fescue	70 c	95 b	100	100	100	100	100
Kentucky blue grass	35 b	75 b	100	100	100	100	100
Perennial ryegrass	100 d	95 b	100	100	100	100	100

Within individual columns, the means denoted by different letters differ significantly according to Duncan's test at a confidence level of 95%; the means without superscript letters are non-significant.

Blue fescue tree rows and tractor alleys had the lowest mean percentage of soil surface sod cover (Table 2). The coverage was satisfactory for the remaining grass species, which exhibited 100% dominance at the beginning of summer in 2018. The highest number of weed taxa was recorded in the summer of 2017, soon after the emergence of the living mulch, when cover crop coverage was limited (Table 3). The number of weed taxa in grass sods decreased or remained at similar levels in subsequent years. However, weed biodiversity was higher in those rows and drive alleys that up to spring 2020 still were not fully covered by blue fescue. In addition to that, taxon number increase was noted among perennial ryegrass maintained in the tractor alleys. A total of 16–17 annual taxa were identified in the tree rows across all living mulches over the 4 years of the research (Table 4), with the exception of the blue fescue, which was 24 in number. Only five–nine weed species had a dominance of 1% or more (Table 5). *Poa annua* L., *Stellaria media* (L.) Vill., *Echinochloa crus-galli* (L.) P. Beauv., and *Erophila verna* (L.) DC. were considered to be the most significant species. The numbers of annual taxa with an inter-row dominance of at least 1% were similar across the four living mulches. The total number of perennial taxa in the blue fescue sod was greater than that in the remaining grass species

Table 3 Mean of the number of identified weed taxa on the soil surface within the living mulch sod in the succeeding years 2017–2020.

Living mulch	Year and season						
	2017	2018		2019		2020	
	Summer	Spring	Summer	Spring	Summer	Spring	Summer
Tree row							
Blue fescue	10	9 b	8 c	11 b	7 b	9 c	7
Red fescue	10	5 ab	4 ab	3 a	2 a	2 a	3
Kentucky blue grass	10	8 b	6 bc	4 a	4 a	4 ab	5
Perennial ryegrass	10	3 a	2 a	5 a	4 a	6 bc	5
Tractor alley							
Blue fescue	12	13 b	11 b	15 b	9	13 b	12
Red fescue	13	8 a	8 ab	8 a	7	6 a	8
Kentucky blue grass	13	9 a	7 ab	7 a	6	6 a	7
Perennial ryegrass	9	6 a	5 a	10 a	7	11 b	9

Within individual columns, the means denoted by different letters differ significantly according to Duncan's test at a confidence level of 95%; the means without superscript letters are non-significant.

Table 4 Total number of identified annual weed taxa on the soil surface within the living mulch sod from the year of grass sowing (2017) to the end of the fifth year after tree planting (2020).

Weed taxa		Living mulch							
		Tree row				Tractor alley			
		Blue fescue	Red fescue	Kentucky blue grass	Perennial ryegrass	Blue fescue	Red fescue	Kentucky blue grass	Perennial ryegrass
1.	*Amaranthus retroflexus* L.	+	+			+		+	
2.	*Anagallis arvensis* L.	+	+			+			
3.	*Arabidopsis thaliana* (L.) Heynh.			+	+	+	+	+	
4.	*Capsella bursa-pastoris* (L.) Medik.	+	+	+	+	+	+	+	+
5.	*Chenopodium album* L.	+	+	+	+	+	+	+	+
6.	*Conyza canadensis* (L.) Cronquist	+		+	+	+	+	+	+
7.	*Crepis* spp.	+		+	+	+	+	+	+
8.	*Daucus carota* L.					+			
9.	*Digitaria sanguinalis* (L.) Scop.	+					+		
10.	*Echinochloa crus-galli* (L.) P. Beauv.	+	+	+	+	+	+	+	+
11.	*Erigeron annuus* (L.) Pers.					+	+	+	+
12.	*Erophila verna* (L.) DC.	+		+	+	+	+	+	+
13.	*Fumaria officinalis* L.					+		+	
14.	*Galinsoga parviflora* Cav.				+	+	+		+
15.	*Geranium pusillum* Burm. f. ex L.	+	+	+	+	+	+	+	+
16.	*Lamium purpureum* L.	+	+	+	+	+	+	+	+
17.	*Lactuca serriola* L.							+	
18.	*Matricaria chamomilla* L.	+	+			+	+	+	+
19.	*Medicago lupulina* L.	+	+	+	+	+	+	+	+
20.	*Myosotis arvensis* (L.) Hill								+
21.	*Poa annua* L.	+	+	+	+	+	+	+	+
22.	*Polygonum aviculare* L.	+	+			+	+	+	+
23.	*Senecio vulgaris* L.	+	+	+	+	+	+	+	+
24.	*Setaria* spp.	+	+	+		+	+	+	
25.	*Sisymbrium officinale* (L.) Scop.	+				+		+	
26.	*Sonchus oleraceus* L.			+		+	+	+	+
27.	*Stellaria media* (L.) Vill.	+	+	+	+	+	+	+	+
28.	*Thlaspi arvense* L.						+		
29.	*Veronica arvensis* L.	+				+	+	+	+
30.	*Veronica hederifolia* L.	+	+		+	+	+	+	+
31.	*Veronica persica* Poir	+		+			+	+	
32.	*Vicia* sp.	+							
33.	*Viola arvensis* Murray	+	+	+	+		+	+	
Total number of taxa		24	16	17	16	26	25	26	20

Table 5 Classification of annual weed taxa, whose share in the tree row or in the tractor alley exceeded 1% of soil surface cover, to the different groups of the soil surface cover (mean for 2017–2020).

Percent of soil surface cover	Living mulch							
	Tree row				Tractor alley			
	Blue fescue	Red fescue	Kentucky blue grass	Perennial ryegrass	Blue fescue	Red fescue	Kentucky blue grass	Perennial ryegrass
1.1–5.0	*12*[*], *15, 16, 18, 23*	*4, 10, 23*	*4, 5, 10, 12, 16, 19, 23*	*4, 5, 15, 16, 19, 21, 23*	*1, 4, 7, 16, 18, 19*	*4, 5, 7, 15, 16, 19, 23*	*4, 5, 12, 15, 16*	*4, 5, 7, 15, 16, 19, 23*
5.1–10.0	*10, 27*	*21, 27*	*27*	*27*	*12, 15, 23*	*10, 27*	*10, 19, 23, 27*	*10, 27*
10.1–20.0	–	–	*21*	–	*10, 27*	*21*	*21*	*21*
20.1–40.0	*21*	–	–	–	*21*	–	–	–
Total number of taxa	8	5	9	8	12	10	10	10

[*] The number in italics in this table corresponds to the number assigned to the taxon in Table 4.

Table 6 Total number of identified perennial weed taxa on the soil surface within the living mulch sod from the year of grass sowing (2017) to the end of the fifth year after tree planting (2020).

Weed taxa		Living mulch							
		Tree row				Tractor alley			
		Blue fescue	Red fescue	Kentucky blue grass	Perennial ryegrass	Blue fescue	Red fescue	Kentucky blue grass	Perennial ryegrass
1.	*Achillea millefolium* L.	+				+			+
2.	*Artemisia vulgaris* L.	+	+	+	+	+	+	+	+
3.	*Arctium tomentosum* Mill.	+					+		
4.	*Bellis perennis* L.					+			
5.	*Carduus* sp.					+			
6.	*Cerastium* spp.	+	+	+	+	+	+	+	+
7.	*Cirsium* sp.					+			
8.	*Convolvulus arvensis* L.					+	+		+
9.	*Epilobium adenocaulon* Hausskn.	+							
10.	*Geum urbanum* L.	+				+			
11.	*Hieracium* spp.	+	+	+		+	+	+	+
12.	*Hypericum perforatum* L.	+		+		+	+	+	+
13.	*Leontodon hispidus* L.	+		+		+	+	+	+
14.	*Malva sylvestris* L.	+	+	+	+	+	+	+	+
15.	*Oxalis stricta* L.		+						
16.	*Prunella vulgaris* L.						+		+
17.	*Plantago lanceolata* L.			+	+	+	+	+	+
18.	*Plantago major* L.	+	+	+	+	+	+	+	+
19.	*Plantago media* L.							+	
20.	Poaceae – Other species	+	+	+	+	+	+	+	+
21.	*Ranunculus repens* L.					+			
22.	*Rumex crispus* L.					+			
23.	*Solidago virgaurea* L.	+							
24.	*Sonchus arvensis* L.	+	+		+	+	+	+	+
25.	*Tanacetum vulgare* L.							+	
26.	*Taraxacum officinale* Web. ex F. H. Wigg	+	+	+	+	+	+	+	+
27.	*Trifolium repens* L.	+	+	+	+	+	+	+	+
28.	*Urtica dioica* L.							+	
29.	*Veronica serpyllifolia* L.	+				+	+	+	+
Total number of taxa		17	10	11	9	21	16	16	16

(Table 6), and more weed species exceeded 1% of the soil surface cover in the tree rows and tractor alley (Table 7). In contrast, red fescue was characterized by the lowest number of weeds (three and seven, respectively). *Trifolium repens* L. and *Taraxacum offcinale* Web. prevailed in all the living mulches.

The total annual weed population in the first year of maintenance for all living mulches was between 40% and 50% in the tree rows and higher in the tractor alleys (Table 8). The occurrence of weeds decreased in the following two vegetation seasons, especially in the red fescue and perennial ryegrass living mulches. The recurrence of annuals was observed in the final year of the study (2020), with high precipitation. The dominance of perennials was low after the emergence of living mulch in summer 2017, particularly in the tree rows (Table 9). Their populations increased in the subsequent vegetation season. Red fescue rows exhibited the lowest weed infestation after 4 years of living mulch maintenance.

4. Discussion

Proper site preparation before planting of trees is the most important part of agrotechnical method against weed infestation (Hammermeister, 2016). Grass

Table 7 Classification of perennial weed taxa, whose share in the tree row or in the tractor alley exceeded 1% of soil surface cover, to the different groups of the soil surface cover (mean for 2017–2020).

Percent of soil surface cover	Living mulch							
	Tree row				Tractor alley			
	Blue fescue	Red fescue	Kentucky blue grass	Perennial ryegrass	Blue fescue	Red fescue	Kentucky blue grass	Perennial ryegrass
1.1–5.0	*6*[*], *11, 12, 14, 18, 29*	*14*	*2, 14, 20*	*6, 14, 26*	*10, 12, 13, 14, 21, 29*	*12, 20, 29*	*12, 17, 18, 20, 29*	*1, 6, 14, 18, 29*
5.1–10.0	*20*	*26*	*26*	–	*6, 18*	*14, 18, 26*	–	–
10.1–20.0	*26*	*27*	*27*	*27*	–	–	*14, 26*	*26*
20.1–40.0	*27*	–	–	–	*20, 26*	*27*	*27*	*27*
>40	–	–	–	–	*27*	–	–	–
Total number of taxa	9	3	5	4	11	7	8	7

* The number in italics in this table corresponds to the number assigned to the taxon in Table 6.

Table 8 Changes in the mean percentage of soil surface under the total annual weed population cover within the living mulch sod in the succeeding years 2017–2020 (mean for spring and summer).

Living mulch	Year							
	Tree row				Tractor alley			
	2017*	2018	2019**	2020	2017*	2018	2019	2020
Blue fescue	50.0	60.0 b	17.6	12.9	100.0	70.0 c	27.6 c	32.5
Red fescue	50.0	17.8 a	–	–	85.0	40.5 b	5.4 a	8.0
Kentucky blue grass	50.0	47.6 b	5.3	12.9	80.0	40.4 b	–	17.8
Perennial ryegrass	40.0	5.3 a	–	20.1	65.0	20.3 a	15.1 b	22.6

* Only summer estimation.
** Without statistical evaluation.
Within individual columns, the means denoted by different letters differ significantly according to Duncan's test at a confidence level of 95%; the means without superscript letters are non-significant.

Table 9 Changes in the mean percentage of soil surface under the total perennial weed population cover within the living mulch sod in the succeeding years 2017–2020 (mean for spring and summer).

Living mulch	Year							
	Tree row				Tractor alley			
	2017*	2018	2019	2020	2017*	2018	2019	2020
Blue fescue	15.3	55.0 b	45.0 c	22.6 b	10.5	52.5	77.5 b	67.5
Red fescue	10.3	30.0 ab	15.3 a	5.5 a	40.0	42.5	50.0 a	47.5
Kentucky blue grass	10.5	30.3 ab	30.0 bc	30.0 b	30.3	42.5	35.0 a	57.5
Perennial ryegrass	10.3	15.0 a	15.4 ab	30.1 b	10.5	27.5	55.0 a	65.0

* Only summer estimation.
Within individual columns, the means denoted by different letters differ significantly according to Duncan's test at a confidence level of 95%; the means without superscript letters are non-significant.

sowing, which was performed in the year following tree planting in spring 2017, was preceded by meticulous and manual preparation of soil under the tree crowns. Majority of the perennial weeds were manually removed, and only 10 taxa were identified in each of the four grasses sown in the tree rows. More perennial taxa were observed in the drive alleys, where only standard tillage was performed. This difference in soil preparation also influenced the total annual and perennial weed population dominances observed during the first data collection. Annual species prevailed in the summer of 2017, and the dominance was in approximately 50% of the area under tree crowns in each living mulch. Similar annual species communities were also observed in the first months of grass living mulches maintenance in the experiments by Harrington et al. (2002) and Licznar-Małańczuk (2014, 2020). Annual weed occurrence was much higher in the drive alleys than in the tree rows. However, meticulous and thorough soil preparation in tree rows suppressed the total perennial weed population in 2017.

Annual and total perennial weed population dominances were lower under the tree crowns in the subsequent experimental years (2018–2020) than under the drive alleys. The careful manual mowing of the sod performed two or three times a year to a height of several centimeters contributed to this pattern. Such practice increased weed suppression over time (Tworkoski & Glenn, 2012) and removed upright annual weeds in young orchards (Harrington et al., 2002). Machine mowing of grass sods in the tractor alleys in the present study was less precise compared to the use of string trimmer in tree row mowing. Moreover, grass sods were compressed during tractor operations. In addition, nitrogen applied under the canopy created better conditions for grass living mulches maintained in the rows, and young, semi-dwarf apple trees did not cast shadows on the sod grasses.

Although the growth conditions of living mulch differed between the tree rows and drive alleys, three of the four evaluated grasses exhibited 100% sod cover in both investigated areas at the beginning of summer in 2018; they were red fescue, Kentucky blue grass, and perennial ryegrass, and their coverages were the same until the end of the study. However, their sods exhibited different weed infestation patterns. Perennial ryegrass, which is a rapidly tillering grass species (Domański & Golińska, 2003), was significantly less infested by annual weeds in spring 2018, and it has been reported that perennial ryegrass performed well in the first 3 years of strawberry cultivation (Newenhouse & Dana, 1989). This grass, with some red fescue mixed sod, effectively suppressed weed infestation during nursery production (Calkins & Swanson, 1995). The mean sod density of two perennial ryegrass cultivars was satisfactory in a 3-year peach study (Tworkoski & Glenn, 2001); however, the decrease in weed mass was not stronger relative to other grass mulches, corroborating the results of the present study for apple orchard. Perennial ryegrass and red fescue for most part did not differ significantly in 2018–2019 in terms of identified taxa counts and total annual and total perennial weed population dominances. However, perennial ryegrass weed infestation increased substantially in the last year of the research (2020) and was similar to that observed for Kentucky blue grass. This effect might have been caused by abundant precipitation (above 800 mm) in 2020, which encourages ongoing weed succession, and this may foreshadow a gradual loss of sod coverage in the future due to the low durability of perennial ryegrass (Merwin, 2003).

The initial sod development of red fescue and Kentucky blue grass was less dynamic than that of perennial ryegrass, with the difference especially pronounced for the latter species. Total annual weed population was effectively eliminated in the rows with red fescue in the course of the 4 years of living mulch maintenance, but the dominance of perennials was reduced to approximately 5% in the last study year. These results agree with those of Harrington et al. (2002, 2005) and Tworkoski and Glenn (2012), who reported that this species kept the weeds under tree canopy under control. In the present study, the total annual taxa gradually became insignificant in the drive alleys with red fescue, whereas in the same place, the perennials were stable over the entire study period. No weed infestation recurrence was observed in this living mulch during the abundant precipitation in the year 2020. The possible hindering factors were satisfactory soil coverage by the living mulch and high durability of its sod, as highlighted by Merwin (2003). Total perennial weed population was significantly higher in 2020 in the tree rows with Kentucky blue grass than in those with red fescue. Blue fescue cultivation was accompanied by the highest weed taxa count and weed population dominance. The coverage of this mulch under the tree crowns did not reach 100% before the summer of 2020, whereas it occurred at 80% level in the drive alleys. The observed pattern is in contrast with the result of earlier evaluations of this species by Licznar-Małańczuk (2014, 2020). In the studies, blue fescue dominance under the tree rows exceeded 90% in the second year after sowing, and the mulch effectively suppressed annual weed species and perennial Poaceae. The evaluation discrepancies may stem from the application of different blue fescue variety, because the utility values of different *F. ovina* cultivars vary (Prończuk et al., 2003).

Moreover, full orchard floor coverage by a living mulch is performed to suppress weed populations (Hammermeister, 2016), whereas grassland floor management is viewed as a way to foster biodiversity in integrated or organic fruit production (Mika, 2004). In the present study, flora abundance present in a grassed orchard was demonstrated by the total counts of identified annual and perennial weed taxa over the entire 4-year research period. These numbers ranged between 16 and 24 annual taxa and between nine and 17 perennial taxa in the tree rows, depending on the grass living mulch species, and they were even higher between rows. Successful weed suppression, as highlighted by Linares et al. (2008), requires the maintenance of cover crop dominance, for which a proper proportion of mulch and weed biomass needs to be obtained. More than half of the identified annual and perennial taxa exhibited mean dominances of not more than 1% of soil surface cover in the four investigated living mulches, and those of several others were within the range 1.1%–5.0%. The presence of these weed taxa arguably contributed to the increased biodiversity in the orchard.

The actual weed infestation problem involved only a few taxa, and *Taraxacum offcinale* (L.) Web. and *Trifolium repens* L. were two perennials that posed a serious problem. These weeds are typical for orchards with grass living mulch (Harrington et al., 2002; Licznar-Małańczuk, 2014, 2020; Paušič et al., 2021; Tworkoski & Glenn, 2012). *Trifolium repens* can also be used as a cover crop in an orchard (Hussain et al., 2020; Licznar-Małańczuk, 2014) because it develops durable sods (Merwin, 2003). When it treated as a weed, its prostrate habitus hinders its elimination during mowing (Harrington et al., 2002), such as *T. offcinale* – a rosette forming species. Nevertheless, *T. repens* and *T. offcinale* populations were kept in check after 4 years of maintaining a dicot species mix with grasses in the experiment by Paušič et al. (2021). Such mulches also foster biodiversity in orchards. The application of two or three grass species mixed with legumes suppresses weed emergence and growth better than a single cover crop (Diyanat, 2015; Linares et al., 2008). The presented results demonstrate the need for further research on cover crop species selection to maintain the dominance of living mulch, limit the growth of notorious perennial weeds, and increase orchard biodiversity.

5. Conclusions

Weed taxa counts and the dynamics of their coverage vary in young apple orchard, depending on the grass species used as the cover crop. Meticulous and manual soil preparation prior to sowing under tree crowns, followed by precise mowing of grasses and nitrogen fertilization in subsequent years, effectively suppressed sod weed infestation more in the tree rows than in the drive alleys.

At least half of the annual and perennial taxa from tree row and tractor alley weed communities occurred sporadically, with a dominance of not more than 1% of the soil surface cover. Their presence contributed to orchard biodiversity but probably did not impair living mulches or apple trees.

Trifolium repens L. and *Taraxacum offcinale* (L.) Web. dominated most of the multi-year weed infestations found in all the investigated grass living mulches. Mechanical control by mowing is not effective for suppressing these weeds and does not limit their expansion in an orchard, potentially leading to cover crop sod reductions.

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