Acta Agrobotanica

Article ID: 745
DOI: 10.5586/aa.745

Publication History
Received: 2020-09-10
Accepted: 2021-01-20
Published: 2021-07-09

Handling Editor
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Authors' Contributions
MLM: study conception and design; MLM and LS: collection, analysis, interpretation of data, and drafting of the manuscript

Funding
This study was supported by the Ministry of Science and Higher Education of Poland as part of the statutory activities of the Department of Horticulture, Faculty of Life Sciences and Technology, Wrocław University of Environmental and Life Sciences.

Competing Interests
No competing interests have been declared.

ORIGINAL RESEARCH PAPER in HERBOLOGY

Weed Occurrence in a Young Apple Orchard Mulched With Two Different Organic Materials

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Abstract

In this study, conducted at the Research Station of the Wrocław University of Environmental and Life Sciences, Poland, we sought to determine the communities of weed species and their temporal occurrence in a young apple orchard mulched with spent mushroom compost or *Miscanthus* straw applied to tree rows. A herbicide fallow treatment was used as a control. During the first year of application, both organic mulches protected against the germination of weed seeds stored within the soil. In subsequent years, however, annual weeds occurred in the mulched tree rows, the most aggressive of which was *Chenopodium album* L. Annual increases in population densities were noted over the 4 subsequent years of research, particularly in the rows receiving spent mushroom compost. Perennial species in the family Poaceae and genus *Malva* were present in soil receiving both organic mulches. *Trifolium repens* L. was the perennial weed most often noted in the *Miscanthus* mulch, whereas *Taraxacum officinale* Web. was more characteristic of the spent mushroom compost. Commencing from the spring of the third year following apple tree planting, weed infestation associated with the spent mushroom compost was similar to that observed in the herbicide fallow, thus necessitating three annual applications of herbicide to further maintain the orchard. The insufficient weed suppression obtained with this mulch precludes its recommendation as an effective weed management system. Although *Miscanthus* straw provided extended tree row protection from weed infestation, herbicide intervention was also required. Notably, however, despite the fact that *Miscanthus* straw provided conditions more favorable to tree growth, apple tree yields and fruit quality tended to be similar under the three investigated orchard soil management systems.

Keywords
spent mushroom compost; *Miscanthus* straw; growth; yield

1. Introduction

The composition of weed species growing in orchards is dependent on the methods of soil cultivation, the succession of agrophytocoenoses, and environmental conditions (Licznar-Małańczuk, 2020; Lisek & Sas-Paszt, 2015). Although herbicide fallow remains a standard system of weed management for orchard, there is currently a trend toward reducing the use of synthetic herbicides (Mia et al., 2020). Among the alternatives to herbicide application is the use of organic mulches, and literature reviews that have assessed sustainable alternatives to chemicals for weed control have described the evaluation of several organic mulches in orchard (Lisek, 2014; Mia et al., 2020). Among these, the following materials have received particular attention: wood chips (Granatstein et al., 2014; Granatstein & Mullinix, 2008; Treder et al., 2004), bark (Harrington et al., 2005; Rifai et al., 2002; Szewczuk & Licznar-Małańczuk, 2000), and sawdust (Rifai et al., 2002). Other material that have also been evaluated include straw derived from grain or rape crops (Andersen et al., 2013; Bielińska & Głowacka, 2004; Tebeau et al., 2017; Ustuner & Ustuner, 2011) and the hay – chopped stalk of dicotyledon plants (Forge et al., 2013; Granatstein & Mullinix, 2008; Rifai et al., 2002). In addition, different compost or manure mulches, including composted fruit waste (Mika, 2004), shredded composted hardwood bark (Atucha et al., 2011), and a mixture of poultry litters with addition of hardwood chips (Brown & Tworkoski, 2004), have also been considered.

Although organic mulches may contribute to reducing the occurrence of weeds in tree rows, their efficacy is dependent on multiple factors. In this regard, Rifai et al. (2002) found mulches to be effective for one or two growing seasons, depending on mulch type and amount and weather conditions, whereas Granatstein and Mullinix (2008) reported acceptable weed control for 3 years in a newly established orchard mulched with wood chips, although during this period, a single renewal of mulch depth was required. Furthermore, Abouziena et al. (2008) found that natural materials applied to the soil surface provided effective weed control if applied as a sufficiently thick layer. However, although increasing the height of a rice straw or cattail mulch layer from 3–4 to 9–12 cm was demonstrated to be effective in this regard, this necessitated the application a large quantity of mulch (23–30 tons per hectare). Similarly, in case of hay mulch, Forge et al. (2013) found that it was necessary to apply the mulch at a rate of approximately 50 tons per hectare. Accordingly, although organic mulches can provide an effective alternative the use of herbicides, the associated costs can he high, not only with respect to the large amounts of bulk material that need to be applied but also to transport expenses (Granatstein et al., 2014).

The profitability of orchards under organic mulch management can, however, be improved by the utilization of local low-cost materials (Forge et al., 2013). For example, with the expansion of white button mushroom (*Agaricus bisporus* L.) production in Poland, there has been a concomitant increase in the amount of spent mushroom substrate or spent mushroom compost that can be used in horticulture as a waste organic material (Becher, 2013; Majchrowska-Safaryan & Tkaczuk, 2013), and Uzun (2004) have highlighted the possibility of employing spent mushroom compost in sustainable fruit cultivation. Spent mushroom substrate supplies nitrogen and, to a lesser degree, other macro- and micronutrients, and is also characterized by slightly acidic properties, with a C:N ratio of approximately 12. The nutrient value of this substrate is determined by the composition and proportions of the substrate raw materials, namely, the species of cereals providing the straw, the type of bird manure, and the calcium content of the mineral waste (Becher, 2013).

A further organic mulch can be obtained from straw of species in the genus *Miscanthus*. These C_4 grasses have high dry-mass yielding potential, particularly in the case of *Miscanthus ×giganteus* J. M. Greef et Deuter (Matyka & Kuś, 2011). The straw of this species comprises approximately 73% stalks, with leaves constituting the remaining 27%, and has a C:N ratio of approximately 100 (Kotecki, 2010).

At present, there is comparatively little information available regarding the composition of weeds in organically managed orchards, and the data that has been published tend to be limited to the most frequently occurring weed species (Lisek & Sas-Paszt, 2015). The aim of the present study was to compare the communities of weed species and their temporal occurrence in a young apple orchard in which a spent mushroom compost or *Miscanthus* straw were applied to tree rows as organic mulches. We also assessed the effects of the two mulches on the growth, yield, and fruit quality of apple trees.

2. Material and Methods

We examined the effects orchard floor management systems on the composition of weed communities and the growth and yield of apple trees at the Fruit Experimental Station of the Wrocław University of Environmental and Life Sciences, Samotwór (Poland) (51°06′12″ N, 16°49′52″ E). In the spring of 2015, 1-year-old apple trees (*Malus domestica* Borkh.) ‘Szampion’ grafted on a semi-dwarf M.26 rootstock were planted on haplic luvisol soil formed from silty light loam. Planting orchard pattern was: 3.5 m between rows with 1.2 m distance between trees in one row (2,380 trees ha^{-1}). The two organic mulches applied were spent mushroom compost (SMC), a waste material remaining following the production of the *Agaricus bisporus* L., and the chopped straw of *Miscanthus* ×*giganteus* J. M. Greef et Deuter (MS). As a control treatment, we used herbicide fallow. The experiment was established following a randomized block design with four replications per treatment, each consisting of a plot (6 m × 1 m) containing five trees (i.e., a total of 12 plots and 20 trees subjected to each treatment).

The study was conducted over the 5-year period from 2015 to 2019, during which time, the herbicide fallow was maintained as a control orchard floor management treatment. As herbicides, we used a mixture of glyphosate and MCPA (2-methyl-4-chlorophenoxyacetic acid) at a dosage of 1,960 g ha^{-1} and 600 g ha^{-1}, respectively. During the first year of orchard establishment, the herbicides were applied in July and October. The weeds were also treated in April, June, and July of the second year after planting, and commencing from the third year, the herbicides were applied three times annually in spring (May), summer (July), and at the end of the vegetation period (November).

The organic mulches were spread on the orchard soil in July of the year in which the apple trees were initially planted. The application of SMC and MS was restricted to rows of trees in the demarcated 6 m × 1 m plots, with mulch depths of 10 and 12 cm, respectively. In the SMC plots, no herbicide application was required in the year of orchard establishment, whereas during the following year (2016), herbicide application was necessary in summer. However, commencing from the third year following tree planting (2017), it was necessary to apply herbicide three times (spring, summer, and fall), as in the herbicide fallow treatment, owing to weed infestation of the SMC. In the case of the MS plots, initial herbicide application was postponed until the summer of the second year following tree planting (2016). Weed infestation during the spring of the subsequent 2 years (2017 and 2018) tended to be minor, enabling us to suspend herbicide use in this season; however, application was deemed necessary in summer and fall. In the fifth and final year of the experiment (2019), weeds in the MS plots were suppressed using the same herbicide application schedule as used for the herbicide fallow treatment. Similar to the control treatment, supplementary applications of herbicide to each organic mulch was based on the mix of glyphosate and MCPA at dosages of 1,960 g ha^{-1} and 600 g ha^{-1}, respectively. Neither of the organic mulches was supplemented with additional mulch during the course of the study.

In the second year following orchard establishment, permanent grass was introduced between the tree rows, which was mown several times during the vegetative season. Commencing from spring 2016, the trees were fertilized with nitrogen, with ammonium sulfate being manually applied under the canopy of individual young trees at an average annual dose of 20 g N $tree^{-1}$, equivalent to approximately 50 kg N ha^{-1}. Trees were trained in the form of a slender spindle, and plant protection was carried out in accordance with most recent recommendations of the Orchard Protection Program. Throughout the experiment, the weather conditions tended to be variable and not always favorable for apple tree cultivation, notably in 2015, when summer hail caused damage to leaves on a proportion of the shoots of young planted trees, and in 2017, causing partial damage to the leaves and skins of fruit.

As a means of noninvasive plant population estimation, during the years from 2016 to 2019, the proportional coverage of individual weed species was assessed as a percentage of the total plot surface area (6 m^2), following the methodology of Lipecki and Janisz (2000). The original proportions of the published scale were modified by splitting the range from 0% to 20% into two separate groups, and consequently, the coverage of each taxon was expressed using a discrete percentage scale in divisions of 0%, 1%, 20%, 40%, 60%, 80%, and 100%. In most instances, determinations were performed separately for each species, although in some cases, we estimated coverage at the genus level. Only underrepresented taxa were omitted from analysis. Given that the proportion of each species was assessed

Table 1 Total precipitation and mean temperatures at the Wrocław-Strachowice Station (51°06′14″ N, 16°52′55″ E) in the years 2016 to 2019.

Year after tree planting	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean or sum (Jan–Dec)
Temperature (°C)													
Second (2016)	−0.4	5.1	4.4	8.8	15.0	18.8	19.7	18.4	16.9	8.5	3.6	1.5	10.0
Third (2017)	−3.0	1.2	7.0	8.0	14.3	18.7	19.3	19.5	13.2	11.0	5.6	3.1	9.8
Fourth (2018)	3.0	−2.0	1.6	13.5	17.0	19.1	20.2	21.4	16.2	11.0	5.2	3.0	10.8
Fifth (2019)	−0.1	3.4	6.9	10.6	11.9	22.3	19.8	20.9	14.8	11.1	7.2	3.7	11.0
Precipitation (mm)													
Second (2016)	41.8	46.5	50.8	51.0	44.8	69.4	115.2	23.1	41.0	86.6	43.2	29.7	643.1
Third (2017)	14.5	21.3	35.3	61.8	28.3	58.1	148.0	46.2	65.1	75.2	35.3	30.2	619.3
Fourth (2018)	17.6	1.9	30.8	25.3	41.2	62.8	100.8	16.8	45.9	34.7	15.4	48.2	441.4
Fifth (2019)	48.5	26.7	31.1	37.1	49.7	25.1	35.0	42.1	53.0	30.6	34.8	17.1	430.8

independently, it was not possible to express relationships between the total proportion of all weed populations at a scale of 100%. Weed coverage was initially evaluated in April 2016, followed by a second evaluation in mid-June of the same year. However, commencing from 2017 until the end of the experiment (2019), weed coverage were estimated three times annually, in spring, the beginning of summer, and fall. The nomenclature of vascular plants is based on that presented by Erhardt et al. (2008).

For the years 2016 to 2019, all fruit was collected from the trees in each plot. As measures of fruit quality, we selected the mass (fruit weight), size (fruit diameter), and extent of blush on the surface of the apple skin. Fruit mass was evaluated as a mean weight of 20 apples per plot. A sample of approximately 30 kg of fruit per treatment was classified into two classes based on whether the skin blush covered more or less that three-quarters of the total surface area. The same sample was also divided into three classes based fruit diameter: less than 6.5 cm, 6.5–7.5 cm, and over 7.5 cm. Fruit affected by hail damage in 2017 was omitted from the quality estimates for that year. As a measure of tree growth, the trunk cross-sectional area (TCSA) of each tree and its increment were calculated from two diameters (north–south and east–west directions), measured 30 cm above the grafting height, with measurements being made in spring 2015 and fall 2019. In addition, crop efficiency coefficient (CEC) was computed as the ratio of the total yield of 4 years (2016–2019) to the trunk cross-sectional area in fall 2019.

Discrete data pertaining to soil coverage of the different weed species and continuous data relating to the yield, fruit quality, and growth of apple trees were evaluated statistically, using a one-way analysis of variance for a randomized block design. Statistical analysis took into account a value related to the abundance of different weed species in excess of 1% coverage of the plot area. In the case of some values relating the blush area and size of fruit, a data obtained in separate years were used as a repetition of analysis of variance. Additionally, in order to fulfill the assumptions of analysis of variance, at least approximately, angular transformations (e.g., using the Bliss function) were applied to some of the data. Multiple comparisons were performed at the 5% significance level using Duncan's multiple range test.

3. Results

During the first 2 years of the study, total annual precipitation exceeded 600 mm, whereas amounts were approximately one-third lower in the subsequent years (Table 1). The high amount of precipitation in 2016 and its temporal distribution proved to be conducive to weed germination and growth. The following year was characterized by a drier spring, although July was extremely wet. Temperatures during the growing seasons of 2016 and 2017 tended to be similar. The year 2018 was characterized by periods of drought, covering the final months of winter, the onset of

Table 2 Changes in the mean percentage soil surface under coverage of different weed species in tree rows of herbicide fallow plots in the years 2016 to 2019.

No.	Specification	Year after trees planting										
		Second (2016)		Third (2017)			Fourth (2018)			Fifth (2019)		
		Sp.	Su.	Sp.	Su.	Fa.	Sp.	Su.	Fa.	Sp.	Su.	Fa.
Annual species												
1	*Arabidopsis thaliana* (L.) Heynh.	40	+	20	+	—	40	—	—	20	—	—
2	*Capsella bursa-pastoris* (L.) Med.	+	60	40	40	80	60	40	40	40	20	40
3	*Chenopodium album* L.	—	+	—	40	20	20	40	40	80	40	80
4	*Echinochloa crus-galli* (L.) P. B.	—	+	—	—	—	—	+	+	—	+	20
5	*Erophila verna* (L.) Chevall.	100	—	100	—	—	20	—	—	100	—	—
6	*Geranium pusillum* Burm.	+	—	20	+	20	+	+	+	—	—	+
7	*Lamium purpureum* L.	+	+	20	+	20	—	+	20	+	—	20
8	*Lamium amplexicaule* L.	+	—	20	+	20	—	—	—	+	—	—
9	*Matricaria chamomilla* L.	+	—	+	—	20	20	—	+	20	+	—
10	*Poa annua* L.	80	20	60	20	60	—	+	40	20	20	20
11	*Polygonum aviculare* L.	+	+	—	+	—	—	—	—	20	20	20
12	*Senecio vulgaris* L.	40	20	20	20	60	—	20	40	+	20	20
13	*Stellaria media* (L.) Vill.	40	20	40	20	80	+	—	20	20	—	20
14	*Viola arvensis* Murray	+	+	+	+	—	—	—	—	+	+	—
Perennial species												
15	*Epilobium adenocaulon* Hausskn.	+	+	+	20	20	+	20	+	—	20	—
16	*Malva* spp.	+	+	+	+	20	—	20	20	+	20	20
17	Poaceae – other species	+	+	+	—	20	—	—	+	—	20	20
18	*Sonchus* spp.	+	+	+	20	40	+	+	20	+	+	+
19	*Taraxacum officinale* Web.	20	+	20	+	20	+	20	20	20	+	+
20	*Trifolium repens* L.	+	+	+	20	20	20	20	20	20	20	20

Sp. – spring; Su. – summer; Fa. – fall. Species occurrence: "+"– individual plants with less than 1% soil surface coverage; 20 – small numbers of plants with between 1% and 20% soil surface coverage; 40 – between 21% and 40% soil surface coverage; 60 – between 41% and 60% soil surface coverage; 80 – numerous between 61% and 80% soil surface coverage; 100 – dominant between 81% and 100% soil surface coverage; and "—" – lack of the species.

spring, and the second half of summer, and temperatures were often very high compared with those in other years of the study. Amounts of precipitation in 2019 were the lowest recorded throughout the study period.

The annual counts of taxa were found to be determined by precipitation, temperature, and orchard floor management (Table 2, Table 3). However, whereas high weed abundance was noted in the herbicide fallow and spent mushroom compost (SMC) plots, the *Miscanthus* straw (MS) plots tended to be more sparsely infested. We recorded between 10 and 13 weed taxa in the herbicide fallow and SMC plots, the exception being in the dry year of 2018 when only seven were recorded. With respect to the summer and fall occurrence weeds, we found that in both 2018 and 2019, there were fewer taxa in tree rows relative to the respective seasons of the initial years of the study. Numerous annual and perennial taxa appeared in the fall of 2017, following the abundant summer precipitation in that year, thereby contributing to a discernible overall increase in weed dominance.

Until spring 2017 (the third year after planting the apple trees), only individual specimens of weeds were noted in MS plots (Table 3). Although the annual weed infestation was higher in the following years, the major species found in this mulch did not exceed 40% dominance of the tree row surface area. The application of MS also contributed to a suppression perennial weeds, which from the fall of 2017 onwards, accounted for approximately 20% of the coverage of the mulch surface area. In the herbicide fallow and SMC treated plots, similar levels of dominance had been recorded for separate perennial species in the spring of 2016, and increased further in the following years, primarily in the herbicide fallow plots. Compared with annual species, the percentage of soil surface covered by individual perennial

Table 3 Changes in the mean percentage soil surface under coverage of different weed species in tree rows receiving application of organic mulches in the years 2016 to 2019.

No.	Specification	Year after trees planting										
		Second (2016)		Third (2017)			Fourth (2018)			Fifth (2019)		
		Sp.	Su.	Sp.	Su.	Fa.	Sp.	Su.	Fa.	Sp.	Su.	Fa.
						Spent mushroom compost						
Annual species												
1	*Arabidopsis thaliana* (L.) Heynh.	+	—	40	—	+	20	—	—	20	—	—
2	*Capsella bursa-pastoris* (L.) Med.	+	+	40	20	60	40	20	20	20	20	20
3	*Chenopodium album* L.	+	20	—	20	40	40	60	100	100	80	60
4	*Echinochloa crus-galli* (L.) P. B.	—	+	—	+	20	—	40	40	—	—	20
5	*Erophila verna* (L.) Chevall.	+	—	80	—	—	20	—	—	60	—	—
6	*Geranium pusillum* Burm.	+	—	20	20	20	+	20	+	—	—	+
7	*Lamium purpureum* L.	+	+	+	+	20	—	—	+	+	—	+
8	*Lamium amplexicaule* L.	+	—	+	+	+	—	—	—	20	—	—
9	*Matricaria chamomilla* L.	+	—	20	+	—	—	—	—	+	—	—
10	*Poa annua* L.	+	+	20	+	20	—	+	+	—	—	+
11	*Polygonum aviculare* L.	+	+	—	+	20	20	+	+	40	40	20
12	*Senecio vulgaris* L.	60	+	40	+	40	+	20	+	—	+	+
13	*Stellaria media* (L.) Vill.	20	+	80	+	100	—	—	20	+	—	—
14	*Viola arvensis* Murray	+	+	+	+	+	—	—	—	+	20	—
Perennial species												
15	*Epilobium adenocaulon* Hausskn.	+	+	—	+	20	—	—	—	—	—	—
16	*Malva* spp.	—	+	+	+	—	—	+	20	20	20	20
17	Poaceae – other species	20	+	+	+	20	+	+	40	+	20	20
18	*Sonchus* spp.	+	+	+	+	20	—	+	20	—	+	+
19	*Taraxacum officinale* Web.	+	+	20	—	20	—	—	+	+	+	—
20	*Trifolium repens* L.	—	+	+	+	+	+	+	—	—	—	—
						Miscanthus straw						
Annual species												
1	*Arabidopsis thaliana* (L.) Heynh.	—	—	+	—	—	20	—	—	20	—	—
2	*Capsella bursa-pastoris* (L.) Med.	—	—	—	+	+	20	20	+	20	20	20
3	*Chenopodium album* L.	—	—	—	—	20	20	40	20	40	20	20
4	*Echinochloa crus-galli* (L.) P. B.	—	—	—	—	—	—	—	—	—	—	—
5	*Erophila verna* (L.) Chevall.	—	—	+	—	—	20	—	—	40	—	—
6	*Geranium pusillum* Burm.	—	—	+	+	20	—	+	+	+	—	+
7	*Lamium purpureum* L.	—	+	+	+	+	—	—	20	20	—	20
8	*Lamium amplexicaule* L.	—	—	—	+	—	—	—	—	—	—	—
9	*Matricaria chamomilla* L.	—	—	—	20	+	+	20	—	20	20	20
10	*Poa annua* L.	—	+	+	20	+	20	+	20	+	—	+
11	*Polygonum aviculare* L.	—	—	—	+	—	+	20	+	20	20	+
12	*Senecio vulgaris* L.	—	+	+	+	20	+	40	20	+	+	+
13	*Stellaria media* (L.) Vill.	—	+	+	20	20	—	+	+	20	—	+
14	*Viola arvensis* Murray	—	—	—	+	—	—	+	—	+	+	—
Perennial species												
15	*Epilobium adenocaulon* Hausskn.	—	—	+	—	—	+	+	+	—	+	—
16	*Malva* spp.	—	—	+	+	—	—	+	20	+	20	20
17	Poaceae – other species	—	+	+	+	20	+	+	20	+	+	20
18	*Sonchus* spp.	—	—	+	+	+	—	+	—	—	+	—
19	*Taraxacum officinale* Web.	—	—	+	—	+	—	+	—	—	+	20
20	*Trifolium repens* L.	—	—	+	+	20	+	+	+	—	20	20

Sp. – spring; Su. – summer; Fa. – fall. Species occurrence: "+" – individual plants with less than 1% soil surface coverage; 20 – small numbers of plants with between 1% and 20% soil surface coverage; 40 – between 21% and 40% soil surface coverage; 60 – between 41% and 60% soil surface coverage; 80 – numerous between 61% and 80% soil surface coverage; 100 – dominant between 81% and 100% soil surface coverage; and "—" – lack of the species.

Table 4 Comparison of the three orchard floor managements with respect to the mean percentage of soil surface under coverage the most important weeds in tree rows in different seasons, mean for the years 2016–2019.

Specification	Spring	Summer	Fall
***Capsella bursa-pastoris* (L.) Med.**			
Herbicide fallow – control	36.5b	32.6b	43.3c
Spent mushroom compost	15.4a	8.1a	21.9b
Miscanthus straw	4.1a	2.9a	3.8a
***Chenopodium album* L.**			
Herbicide fallow – control	20.2ab	22.8ab	38.4b
Spent mushroom compost	31.6b	34.1b	56.7c
Miscanthus straw	8.9a	8.9a	12.0a
***Erophila verna* (L.) Chevall.**			
Herbicide fallow – control	72.5c	—	—
Spent mushroom compost	39.1b	—	—
Miscanthus straw	7.9a	—	—
***Poa annua* L.**			
Herbicide fallow – control	31.3b	10.3b	33.4b
Spent mushroom compost	4.2a	0.6a	3.7a
Miscanthus straw	3.0a	2.9a	1.9a
Poaceae – other species			
Herbicide fallow – control	0.3a	4.0	8.5
Spent mushroom compost	4.3b	5.4	15.3
Miscanthus straw	0.2a	0.8	10.2
***Senecio vulgaris* L.**			
Herbicide fallow – control	12.8b	9.3b	33.5b
Spent mushroom compost	20.2b	1.9a	12.0a
Miscanthus straw	0.5a	6.5ab	12.0a
***Stellaria media* (L.) Vill.**			
Herbicide fallow – control	19.0b	5.2b	31.7b
Spent mushroom compost	21.6b	0.1a	38.3b
Miscanthus straw	4.1a	5.1b	5.4a
***Trifolium repens* L.**			
Herbicide fallow – control	3.1	10.3b	15.1b
Spent mushroom compost	0.2	0.5a	0.2a
Miscanthus straw	0.3	1.8a	3.9b

"—" – up to 1% soil surface coverage without statistical 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 letters are nonsignificant.

weeds tended to be stable with respect to orchard water status. Nevertheless, in plots subjected to all three orchard floor management treatments, we recorded an increase in perennial weed dominance in the fall of 2017, followed by a decline in the spring and summer of the dry year of 2018.

In terms of the mean soil coverage of annual weeds, that of *Capsella bursa-pastoris* (L.) Med., *Poa annua* L., and *Erophila verna* (L.) Chevall. (the latter of which was recorded in spring) was significantly higher in the herbicide fallow plots than in either of the mulch-treated plots (Table 4). There were no significant differences between the herbicide fallow and SMC treatments with respect to the spring dominance of *Chenopodium album* L., *Senecio vulgaris* L., and *Stellaria media* (L.) Vill, and the abundance of these species tended to be low in MS plots, and remained at low levels during summer. In fall, *Stellaria media* was found to have an even higher degree of cover, whereas *Chenopodium album* regained dominance in the herbicide fallow and SMC plots, with the mean soil surface area coverage of the latter exceeding 50% of the tree rows under a SMC mulch. Given their similarities,

Table 5 The highest mean percentage of soil surface under coverage of the most important weed species in tree rows of plots receiving application of herbicide fallow or spent mushroom compost mulch for the years 2016 to 2019.

Year after trees planting	*Capsella bursa-pastoris* (L.) Med.	*Chenopodium album* L.	*Erophila verna* (L.) Chevall	*Poa annua* L.	Poaceae – other species	*Senecio vulgaris* L.	*Stellaria media* (L.) Vill.	*Trifolium repens* L.
Herbicide fallow – control								
Second (2016)	50.0	—	85.0b	65.0b	—	30.0b	30.3a	—
Third (2017)	75.0	30.0a	100.0b	60.0b	10.3	55.0c	65.0b	20.0
Fourth (2018)	60.0	30.0a	20.0a	30.0ab	—	35.0b	15.0a	15.3
Fifth (2019)	40.0	75.0b	85.0b	15.0a	15.3	10.5a	15.0a	10.3
Spent mushroom compost								
Second (2016)	—	5.8a	—	—	15.5	60.0b	15.5a	—
Third (2017)	45.3	35.0b	80.0c	15.5	5.5	35.3ab	95.0b	—
Fourth (2018)	25.0	85.0c	15.3a	—	25.0	5.5a	20.0a	—
Fifth (2019)	15.3	95.0c	60.0b	—	15.3	—	—	—

"—" – up to 1% soil surface coverage without statistical 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 letters are nonsignificant.

Table 6 Growth and crop efficiency coefficient of apple trees under the three assessed orchard floor management treatments for the years 2016 to 2019.

Specification	Trunk cross-sectional area (TCSA) (cm^2)			Total length of annual shoots 2016–2017 (cm)	Number of annual shoots 2016–2017		Crop efficiency coefficient (CEC) 2019 ($kg\ cm^{-2}$)
	Spring 2015	Fall 2019	Increase: spring 2015 – fall 2019		<20 cm	>20 cm	
Herbicide fallow – control	0.97	3.66a	2.69a	458	51	5	3.83b
Spent mushroom compost	0.93	3.87a	2.94a	431	40	7	3.07ab
Miscanthus straw	0.92	6.32b	5.40b	760	49	12	2.29a

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 letters are nonsignificant.

we analyzed the dominance maxima of weed species recorded in plots subjected to the control and SMC mulch treatments (Table 5). Annual increases in *Chenopodium album* populations were noted over the years 2016 to 2019. The remaining weed species were abundant in 2017, and in the following dry years of 2018 and 2019, the dominance of these taxa either remained at a similar level or declined significantly relative to those recorded in 2017.

In terms of fruit tree growth and fruit yield, we recorded the most vigorous apple tree growth in MS plots (Table 6). The favorable growth conditions obtained with this floor management system were found to result in a reduction of the crop efficiency coefficient compared with that of trees in the herbicide fallow plot. However, we found that apple tree yields were similar for the three investigated orchard floor management systems (Table 7), the exception being the initial fruit-bearing year (2016), during which yields harvested from the mulched trees were significantly lower. Furthermore, we established that the orchard floor management system had no significant influence on either fruit diameter or the blush surface area, although mean fruit weight was found to be significantly higher in plots treated with the MS mulch than in those receiving to other two treatments.

4. Discussion

The proper depth of organic mulch determines the density and dry mass of weeds that grow in orchards in response to mulch treatments (Abouziena et al., 2008).

Table 7 Yield and fruit quality of apple trees under the three assessed orchard floor management treatments for the years 2016 to 2019.

Specification	Yield (kg tree^{-1})					Mean fruit weight (g)*	Percent of fruit with*			
	2016	2017	2018	2019	Total 2016–2019		Blush >¾ of skin surface	Diameter (cm)		
								>7.5	6.5–7.5	<6.5
Herbicide fallow – control	0.98b	3.92	5.19	4.13	14.22	121a	53	26	34	40
Spent mushroom compost	0.61a	3.70	4.93	2.62	11.86	120a	55	31	18	51
Miscanthus straw	0.30a	2.17	7.36	4.72	14.54	142b	61	38	22	40

* Mean for the years 2016 to 2019. 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 letters are nonsignificant.

The durability of applied mulch is dependent on the speed of its decomposition. According to Quemada and Cabrera (1995) C and N content of organic material is an accurate predictor of the crop residue decomposition rate. A high C:N ratio, as found in the *Miscanthus* straw, hinders the rapid N mineralization of an organic material, thereby extending its durability, and we accordingly found that a 12-cm layer of straw was effective in suppressing the germination of weed seeds in the soil beneath the mulch. Indeed, we found that the composition of the weed flora in MS plots tended to be comparatively very poor, with only five species being recorded in the second year following tree planting (2016). Moreover, there was no appreciable increase in the number of weed species during the subsequent years of the present study. In contrast, depending on season, in both herbicide fallow- and SMC mulch-treated plots, we recorded up to approximately 20 species from the beginning to the end of the experiment, and despite orchard floor management, the composition of weed flora was often found to be poorer compared with that reported by Lisek and Sas-Paszt (2015), who examined different types of orchard and the associated weed infestation. We suspect that this disparity in observations can probably be attributed to the drought conditions at our study site in the years 2018 and 2019.

During the entire initial year of application, the rows of the trees receiving an MS mulch tended to be very well protected from weed infestation. Similarly, Granatstein et al. (2014) demonstrated that covering soil with wood chip mulch almost completely suppressed weed biomass over a similar period of time. During summer of the second year following tree planting (2016), we recorded only a comparatively few single wind-blown seeds germinating at the MS mulch surface, which is similar to the findings of Harrington et al. (2002), who evaluated a bark mulch. Perennial weeds were represented mainly by species of *Malva* spp. and Poaceae. Different grasses have frequently been identified in straw mulches prepared from different species of cereal (Tebeau et al., 2017; Ustuner & Ustuner, 2011) and rape (Andersen et al., 2013). Application of the mulch also proved to be conducive to the growth of the perennial creeping weed *Trifolium repens* L. Such species tend to gradually propagate from drive alleys into organic mulch by means of lateral stoloniferous growth (Harrington et al., 2002).

Annual renewal of wheat and barley mulches in the Tebeau et al. (2017) experiment provided substantial weed control, which can presumably be attributed to an obstruction of physical space and curtailment of exposure to sunlight, whereas Granatstein and Mullinix (2008) found that a single renewal of wood chip mulch was sufficient to obtain satisfactory weed control for a period of 3 years. However, application of the same mulch type over a nonwoven fabric proved to be effective for no longer than one year in the newly established orchard, when *Elymus repens* (L.) Gould was presented in the new established orchard (Granatstein et al., 2014). Given that we did no re-apply MS mulch in the present study, it was found to be necessary to apply herbicide in the summer and fall during the third and fourth year following tree planting, and throughout the final year of the study. We, nevertheless, speculate that a renewal of MS depth, for example, at the beginning of the third year of orchard management (2017), would probably have suppressed the existing weed growth, thereby avoiding the necessity of applying agrichemicals in the orchard.

Although application of SMC mulch initially suppressed the germination of seeds within the soil, in contrast to the MS mulch, it was ineffective in preventing the growth of separate weed species in the top layer of the mulch during the second year following tree planting (2016). During this year, the spring dominance of *Stellaria media* and Poaceae species reached up to 20% of the tree row surface area, whereas the coverage of *Senecio vulgaris* L. exceeded 40%. Simultaneously, the herbicide fallow weed infestation comprised several annual species, already, as well as *Taraxacum officinale* Web. – a notorious perennial orchard weed (Derr, 2001; Licznar-Małańczuk & Sygutowska, 2016). In the third year following tree planting (2017), the weed infestation of SMC plots was found to be very similar to that recorded for the plots receiving the herbicide fallow treatment. As suggested by Majchrowska-Safaryan and Tkaczuk (2013), the weed species germinating on the investigated organic materials may have originated from the mulch itself. However, there is also a high probability that the seeds of these weeds were blown by the wind subsequent to mulch application, and indeed, we observed a close similarity between species composition of weeds that developed in the SMC and herbicide fallow plots in the spring 2016. This tends corroborate the contention of Uzun (2004), who reasoned that button mushroom substrates would probably not contain viable seeds, given the high temperatures inherent in the associated composting and pasteurization processes.

Nonetheless, the performance of the SMC mulch with respect to the suppression of weed infestation did not conform with expectations. A clear increase in weed dominance was apparent in the spring of 2017, the third year following tree planting, with rainfall, particularly in April and July, being seen as an additional contributory factor. Annual species were notably prevalent in the present experiment, which is similar to the findings of Mika (2004), who evaluated the efficacy of composted fruit waste. Consequently, three annual herbicide applications were required to further maintain the orchard without renewing the mulch, which is the same number applications adopted for the herbicide fallow treatment. A further factor potentially contributing to abundant weed growth is the high rate of mulch decomposition contributed to the weed infestation increase. It was fostered by the low C:N ratio of the organic material (Becher, 2013).

Uzun (2004) has, nevertheless, advocated the application of SMC as an orchard fertilizer, given its slow release of constituent elements, which are conceivably used more efficiently by plants than are the nutrients obtained from mineral fertilizers. It is thus plausible that in the present study, mulch nutrients primarily benefited weeds germinating on the mulch, whereas the supply of these nutrients to the more deeply rooted trees was comparatively limited. This would explain why the growth and yield of the apple trees mulched with the SMC did not differ significantly from those of trees subjected the herbicide fallow treatment, and tends to be consistent with the findings of Forge et al. (2013), who found that an increase in available soil nutrient contents is not the primary factor determining the tree vigor. We observed that the value and rate of increase of trunk cross-sectional area were both significantly higher among trees receiving the MS mulch than those under the application of the SMC mulch and in the herbicide fallow plots. However, to a larger extent, we suspect that this more vigorous growth can be attributed to improved water availability in the soil rather than to an enrichment in nutrients, which would be consistent with the findings of Treder et al. (2004), who showed that in an unirrigated orchard, soil water content decreased at a considerably lower rate under a wood chip mulch than under conditions of manual soil cultivation. In the present study, the yields of more vigorously growing trees mulched with MS did not outperform those obtained under the herbicide fallow treatment. This pattern is consistent with the observations of Atucha et al. (2011) pertaining to both the initial and later years of the orchard maintenance.

Collectively, our observations indicate that application of an MS mulch provides better weed suppression than either herbicide fallow management or mulching with

SMC. The potential for producing this material in Poland would appear to be promising, given the straightforward technology of cultivating perennial *Miscanthus* ×*giganteus* grass and the high dry matter yields attained (Kotecki, 2010). The high transportation costs of organic materials, mentioned by Granatstein et al. (2014), could be avoided by establishing plantations of this grass in close proximity to recipient orchards. In contrast to the application of MS, which could provide a viable alternative to herbicide fallow for the orchard floor management of young apple trees, we found that SMC mulch performed poorly as an orchard weed suppressant. Nevertheless, spreading SMC along the tree rows could be considered as a potential means of utilizing this waste material, which is characterized by a high rate of decomposition and mineralization, making it a suitable organic fertilizer for orchards.

5. Conclusions

Miscanthus straw derived from crops established in close proximity to orchards is a potentially suitable organic mulch for suppressing weed infestation in rows of young apple trees. However, mulch depth renewal or integrated treatment with interventional herbicide application under tree crowns will be necessary if this organic material is to be exploited over several years.

In contrast, the limited suppression of weeds obtained with spent mushroom compost precludes recommendation of the application of this material as an effective weed management system, although it may have potential utility as a source of organic fertilizer in young apple orchards. Accordingly, apple tree row mulching could be considered as a viable disposal outlet for the organic waste generated at the end of the button mushroom production cycle.

The crops harvested from apple trees mulched with *Miscanthus* straw and spent mushroom compost did not differ significantly from the yields obtained with herbicide fallow. Application of a stable and durable organic material such as *Miscanthus* straw in young orchards can protect the soil and contribute to improved fruit tree growth.

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