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MULTIFUNCTIONAL LIVING MULCHES FOR WEEDS CONTROL IN ORGANIC APPLE ORCHARDS

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ABSTRACT

A trial assessing the suitability of multifunctional living mulch to maintain the soil and reduce weed infestation was carried out in an organic apple orchard in the years of 2019–2020. Perennial plants (*Alchemilla vulgaris*, *Fragaria vesca*, *Mentha piperita*) and annual crops (*Tropaeolum majus* and *Cucurbita maxima*) were grown on the rows of the apple trees (understory). The weeds number and soil weeds coverage in tree rows were assessed. Regardless of the living mulch species utilized, the soil resulted to be mostly covered by perennial weed species such as: *Equisetum arvense* and *Taraxacum officinale* and annual species such as: *Lamium purpureum*, *Stellaria media*, *Galinsoga parviflora*, *Capsella bursa-pastoris* and *Poa annua*, which were the most common species also for the natural cover used as control. However, all living mulch species limited weed infestation level but *M. piperita*, *F. vesca*, and *T. majus* suppressed more weed growth. It is concluded that living mulch species can be a feasible practice to manage the soil in the tree rows in organic orchards.

Key words: agroecology, apple trees, living mulch, weeds

INTRODUCTION

In orchards, the effect of excessive weed infestation is competition with trees for production factors such as water, nutrients, light and pollinating insects [Abbas et al. 2018] resulting in reduced tree growth and yield [Abouziena et al. 2016, Rodrigues and Arrobas 2020]. Moreover, orchards with soil overgrown by weeds can increase frost risks [Futch 2000] and can create favourable conditions for diseases [Jones and Sutton 1996], pests and rodents [Byers 1984] damages to the tree crop and makes difficult implementing pruning, irrigation and other agricultural practices.

In organic orchards, in management of the soil under the trees, the practices such as the cover cropping and mulching are increasingly used as a method for weed control [Bond and Grundy 2001]. Cover crops and living mulches have been used to reduce the cost of non-chemical weed control, mainly hand and mechanical weeding and for improvement of the physical, chemical and biological properties of the soil [Wardle et al. 2001]. The latter functions are deemed particularly important in organic tree cropping systems due to the impossibility of performing rotations, which are the core practice of the organic farming soil management. Ground cover with living mulch can enhance biodiversity, and deliver a lot of other agroecosystem services also [Mia et al. 2020a, Mia et al. 2021]. Among these services can be included increased populations of beneficial organisms [Futch 2000], reduction of soil pests [Faby 2001], improved soil fertility and resilience [Hartwig and Ammon 2002, Hoagland

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et al. 2008]. They can also counteract the soil erosion, provide nutrients to the tree crop [Sanchez et al. 2003] and reduce nitrogen losses [den Hollander et al. 2007, Żelazny and Licznar-Małańczuk 2018]. It has been postulated that living mulches on tree rows can have a similar function as organic or plastic mulches [Mika et al. 1998]. Moreover, the possibility of using living mulches as a source of a secondary economic benefits would transform the practice from an immaterial ecosystem service provider into a monetizable second cash crop for the farmer, eventually promoting its adoption in commercial orchards.

When selecting plant species for the use as living mulch, factors such as their adaptation to specific climatic conditions, possessing a shallow root system and adequate aboveground biomass, high drought tolerance and low agrotechnical requirements should be considered [Bugg et al. 1996, Hartwig and Ammon 2002]. Plant species used as living mulch should not be attractive to potential diseases or pests [Mia et al. 2020b] and be characterized by low competitiveness to apple trees. Selected living mulch species should also keeping weeds at a density that does not negatively impact on orchard trees [Mia et al. 2020b].

The mechanisms that contribute to the regulation of weed infestation and weed species composition by cover crops and living mulches include shading and competition for water and nutrients [Teasdale and Mohler 2000, Liebman and Davis 2000]. Living mulches create a compact cover on the soil surface, limit weed growth and can change the quantitative and qualitative composition of weeds. Weed infestation depends on the extent of soil cover by the living mulch and the amount of mass it produces [Teasdale 1993, Linares et al. 2008]. On the other hand, soil cover by living mulch plants depends on their morphological characteristics as well as density and sowing or planting date [den Hollander et al. 2007]. Species with a long growing season and late flowering have a higher biomass [Ross et al. 2001]. Furthermore, Bugg et al. [1996] report that the amount of biomass produced by living mulches can be an indicator of the potential amount of organic matter they leave in the soil, which is an additional ecosystem service they can provide. It has a great importance, especially in fruit trees cultivation, which have a high nutrient demand, especially at the beginning of the growing season, and the availability of organic fertilizers continues to decline.

The main species used as cover crops or living mulches in orchards are belonging to the Fabaceae family [Mika et al. 1998, Granatstein and Mullinix 2008, Teravest et al. 2010, Ross et al. 2001] and Poaceae family [Mika et al. 1998, Teravest et al. 2010]. However, the move towards more sustainable agroecological management practices in orchards, including organic ones, has fostered the search of living mulch species providing multiple ecosystem services simultaneously and beyond the simple weed control.

The branchy species with low requirements and easy to grow, like *Alchemilla vulgaris*, *Fragaria vesca*, *Mentha piperita*, *Tropaeolum majus* and *Cucurbita maxima* were selected for the research. These species grow well in semi-shaded places which prevail in the rows, under the crown of trees. *A. vulgaris*, *T. maju*s and *M. piperita* crops can be a source of herbal raw material, and *F. vesca* and *C. maxima* fruits can provide additional income. These species attract pollinating and beneficial insects, also. Selected species are not competitive to apple trees but living mulches can reduce the natural biodiversity, as the planted species can displace the native species.

A trial was conducted to determine the suitability of living mulch species, selected for weed control in an organic apple orchard. We hypothesized that the selected living mulch species could support the weed control in the row of apple trees in organic orchards.

MATERIAL AND METHODS

The trial was conducted in an organic apple orchard in the experimental farm of the National Institute of Horticultural Research in Skierniewice (central Poland 51°58'0"N, 20°9'0"E). The presented studies are a part of a larger project, the results of which are posted in various publications. The 8-year-old apple orchard of cv. ‘Gala’ and ‘Golden Delicious’ on M9 was established on a loamy sandy soil (luvisol soil; sand 78% + silt 18% + clay 4%) containing 3,2% of soil organic matter and pH 6.2. Trees had been planted in a spacing of 3.5 × 1.5 m. Five living mulch species were planted on the tree row: 3 perennials (*Alchemilla vulgaris*, *Fragaria vesca* and *Mentha piperita*) and 2 annuals (*Tropaeolum majus* and *Cucurbita maxima*). The perennial species were planted in autumn 2018 and were observed in both years of experiments, while the annual crops were planted each year at spring time, after preparation the soil. In the inter-rows the orchard turf was maintained and it was systematically mowed. The trial was performed with a completely randomized design, with 4 replications, and the size of each plot was 12.5 m^2.

The number of weeds was determined by counting the individuals of each species in a 20 × 50 cm frame at 4 randomly selected places in the tree rows and weed coverage was evaluated by visual assessment, estimating as a percentage, in the vertical projection, what part of the soil surface was occupied by weed species, respectively.

Each year the weeds number and the soil coverage by weeds were performed at spring – after emergence of weeds, in the summer, during the most intensive vegetation phase, and in autumn, at the end of the vegetation period. The dates of the assessments in the 2 years varied depending on the weather conditions. After the summer assessment, hand weeding was carried out and existing weeds were removed to prevent them from producing seeds. However, the new weeds emergence appeared shortly after weeding and their species composition and abundance were determined during the autumn assessment.

The results were analyzed by ANOVA and the Newman-Keuls test ($p \leq 0.05$) was used to compare the significance of means using the software Statistica v. 13.0 (Statsoft Inc.).

RESULTS

Impact of living mulches on occurrence of weeds. The occurrence of 32 weed species throughout the study period was recorded in the organic apple orchard (Tab. 1). Among these species, 24 were as spring annual or winter annual, 1 biennial and 7 perennial. In experiment 4 species (*Lamium purpureum*, *Erodium cicutarium*, *Polygonum aviculare* and *Bromus mollis*) were annual weeds.

The weed population comprised 26 dicotyledonous species (*Chenopodium album*, *Veronica arvensis* and others) and 6 monocotyledonous, namely: *Echinochloa crus-galli*, *Bromus mollis*, *Agropyron repens*, *Digitaria sanguinaris*, *Setaria* sp. and *Poa annua*. Several species, irrespective of the classification of growing season habits were noted in all assessment terms performed during the growing season (spring, summer and autumn). A few weed species (e.g. *Cirsium arvense*, *Fallopia convolvulus*, *Galeopsis tetrahit*, *Matricaria maritima subsp. inodora*, *Polygonum persicaria*, *Raphanus raphanistrum*) were recorded only during some observation terms, mainly at the spring, and *Erophila verna* (syn. *Draba verna*) was recorded in all mulches but only at spring. According to their development, the number of weed species found in the natural cover (control) and under the different living mulches in all 3 terms of observation was different. In the natural cover at the spring appeared 22 weed species, in the summer 25 species and in the autumn 21 species.

Impact of living mulches on weed population size. The number and biomass of weeds and the soil coverage might be indicators of weed infestation intensity. The weed infestation was strongly influenced by the living mulch species (Figs 1–3). At the time of the spring assessment the total weeds number in tree rows mulched with *T. majus* and *C. maxima* was significantly lower than in natural cover (reduction by 50.4% and 43.4%, respectively), while for the other living mulch species no differences emerged compared to the control, totalling on average 908,4 plants · m^{-2} (Fig. 1).

During spring time, irrespective of the living mulch species, the weed population structure was dominated by annual species, accounting on average for 88.4% of the total weeds. The highest number of annual weeds was recorded in tree rows mulched with *M. piperita* (919.3 pcs · m^{-2}) and slightly lower with *F. vesca* (796.8 pcs · m^{-2}) and *A. vulgaris* (787.5 pcs · m^{-2}). On the other hand, the highest share of perennial weeds occurred in natural cover (120.1 pcs · m^{-2}), and the lowest with the *C. maxima* mulch (47 pcs · m^{-2}). The other living mulch species showed a similar abundance of perennial weeds, ranging from 7.6% (*F. vesca*) to 17.9% (*T. majus*) of the total number of weeds in the population, about 30% less than in the natural cover. Mulching with *M. piperita* resulted also in the most abundant share of dicotyledonous weeds (758.7 pcs · m^{-2}), followed by natural cover (637.6 pcs · m^{-2}), *F. vesca* mulch (615.7 pcs · m^{-2}) and *A. vulgaris* mulch (574.5 pcs · m^{-2}). The lowest share of this class of weeds was noted in *T. majus* and *C. maxima* mulches (236.6 and 268.5 pcs · m^{-2},

Table 1. The occurrence of weed species in the weed population of apple tree rows managed with living mulches, depending on the seasonal growing assessment

Weed species*	Occurance of weeds in living mulch species*						Biological group of weeds**
	Alchemilla vulgaris	*Fragaria vesca*	*Mentha piperita*	*Tropaeolum majus*	*Cucurbita maxima*	Contol	
Dicotyledonous weeds							
Amaranthus retroflexus	+◊	+◊	+◊+	+	–	+◊+	annual
Arnoseris minima	+◊	◊+	++	+◊+	++	+◊+	annual
Capsella bursa-pastoris	+◊+	+◊+	+◊+	+◊+	+◊+	+◊+	annual
Chenopodium album	+◊+	+◊+	+◊	+◊	+◊	+◊	annual
Cirsium arvense	+	+	–	–	–	–	perennial
Equisetum arvense	+◊+	+◊+	+◊+	+◊+	+◊+	+◊+	perennial
Erigeron canadensis	–	+◊	◊	+◊+	+	+◊	biennial
Erodium cicutarium	++	+◊	+◊+	◊	+◊+	+◊+	annual
Erophila verna	+◊	+	+	+	+	+	annual
Fallopia convolvulus	+	+	+	–	+	–	annual
Galeopsis tetrahit	–	+	–	◊	–	◊	annual
Galinsoga parviflora	+◊+	+◊+	+◊+	+◊+	+◊+	+◊+	annual
Geranium pusillum	+◊+	+◊+	◊+	◊	+◊	+◊+	annual
Hypochaeris radicata	++	+◊+	+◊+	++	+◊+	+◊+	perennial
Lamium purpureum	+◊+	+◊+	+◊+	+◊+	+◊+	+◊+	annual
Matricaria maritima subsp. *inodora*	–	–	–	+	+	–	annual
Polygonum aviculare	+	+◊+	◊	+	+◊	+◊+	annual
Polygonum persicaria	+	◊	–	◊	–	–	annual
Raphanus raphanistrum	+	+	+	–	–	+	annual
Rumex acetosella	+◊+	+◊	+◊	–	–	+◊	perennial
Spergula arvensis	++	+◊+	◊+	◊	+	–	annual
Stellaria media	+◊+	+◊+	+◊+	+◊+	+◊+	+◊+	annual
Taraxacum officinale	+◊+	+◊+	+◊+	+◊+	+◊+	+◊+	perennial
Trifolium repens	◊	◊+	◊+	–	◊	◊+	perennial
Veronica arvensis	++	+◊	◊	+◊+	+◊+	+◊+	annual
Viola arvensis	+◊+	++	◊	–	–	+◊+	annual
Monocotyledonous weeds							
Agropyron repens	++	+◊+	+◊+	+◊+	+◊+	◊+	perennial
Bromus mollis	+◊+	+◊+	++	+◊+	+◊+	+◊+	annual
Digitaria sanguinalis	+	◊+	◊+	◊+	◊+	◊+	annual
Echinochloa crus-galli	+◊	+◊+	+◊	+◊+	+◊	+◊+	annual
Poa annua	+◊+	+◊+	+◊+	+◊+	+◊+	+◊+	annual
Setaria sp.	◊+	◊	+	◊	◊+	◊+	annual
Number of species	29	31	28	26	25	27	

* The period of weeds occurrence: spring (+); summer (◊); autumn (+)

** Four species (*Lamium purpureum*, *Erodium cicutarium*, *Polygonum aviculare* and *Bromus mollis*) in the experiment were annual weeds, although under favourable conditions they can be a biennial species.

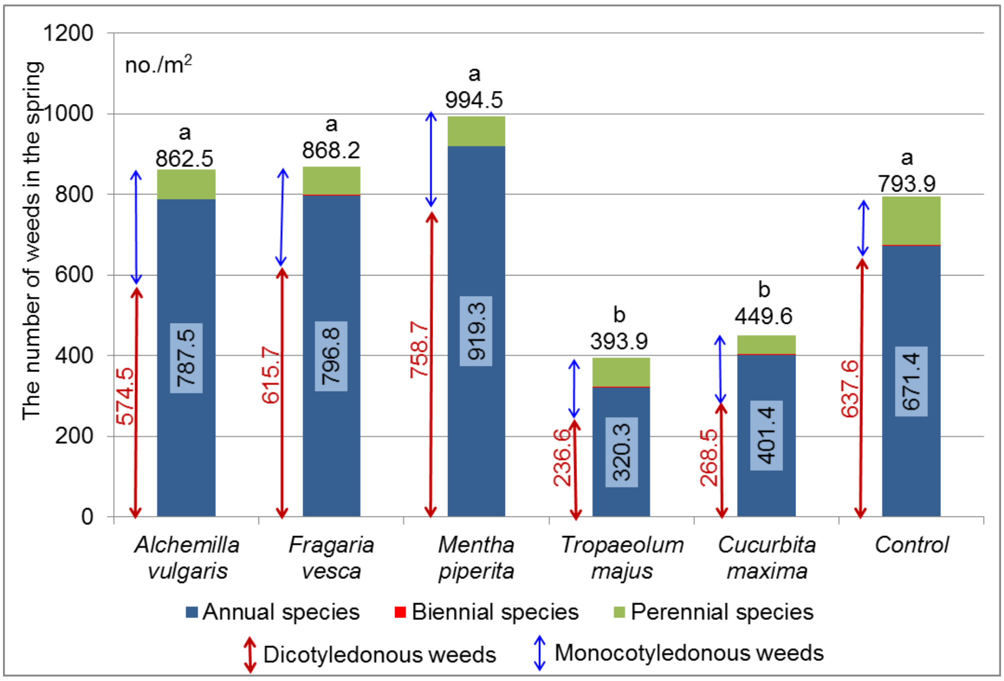

Fig. 1. The weeds number in tree rows at spring, by taxonomical classes and growth behaviour, depending on living mulch species (means of 2019–2020). The data with the same letters are not statistically different

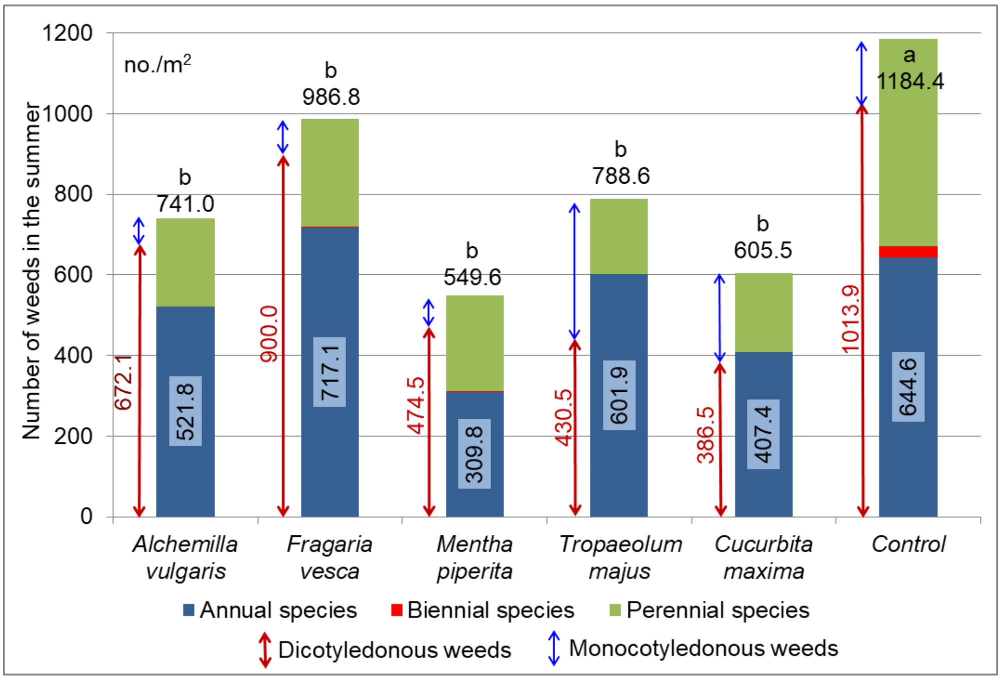

Fig. 2. The weeds number in tree rows at summer, by taxonomical classes and growth behaviour, depending on living mulch species (means of 2019–2020). The data with the same letters are not statistically different

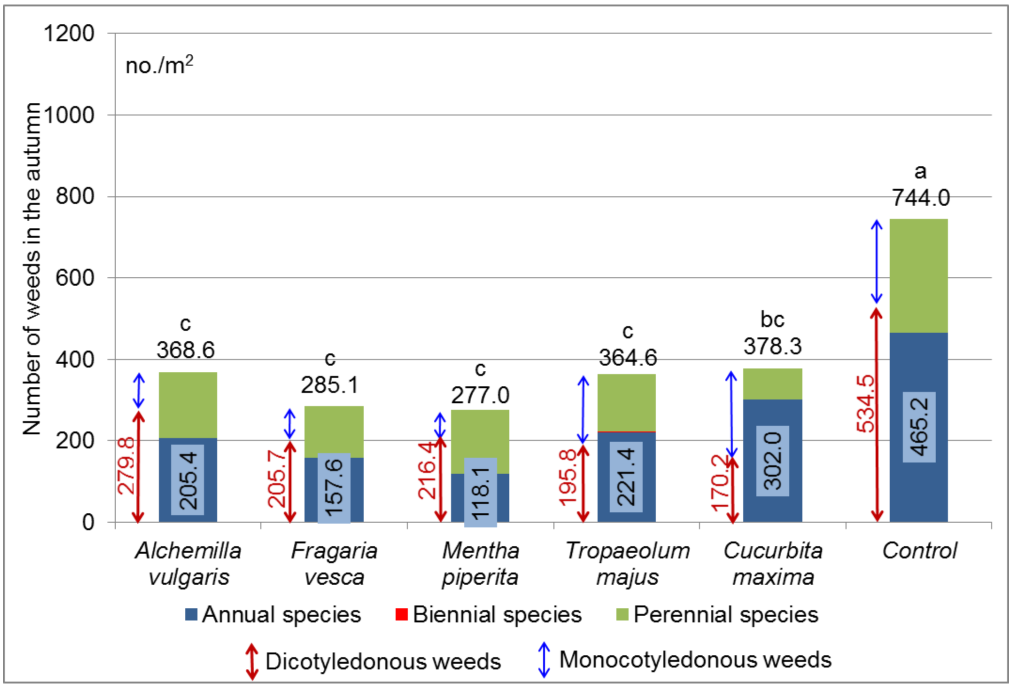

Fig. 3. The weeds number in tree rows in autumn, by taxonomical classes and growth behaviour, depending on living mulch species (means of 2019–2020). The data with the same letters are not statistically different

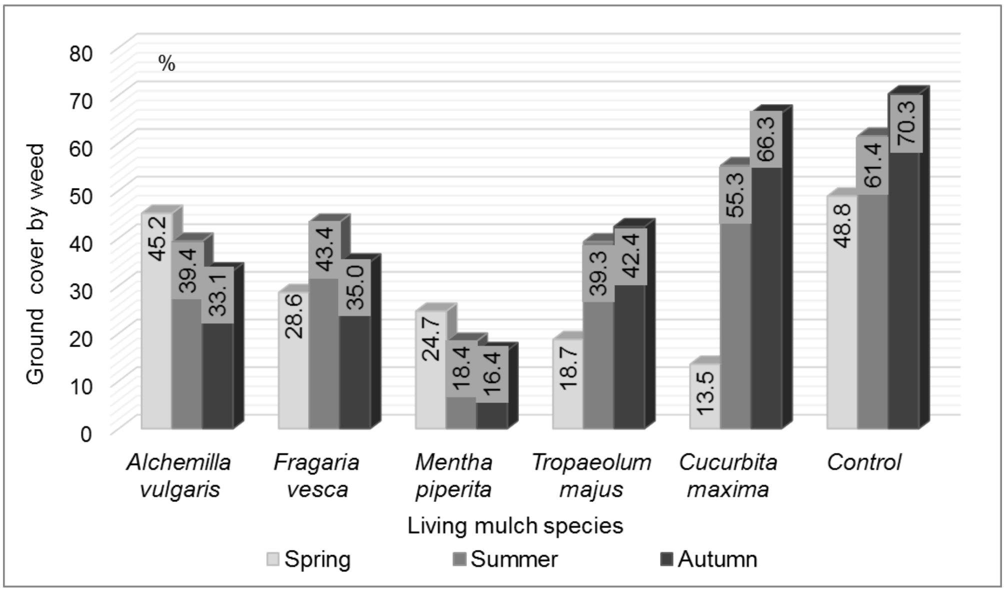

Fig. 4. The percentage of soil coverage by overall weeds in the rows of apple trees, depending on living mulch species (means of 2019–2020)

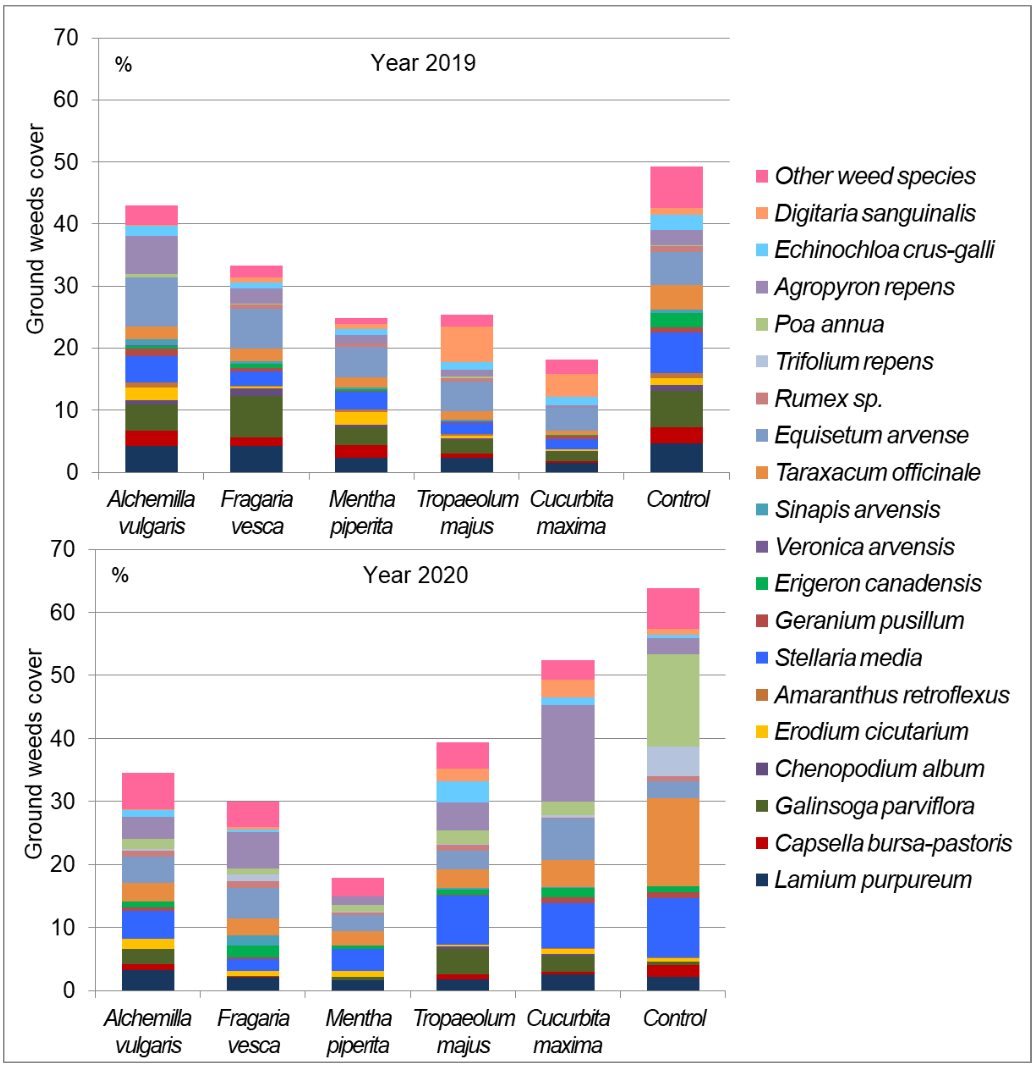

Fig. 5. The soil coverage by weed species in the rows of apple trees, depending on the living mulch species (means of 3 evaluation terms – spring, summer and autumn)

respectively), which recorded also the lowest number of monocotyledonous weeds, at a level similar to natural cover. On the other hand, mulching with *A. vulgaris* resulted in the highest number of monocotyledonous weeds followed by the *F. vesca* and *M. piperita* mulches (Fig. 1).

During the summer assessment a significant reduction of the total weeds number, in comparison to natural cover, on the plots mulched with *M. piperita* (by 53.6%) and *C. maxima* (48.9%) was observed (Fig. 2). *Alchemilla vulgaris* and *T. majus* mulches allowed to reduce the incidence of weeds at 37.4% and 33.4%, respectively, in comparison to natural cover (control), while *F. vesca* mulch reduced the number of total weeds by only 16.7%. Interestingly, in several cases, weed species such as *Erophila verna*, *Polygonum persicaria* and *Spergula arvensis* were not observed in tree rows with natural cover, but were present with living mulch species. The number of weed plants in some plots with living mulches was greater than in the natural cover for a few specific species, namely *Erodium cicutarium* in *M. piperita* and *C. maxima*; *Galeopsis tetrahit* in *T. majus*; *Lamium purpureum* in *A. vulgaris* and *T. majus*; *Hypochaeris radicata* in *F. vesca* and

M. piperita; *Veronica arvensis* in all living mulches, except *A. vulgaris*, and *Viola arvensis* in *A. vulgaris*.

Considering the structure of the weed population, annual species were about 50% more abundant with *A. vulgaris*, *F. vesca* and *T. majus* compared to natural cover, which share was similar to both *M. piperita* and *C. maxima*. This was paralleled by a lower number of perennial weeds on plots mulched with *A. vulgaris*, *F. vesca* and *T. majus* compared to control. Dicotyledonous weeds shared the majority (about 90%) of the population in *A. vulgaris*, *F. vesca* and *M. piperita,* similarly to the natural cover, while *T. majus* resulted to have dicots and monocots sharing an equal percentage of plants (Fig. 2).

In autumn the total weeds number in tree rows with living mulch species ranged from 277 to 378.3 pcs · m^{-2} and was significantly lower in comparison to the natural cover (744 pcs · m^{-2}) where the highest abundance of both annual and perennial weed species was recorded (Fig. 3). In tree rows with living mulches, the highest number of annual species was recorded in *C. maxima* (302 pcs · m^{-2}), while the lowest in *M. piperita* mulch (118.1 pcs · m^{-2}), which constituted 79,8% and 42.6% of that from natural cover, respectively.

In the living mulches the highest share of perennial weeds in the weeds population was recorded on plots mulched with *M. piperita* (57.4%), and the lowest was determined in *C. maxima* plots (20.2%), while the other mulching species were ranging around 40%, similarly to the natural cover.

Considering the taxonomical classification, a high abundance of dicotyledonous weeds (about 75%) was recorded with *M. piperita*, *A. vulgaris* and *F. vesca*, which resulted similar to natural cover, while it was lower in *T. majus* (53.7%) and *C. maxima* (45.0%). As a consequence, the latter living mulch species presented a large share of monocotyledonous weeds, about 55%, while *M. piperita* presented the lowest percentage (21.9%).

When comparing the dynamic of the weed population size over the year, the total number of weeds in the autumn resulted to be the smallest in comparison to the spring and summer assessments, regardless of the method of soil maintenance in tree rows (Figs 1–3). In the natural cover the highest number of total weeds was recorded in the summer (1184,4 pcs/m^2), on average about 65% higher than in spring and autumn. The different species of living mulches induced a diverse population size dynamic. *A. vulgaris* and *M. piperita* recorded the highest number of weeds in spring, which steadily decreased during the growing season. On the other hand, *F. vesca*, *T. majus* and *C. maxima* resulted to have a peak in summer.

The different dynamic was visible also considering both the taxonomic and growth classification of the weed species. The number of annual weeds in tree rows mulched with *A. vulgaris*, *F. vesca*, *M. piperita* and in natural cover followed a decreasing trend from spring to autumn, while a peak was observed in *T. majus* and *C. maxima* in summer (Figs 1–3). Considering the botanical classes, all living mulch species, except *M. piperita*, showed a peak in the number of dicotyledonous weeds in summer, while *M. peperita* presented a decreasing trend from spring to autumn. On the other hand, the number of monocotyledonous weeds with *A. vulgaris*, *F. vesca*, *M. piperita* and in natural cover was higher in spring than in summer and autumn, while in *T. majus* the highest weeds number was in summer. In *C. maxima* mulch this group of weeds had a similar abundance throughout the year.

In living mulches such as *A. vulgaris*, *F. vesca* and *M. piperita*, the most numerous species was *Capsella bursa-pastoris*, followed by *Equisetum arvense*. In *T. majus*, the highest number of *Equisetum arvense*, *Digitaria sanguinalis* and *Echinochloa crus-galli* was obtained, and in *C. maxima* it was *Equisetum arvense* and *Echinochloa crus-galli*. In natural cover the greatest number of such weeds as *Equisetum arvense*, *Stellaria media*, *Capsella bursa-pastoris* was noted and slightly lower *Taraxacum officinale* and *Lamium purpureum*.

Weed coverage. The soil coverage by weeds in the rows of apple trees with living mulches was variable depending on the season (Fig. 4) and year (Fig. 5). In every observation period, the highest soil coverage by weeds was observed with natural cover (Fig. 4). All living mulch species reduced the soil coverage by total weed in tree rows, in comparison to the natural cover, regardless to the observation period.

In the spring the soil coverage by weeds ranged between 45.2% with *A. vulgaris* to 13.5% in *C. maxima* (Fig. 4). This resulted in a reduction of 60–70% with *C. maxima* and *T. majus* in comparison to natural cover, and a lower reduction with the other living mulch species. However, in summer, the situation changed, and *C. maxima* resulted to have the highest percentage of soil covered by weeds (55.3%), while in all the other living mulch species it was lower (around 40%) and the smallest with *M. piperita* (18.4%) (Fig. 5), resulting in a reduction from 70% (*M. piperita*) to about 30% (*T. majus*, *A. vulgaris* and *F. vesca*) compared to natural cover. In autumn *C. maxima* resulted again to allow a high weeds soil coverage (66.3%), while less weeds coverage was observed in mulches with *T. majus* (42.4%), *F. vesca* (35%), *A. vulgaris* (33.1%) and the lowest in *M. piperita* (16.4%).

The soil coverage dynamic followed a similar trend as for the population size. Plots with *C. maxima* and *T. majus* living mulches showed a systematically increase of the weeds soil coverage, while those mulched with *A. vulgaris* and *M. piperita* showed a decreasing trend throughout the year. *F. vesca* showed a peak in the summer. Living mulch with *M. piperita* caused the highest reduction of soil weeds coverage during all terms of the growing season.

The living mulch species induced a different soil coverage by weed species when considering the average of the 3 seasonal assessments (Fig. 5). In 2019, in tree rows with natural cover, the soil was most heavily covered by weed species such as *Stellaria media* (6.5%), *Galinsoga parviflora* (5.8%), *Equisetum arvense* (5.3%) and *Lamium purpureum* (4.6%). A small soil coverage, less than 1%, was provided by species such as *Chenopodium album*, *Amaranthus retroflexus*, *Geranium pusillum*, *Sinapis arvensis*, *Rumex* sp. and *Poa annua*, while species such as *Veronica arvensis* and *Trifolium repens* were not observed at all. In 2020, the soil in tree rows with natural cover was most heavily covered by *Poa annua* (14.6%), *Taraxacum officinale* (14%), *Stellaria media* (9.5%) and *Trifolium repens* (4.7%), while less than 1% of the soil was covered by such weeds as *Galinsoga parviflora*, *Amaranthus retroflexus*, *Erodium cicutarium*, *Geranium pusillum*, *Veronica arvensis*, *Sinapis arvensis*, *Trifolium repens* and *Digitaria sanquinalis*. The annual species like *Chenopodium album* and *Sinapis arvensis* were not present in natural cover.

Most of living mulch species reduced the soil coverage by weed species in both years, although the level of reduction was variable. In 2019, the soil coverage by weed species such as *Lamium purpureum*, *Capsella bursa pastoris*, *Stellaria media*, *Erigeron canadensis*, *Taraxacum officinale*, *Echinochloa crus-galli* was reduced by all living mulches used in the trials. The following species were also reduced, with some exceptions: *Galinsoga parviflora* with the exception of *F. vesca* mulch, *Equisetum arvense* with the exception of *A. vulgaris* and *F. vesca*, *Agropyron repens* with the exception of *A. vulgaris*. In 2020, all living mulch species limited the soil coverage by weed species such as *Capsella bursa pastoris*, *Stellaria media*, *Taraxacum officinale*, *Trifolium repens*, *Poa annua* while the soil coverage by *Lamium purpureum* was reduced only by *M. piperita* and *T. majus* mulches and *Agropyron repens* by *M. piperita* mulch.

DISCUSSION

Maintaining living mulches in tree rows in organic orchards is one of the non-chemical methods of weed control. However, to preserve biodiversity, it is important to keep the weed infestation at a relatively low level, which does not threaten the cultivated crops [Mika 2004, Bond and Grundy 2001]. The 5 plant species used as living mulches in the trial were selected for their different properties (as providers of ecosystem services – e.g. *T. majus*, or as multifunctional crops – e.g. *C. maxima*, *M. piperita*, *A. vulgaris*). According to the literature, the selection of an appropriate species for living mulch is crucial for weed control and tree yield [Bugg et al. 1996, Hartwig and Ammon 2002]. The studies of Hogue et al. [2010] showed that the losses in apple yield can range from 11% to 24%, depending on the species used as living mulch. Neilsen and Hogue [2000] found that white clover grown in tree rows in apple orchard, despite providing nutrients to the soil, also reduced fruit yield compared to the control. The authors conclude that growing of perennial species as living mulches in tree rows needs less labor and gives good soil protection, unlike annual species which have to be sown each year and usually do not enough protect the soil at the beginning of the growing season.

It was found that the living mulch species grown in the rows of apple trees affected the abundance of weeds and the composition of weeds population. The weed species observed in the trial were often found in orchards [Mika 2004, Lisek 2012]. Lisek [2014] reported that about 30 weed species, both annual and perennial, are common in Polish orchards. The impact of weeds on the crop depends on the share of each specific weed species in weeds population and its competitiveness. Domaradzki et al. [2007] found that weed species diversity in organic production is higher than in conventional, due to the less intensive production system.

The annual weeds emerging from the spring to autumn, such as: *Stellaria media*, *Capsella bursa-pastoris*, *Geranium pusillum*, *Viola arvensis*, *Poa annua* and some other grasses, were those mainly found within the weed population of the trial (Tab. 1). Weeds like *Veronica* sp., *Erigeron canadensis*, usually germinate in autumn and in the spring. In apple orchard, these species, depending on the site, were observed throughout the growing season. The listed species can overwinter in different growth stages. Weeds requiring a higher temperature for germination, such as *Galinsoga parviflora*, *Amaranthus retroflexus*, *Echinochloa crus-galli*, *Setaria pumila*, Digitaria sanguinalis can appear in late spring and in the summer. Among perennial weeds some species overwinter in rosette, e.g. T*araxacum officinale*, others only in the underground organs, e.g. *Cirsium arvense*, *Convolvulus arvensis* and some of them, e.g. Elymus repens, remain green during mild winters and freeze during cold and snowless ones [Paradowski 2017]. The high abundance of annual weeds in the mulched tree rows should be explained by the variability of seed bank and the occurrence, at different intensity, of species with different temperature requirements and different development potential.

The harmfulness of most weeds is determined primarily by their number and biomass. Some authors report that the harmfulness of weed communities with a simplified composition may be higher than that of more diverse ones [Rola 1982].

In the experiments all living mulches clearly reduced the weeds number in the rows of apple trees at the summer and in the autumn wherein the higher reduction in autumn was observed (Figs 2 and 3). In the spring the weeds number reduction in mulches with *T. majus* and *C. maxima* was noted only (Fig. 1). The soil coverage by overall weeds has been limited by all living mulches in all observation terms and the highest effects was obtained in living mulches with *M. piperita*, *F. vesca* and *T. majus* (Fig. 4).

The highest abundance of Equisetum arvense and Stellaria media was found in the natural cover (Fig. 5). These species are the most common weeds in orchards [Lisek 2012, Hwang and Park 2016]. In living mulch with *F. vesca* the plant number of Stellaria media was reduced by 18.9% (Figs 2–4). Schumacher et al. [1988] indicate that *F. vesca* can be used as a living mulch due to its spreading shape. Neri et al. [2021] confirm the beneficial effect of *F. vesca* used as living mulch in the rows of organic grapevines on controlling weed infestation. The authors report that *F. vesca* maintain weed diversity and reduces the impact of *Convolvulus* spp., which belongs to the most dangerous and invasive weed species. Neri et al. [2021] also report that *F. vesca* used as a living mulch in organic grapevines provided an extensive soil cover without detrimental effects on grapevine yield.

The effect of living mulches on weeds infestation was also confirmed by other authors [Petit et al. 2018]. The best results, both in the terms of weeds quantity and soil coverage, were obtained when M. piperita was used, which was not mentioned as crop suitable for living mulch before. *M. piperita* strongly reduced the growth of annual weeds and *Taraxacum officinale*. *Taraxacum officinale* is a perennial species commonly found in grass mulches [Tworkoski and Glenn 2012]. *Tropaeolum majus* also contributed to a significant reduction of soil coverage by *Taraxacum officinale* (Fig. 5), while in earlier studies Licznar-Małańczuk [2020] did not show sufficient expansion and inhibition of weed growth.

CONCLUSIONS

The soil management in the rows of apple trees is a key challenge for the growers in modern organic orchards. From the trial it emerged that:

1. All plant species used as living mulches in apple tree rows reduced weeds number compared to natural cover but in mulches with *A. vulgaris* and *F. vesca* the best effect was obtained later than in other crops.
2. The soil coverage in tree rows was dominated by a perennial weeds such as *Equisetum arvense* and *Taraxacum officinale* and annual weeds, e.g. *Lamium purpureum*, *Stellaria media*, *Galinsoga parviflora*, *Capsella bursa-pastoris* and *Poa annua*, irrespective of the living mulch species.

3. *Mentha piperita* and *T. majus* strongly reduced the growth of both annual and perennial weeds from the first season.
4. The soil coverage by overall weeds in tree rows with natural cover and in *C. maxima* and *T. majus* mulches had systematically increased in subsequent terms and in *A. vulgaris* and *M. piperita* systematically decreased.
5. A correct selection of living mulch species could support the weed control in the tree rows in organic orchards.

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