ACTA AGROBOTANICA
Vol. 67 (1), 2014: 47–54
Original Research Paper
DOI: 10.5586/aa.2014.001

THE DIVERSITY OF WEED SPECIES OCCURRING IN LIVING MULCH IN AN APPLE ORCHARD

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Received: 20.03.2013

A b s t r a c t

In a study conducted at the Research Station of the Wrocław University of Environmental and Life Sciences, weed occurrence in living mulches maintained in apple tree rows of 'Pinova' cv. was assessed during the first seven years after sowing. The trees were planted in spring 2004 (3.5 × 1.2 m). In the same year, living mulches: colonial bent grass, white clover and French marigold, were sown into 1 m wide tree rows. Blue fescue, the only perennial cover crop with herbicide application against dicot weeds once in the second year after sowing, was introduced in the second year after planting the trees to replace dwarf nasturtium which was sown in the year of orchard establishment. In the inter-row spaces, perennial grass was maintained.

During the first seven years, variation in weeds was observed depending on living mulch. Multi-species weed infestation persisted throughout the study period only in the case of annually resown French marigold. Perennial living mulches were significantly suppressed the annual weeds. Significant suppression of *Taraxacum officinale* Web. was found where the soil surface was covered by perennial grass sod in more than ¾. The maintenance of blue fescue resulted in significantly lower average soil coverage by *Elymus repens* (L.) Gould; the growth of this weed significantly contributed to the reduction of white clover sod and French marigold plants.

Key words: apple tree**,** cover crop, weedy orchard, *Elymus repens*, *Taraxacum officinale*

INTRODUCTION

Weed infestation in agricultural crops is determined by a range of factors, such as: crop rotation, tillage, soil fertility, and habitat conditions [1]. In case of fruit crops, the most important factors additionally include the following: method of tree planting [2], fertilization [3], and in particular orchard floor management within and between tree rows [4–6]. High variation in weed occurrence between years following the tree planting is also specific to fruit production. Over a period of several years, it is possible to observe the growth or decline of selected weed populations. Some species appear only in single growing seasons, whereas other ones occur every year and their presence can be described as nearly constant [7,8]. Long-term application of post-emergence herbicides is an effective method of weed suppression within rows of trees [9], yet, following the trends in the area of crop farming [10–12], modern horticulture has been striving to reduce the use of chemical means of weed control and to replace them with more environmentally friendly methods. One of them is the application of living mulches within or between rows of fruit [4–6,13,14] or ornamental [15] trees. The presence of the cover crop, however, results in less favourable conditions for tree growth and development [16]. What is more, the density of plants composing the living mulch is insufficient to prevent fast emergence of weeds – especially in the year of sowing. Under a high level of weed infestation, the competition between the living mulch and the tree increases substantially [4,13,14]. In the years after the sowing of the mulch, weed suppression depends on the composition of the cover crop. Some species, such as red fescue with perennial ryegrass [15], white mustard [5] and common vetch [17], were found to have satisfactory potential in this regard. On the other hand, the application of bird's foot trefoil [15], velvet bean [6], or white clover [18] did not bring positive results.

The aim of this study was to estimate the diversity of weed species occurring in the living mulch in an apple orchard during the first seven years after tree planting.

MATERIALS AND METHODS

Apple trees (*Malus domestica* Borkh.) cv. 'Pinova' on a dwarf rootstock P 22, P 16 and P 2 were planted in spring 2004 at a distance of 3.5 × 1.2 m (2380 trees × ha^{-1}) on luvic soil derived from silty light loam. Immediately after planting, three cover crops, used as living mulches, were sown: white clover (*Trifolium repens* L) cv. 'Sonja' (10 kg × ha^{-1}), colonial bent grass (*Agrostis vulgaris* With. syn. *Agrostis tenuis* Sibth. and *Agrostis capillaris* L.) cv. 'Frasek' (34 kg × ha^{-1}), and the dwarf cultivars 'Carmen' or 'Kolumbina' of annual French marigold (*Tagetes patula* L.) (10 kg × ha^{-1}) – the latter mulch renewed in the subsequent years by sowing 15 kg of seed per hectare. The fourth of the investigated species, blue fescue (*Festuca ovina* L.) cv. 'Edolana', was sown in spring 2005 (30 kg × ha^{-1}) to replace annual dwarf nasturtium (*Tropaeolum majus nanum* L.). In the second year after sowing (2006), dicotyledonous weeds developing within the blue fescue sod were treated with an herbicide based on MCPA (2-methyl-4-chlorophenoxyacetic acid) applied at a rate of 2 l × ha^{-1}. Prior to sowing this perennial mulch of blue fescue and at the beginning of the second year after tree planting (2005), before the renewal of the French marigold mulch, chemical weed control was applied using a mix of glyphosate and MCPA (8.0 + 1.5 l × ha^{-1}). Dicotyledonous weeds developing in French marigold after the growing period in the third year (2006) and monocotyledonous once after the fifth year (2008) were treated with an herbicide based on MCPA – 3,5 l × ha^{-1} and glyphosate – 8,0 l × ha^{-1}, respectively. At the beginning of the seventh year after sowing French marigold (2010), developing weeds were treated twice with an herbicide based on a mix of glyphosate and MCPA (4.0 + 2.0 l × ha^{-1})

The living mulches were only sown in tree rows, in four replications. Between the rows, permanent grass sod was introduced and it was mown several times per growing season. Within each replication, three plots with a dimension of 6 × 1 m were delimited. The degree of soil coverage by living mulches was assessed with a 5% measurement error as the percentage of the total plot area (6 m^2) occupied by the mulching plant. In the same plots, the percentage of the soil surface occupied by weed species was determined. For this purpose, a non-invasive method of weed population assessment, following the methodology of Lipecki and Janisz [8], was employed. The assessments were performed separately for each species, while in some cases for the genus of weeds; the underrepresented taxa were omitted. The proportion of the plot area occupied by each species was expressed using a discrete percentage scale: 0, 20, 40, 60, 80 and 100%. As the share of each species was assessed independently, it was impossible to express the relationship between the total percentage of all weed populations and living mulch sod at a scale of 100%. The first assessment took place in the year of sowing (2004), after the emergence of the mulching plants. In the subsequent years (2005–2010), it was done in July.

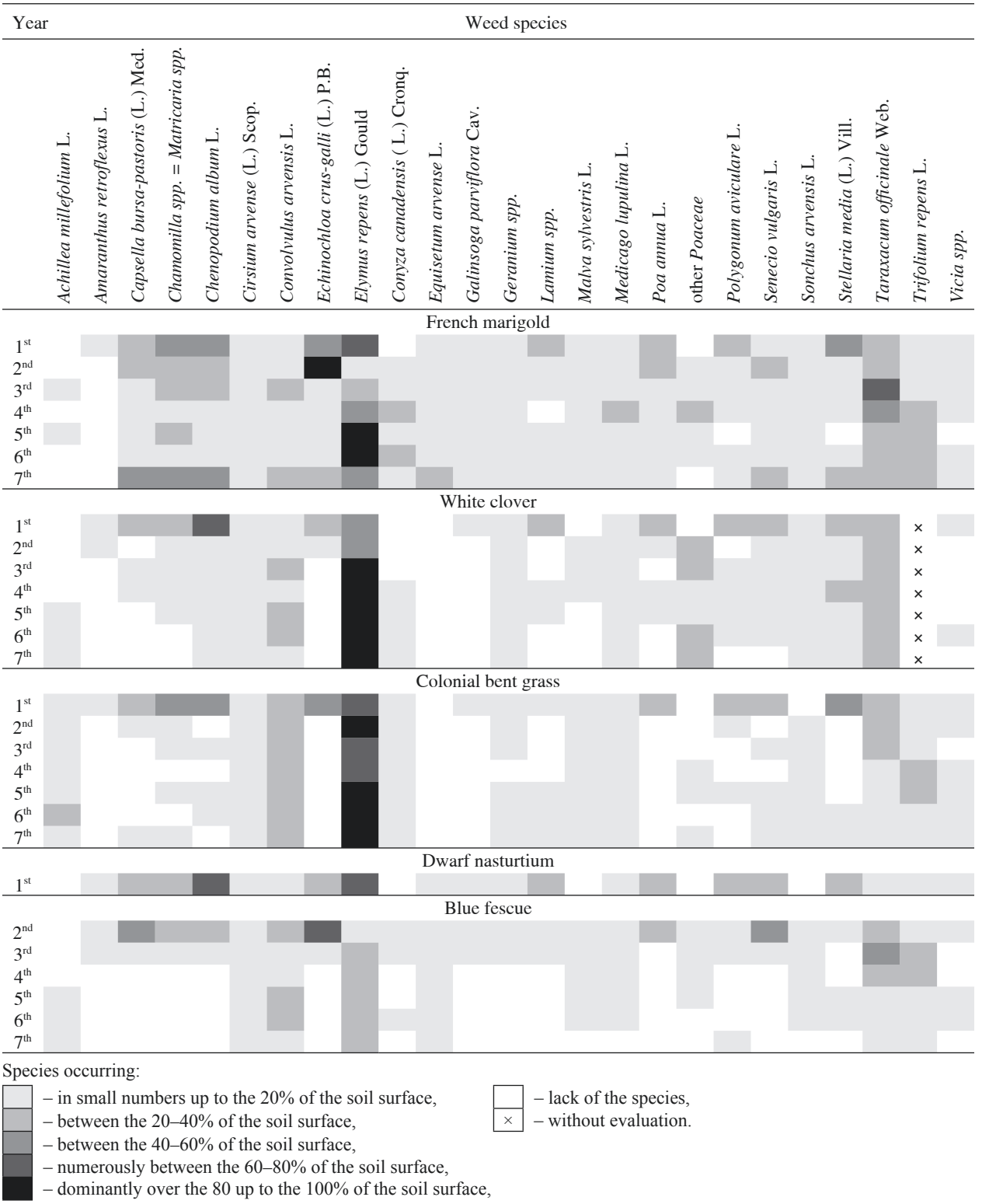
The data obtained in the year of sowing the living mulch and the averaged data from the subsequent two-year periods pertaining to the degree of soil coverage by the living mulches and to weed occurrence were analyzed using one-way analysis of variance for a Randomized Block Design. Prior to the analysis, the data were angularly transformed (by the Bliss function). Additionally, in order to fulfil the assumptions of analysis of variance, at least approximately, logarithmic or exponential transformations were applied to some of the continuous data. The multiple comparisons were performed at the 5% significance level using Duncan's Multiple Range Test.

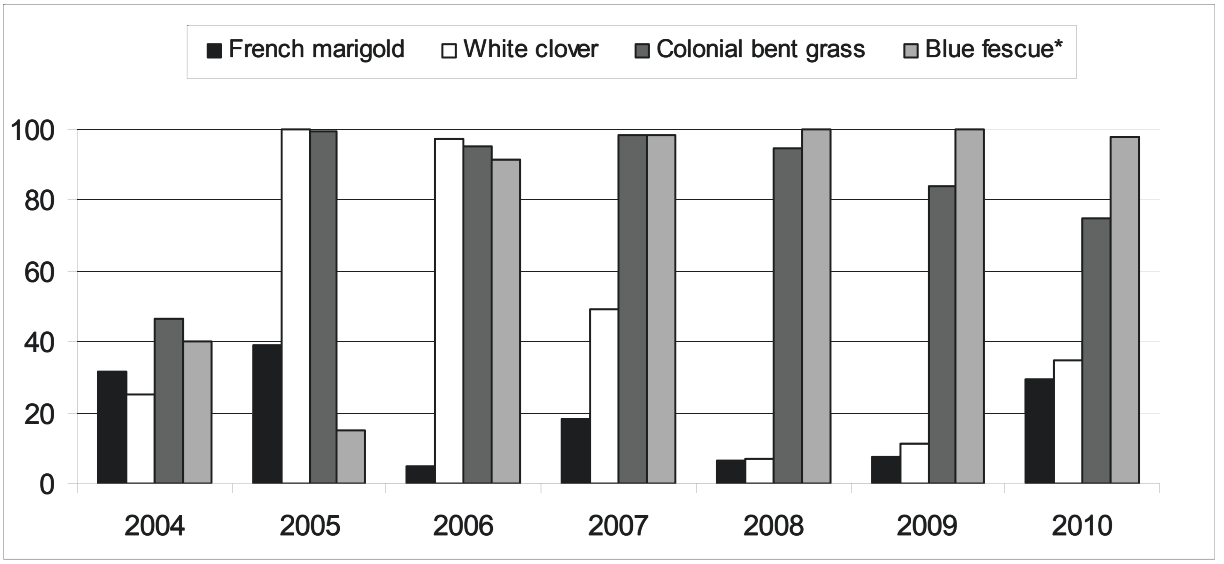
RESULTS

The percentage of the soil surface in the tree rows covered by living mulch was found to vary depending on living mulch species (Fig. 1). The degree of soil coverage by annual French marigold plants was low in every year of the study. In contrast, beginning from the second year after their sowing, the blue fescue and colonial bent grass mulches formed a very good sod. In the living mulch of white clover, substantial variation in mulch cover was observed during the first seven years following the orchard establishment. As early as in the year of sowing of all living mulches, weed infestation was observed, involving about 20–24 species (Table 1). In the subsequent years, similar diversity of weed species was noted only in the annually renewed mulch – French marigold. The maintenance of the perennial living mulches contributed to a gradual reduction in the number of weed species, in particular of annual ones. The blue fescue showed the highest efficacy in this regard. In the seventh year of the study (2010), only eight species, two of them annual, were observed. The percentage of the soil surface occupied by the majority of the described weed species most often did not exceed 20% and only in some cases it reached 40% – sporadically more. The highest abundance was shown by the population of *Elymus repens* (L.) Gould. It exceeded 80% in the white clover, colonial bent grass and annual French marigold sod. Together with several other perennial and annual weed species, this species was found to be the most important weed in the orchard (Table 2). Among the most important annual weed species, significantly higher mean annual soil coverage within the tree rows was most frequently noted only in the living mulch of French marigold. No differences in the occurrence of perennial weed species *Convolvulus arvensis* L. and *Trifolium repens* L. were observed between the investigated mulch species.

At the same time, *Elymus repens* (L.) Gould showed significantly higher mean annual soil coverage within the white clover and colonial bent grass sod in comparison with the other living mulches. The occurrence of *Taraxacum officinale* Web. was significantly higher in French marigold than in the perennial grasses.

Table 1
The percentage of the soil surface under the weed species in the tree rows from the year of the sowing (2004) up to the year 2010, depending on the kind of living mulch





* – in 2004 dwarf nasturtium

Fig. 1. The percentage of the soil surface under the living mulch cover in the tree rows, from the year of the sowing (2004) up to the year 2010

Table 2
The mean annual (2004-2010) percentage of the soil surface under the most important weed species in the tree rows depending on the kind of living mulch

Living mulch	Weed species										
	Perennial				Annual						
	Convolvulus arvensis L.	*Elymus repens* (L.) Gould	*Taraxacum officinale* Web.	*Trifolium repens* L.	*Capsella bursa-pastoris* (L.) Med.	*Chamomilla spp.* = *Matricaria spp.*	*Chenopodium album* L.	*Echinochloa crus-galli* (L.) P.B.	*Poa annua* L.	*Senecio vulgaris* L.	*Stellaria media* (L.) Vill.
French marigold	20,2 a*	56,7 b	31,0 c	17,6 a	15,0 c	28,3 c	24,3 c	26,9 d	13,3 c	16,2 c	16,0 b
White clover	16,7 a	82,1 c	21,9 bc	×	4,0 a	6,2 a	16,2 b	3,6 a	3,8 a	7,6 b	14,3 b
Colonial bent grass	24,0 a	79,8 c	20,5 ab	16,2 a	4,8 ab	10,0 b	9,8 a	6,9 b	4,0 a	4,5 a	8,6 a
Blue fescue**	17,6 a	30,0 a	17,6 a	16,4 a	9,8 b	13,1 b	15,0 ab	16,0 c	6,7 b	11,9 b	10,5 a

* – within individual columns, the means marked with varied letters differ significantly according to the Duncan's test at the confidence level 95%.
** – in 2004 dwarf nasturtium
× – without evaluation

The percentage of the soil surface occupied by the most important weed species in the year of sowing and in the subsequent two-year periods was distinctive for each living mulch (Table 3). In the case of French marigold, all weeds were present in each time period studied. In the perennial mulches, a decline in annual weeds was observed. In the periods that followed the orchard establishment, the percentage of the soil surface occupied by annual species was significantly lower than in the year of mulch sowing. A significant reduction in the surface area occupied by the perennial species *Taraxacum officinale* Web. was observed only in the case

of colonial bent grass and blue fescue. In contrast, in the white clover mulch, a significant growth in the *Elymus repens* (L.) Gould population took place. The share of the other most important perennial weeds in the sod of the perennial living mulch species was constant. The assessment of soil coverage by the living mulch, which was conducted in the same period, showed a significant decrease in French marigold in relation to the year of sowing (Table 4). In case of white clover and colonial bent grass, the percentage of mulch cover was significantly lower than the respective mean coverage observed during the second and third year after sowing.

Tabele 3
The change in the mean percentage of the soil surface under the most important weed species in the tree rows depending on the kind of living mulch, in the succeeding periods during the years 2004–2010

Period	Weed species										
	Perennial				Annual						
	Convolvulus arvensis L.	*Elymus repens* (L.) Gould	*Taraxacum officinale* Web.	*Trifolium repens* L.	*Capsella bursa-pastoris* (L.) Med.	*Chamomilla spp.* = *Matricaria spp.*	*Chenopodium album* L.	*Echinochloa crus-galli* (L.) P.B.	*Poa annua* L.	*Senecio vulgaris* L.	*Stellaria media* (L.) Vill.
French marigold											
Year of sowing	18,3 a*	65,0 b	23,3 ab	15,0 ab	20,0 b	43,3 b	48,3 c	41,7 c	20,0 b	18,3 a	41,7 d
2nd – 3rd year mean	20,8 a	22,5 a	41,7 c	8,3 a	18,3 b	27,5 a	20,0 b	50,8 c	19,2 b	20,8 a	8,3 b
4th – 5th year mean	16,7 a	75,0 b	35,0 bc	23,3 b	2,5 a	18,3 a	12,5 a	8,3 a	10,8 a	11,7 a	1,7 a
6th – 7th year mean	24,2 a	68,3 b	20,0 a	22,5 b	21,7 b	31,7 ab	28,3 b	14,2 b	6,7 a	15,0 a	25,0 c
White clover											
Year of sowing	10,0 a*	45,0 a	20,0 a	×	25,0	28,3 c	68,3 c	21,7 b	21,7 b	20,0 c	38,3 b
2nd – 3rd year mean	15,8 a	65,8 b	22,5 a	×	–	5,8 b	14,2 b	1,7 a	–	6,7 b	8,3 a
4th – 5th year mean	18,3 a	100,0 c	21,7 a	×	–	1,7 a	6,7 ab	–	1,7 a	7,5 b	11,7 a
6th – 7th year mean	19,2 a	99,2 c	22,5 a	×	–	–	1,7 a	–	–	2,5 a	10,8 a
Colonial bent grass											
Year of sowing	20,0 a*	75,0 a	23,3 bc	10,0 a	25,0 b	50,0 b	53,3 b	48,3	25,0 b	20,0 b	48,3 b
2nd – 3rd year mean	25,0 a	78,3 a	30,0 c	14,2 a	1,7 a	7,5 ab	1,7 a	–	1,7 a	–	3,3 a
4th – 5th year mean	22,5 a	77,5 a	17,5 ab	20,0 a	–	1,7 a	5,0 a	–	–	1,7 a	–
6th – 7th year mean	26,7 a	85,8 a	12,5 a	17,5 a	2,5 a	–	–	–	–	3,3 a	2,5 a
Blue fescue											
Year of sowing	20,0 a*	18,3 a	23,3 b	11,7 a	40,0 b	35,0 b	23,3 b	78,3 b	21,3	53,3 b	10,0 a
2nd – 3rd year mean	13,3 a	25,0 a	34,2 b	20,0 a	1,7 a	9,2 a	3,3 a	1,7 a	–	5,0 a	–
4th – 5th year mean	20,8 a	20,8 a	5,0 a	16,7 a	–	–	–	–	–	–	2,5 a
6th year	18,3 a	21,7 a	6,7 a	18,3 a	–	–	–	–	–	–	–

* – within separate living mulch treatment within individual columns, the means marked with varied letters differ significantly according to the Duncan's test at the confidence level 95%.
× – without evaluation

Table 4
The change in the mean percentage of the soil surface under the living mulch cover in the tree rows, in the succeeding periods during the years 2004–2010

Period	Living mulch			
	French marigold	White clover	Colonial bent grass	Blue fescue
Year of sowing	31,7 c*	25,0 a	46,7 a	15,0 a
2nd – 3rd year mean	22,1 bc	98,8 b	97,1 c	95,0 b
4th – 5th year mean	12,3 a	27,9 a	96,5 c	100,0 d
6th – 7th year mean**	18,5 ab	22,9 a	79,6 b	97,9 c

* – within individual columns, the means marked with varied letters differ significantly according to the Duncan's test at the confidence level 95%.
** – the blue fescue the only in the 6th year after sowing

DISCUSSION

In the year of the establishment of the experiment, multi-species weed infestation was found. The number of observed species was about 25. Annual weeds, such as: *Chenopodium album* L., *Poa annua* L., *Stellaria media* (L.) Vill., *Senecio vulgaris* L., as well as several perennial species: *Convolvulus arvensis* L., *Elymus repens* (L.) Gould, *Taraxacum officinale* Web. and also *Trifolium repens* Web. – a species commonly encountered also in fruit production based on herbicide fallow [2,8] as well as in orchards in which tree row mulching with organic materials is used for several years [9], were found to be the most important. Similarly as in the study by Hartley et al. [4], in the present experiment the relationship between soil coverage and weed biomass was determined by a relevant choice of the living mulch. All the investigated perennial living mulches showed high ability to suppress annual weeds. This observation is in agreement with the study by Calkins and Swanson [15] concerning a mix of grasses. Similar results were not obtained in the rows mulched with annual French marigold. In this mulch, similarly as in the case of orchards that use herbicide fallow [7,8,19], annual weeds were observed every year. However, a better choice of the annual living mulch species, common vetch, enabled a reduction in weed density and biomass [17].

The seven-year study conducted in the rows of the 'Pinova' apple tree variety and a shorter study on the 'Ligol' variety [19] have shown that the maintenance of perennial living mulches is intrinsically linked to the occurrence of perennial weed species. The percentage of the soil surface that they occupy can vary significantly across years or remain at the same level as in the year of orchard establishment. Such fluctuations are also observed in herbicide fallow [8]. Similarly as in case of chemical weed control, several-year-long soil coverage with the sod of perennial grasses exceeding ¾ of the tree row surface area led to significant suppression of the population of *Taraxacum officinale* Web., whereas the abundance of *Convolvulus arvensis* L. did not change. Among the two grass species evaluated, blue fescue – the mulch treated with a single application of herbicide to control dicotyledonous weed species – showed slightly lower weed infestation. In the study by Hartley et al. [4], similar chemical treatment led to satisfactory soil coverage by a living mulch of red fescue and white clover mixed together amounting to 75%.

In living mulch, perennial weed species are much harder to control than annual ones [12]. In the conducted experiment, *Elymus repens* (L.) Gould was found to the most persistent perennial weed species. In case of the blue fescue, significantly lower soil coverage by this plant in relation to colonial bent grass and white clover was additionally the result of better soil preparation prior to the sowing of the mulch. The introduction of blue fescue, in the second year after planting the apple trees, was preceded by hand weeding of dwarf nasturtium in the year of orchard establishment and by chemical weed suppression, which took place before sowing the grass. The blue fescue sod efficiently controlled the population size of *Elymus repens* (L.) Gould, keeping it at a level of about 20% in the subsequent years of the orchard. This result is similar to the one shown by Bergkvist et al. [20] in winter wheat in the red fescue living mulch, where annual biomass of *Elymus repens* (L.) Gould rhizomes was reduced by 40%. The possibility of replacement of couchgrass by perennial ryegrass in an apple orchard was also observed in the study of Lipecki and Janisz [7] – probably as an effect of frequent mowing of the weed sod. The maintenance of the white clover cover produced opposite results. Despite the fact that already in the second year after planting the apple trees the mulch was occupying 100% of the tree row surface area, *Elymus repens* (L.) Gould was able to spread in it and eventually proved to be more dominant. In consequence, the soil surface covered by the sod of this living mulch underwent significant shrinkage to a level

of 20%. The study of Hiltbrunner et al. [11] on the introduction of several species of clover and other legumes into cereal cultivation showed an efficient reduction in the occurrence of dicotyledonous weeds in comparison with monocotyledonous species, such as *Poa trivialis* L. In case of the white clover mulch, a higher occurrence of this weed was shown by Hogue et al. [18]. The higher ability of grass mulches to suppress weeds in comparison with living mulch species of the Fabaceae family, shown by this experiment, is in agreement with the results reported by Calkins and Swanson [15].

CONCLUSIONS

1. Multi-species weed infestation in the year of sowing living mulch in the rows of cv. 'Pinova' apple trees underwent changes in the subsequent years of the maintenance of the perennial mulch species, which included a complete decline or significant reduction in the percentage of the soil surface occupied by annual weeds.
2. It is possible to maintain the population of perennial weed species at a constant level or even to significantly suppress *Taraxacum officinale* Web. in the years following orchard establishment by introducing properly chosen living mulch species in the rows of apple trees – blue fescue and colonial bent grass.
3. The dominance of perennial weed cover in an orchard can be the result of a significant growth of the *Elymus repens* (L.) Gould population and can lead to a significant decrease in the proportion of the soil surface covered by white clover and annual French marigold living mulches.

Acknowledgements

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, Wrocław University of Environmental and Life Sciences.

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Różnorodność gatunkowa chwastów w żywych ściółkach w sadzie jabłoniowym

Streszczenie

Zachwaszczenie żywych ściółek w sadzie było oceniane na terenie Stacji Badawczo-Dydaktycznej Uniwersytetu Przyrodniczego we Wrocławiu w pierwszych siedmiu latach po ich wysiewie w rzędach drzew jabłoni odmiany 'Pinova'. Drzewa wysadzono wiosną 2004 roku w rozstawie 3,5 × 1,2 m. W tym samym roku w rzędach drzew o szerokości 1 m. wysiano żywe ściółki: mietlicę pospolitą, koniczynę białą oraz aksamitkę rozpierzchłą. Kostrzewę owczą, jedyny gatunek okrywowy, w którym jednokrotnie zastosowano herbicyd na chwasty dwuliścienne w drugim roku po wysiewie żywej ściółki, wprowadzono do sadu wiosną w drugim roku po posadzeniu jabłoni. Zastąpiła ona stosowaną w pierwszym roku po posadzeniu nasturcję karłową. W międzyrzędziach utrzymywano murawę.

W okresie pierwszych siedmiu lat po założeniu sadu obserwowano różnicowanie się zbiorowisk chwastów w zależności od zastosowanej w rzędach drzew żywej ściółki. W każdym roku wielogatunkowe zachwaszczenie utrzymało się jedynie w przypadku corocznie wysiewanej aksamitki rozpierzchłej. Uprawa wieloletnich roślin okrywowych istotnie ograniczała populacje chwastów jednorocznych. W przypadku pokrycia gleby darnią wieloletnich traw, przekraczającym ¾ powierzchni w rzędach drzew, stwierdzono również istotne ograniczenie populacji *Taraxacum officinale* Web. Dodatkowo uprawa kostrzewy owczej charakteryzowała się istotnie mniejszym średnim rocznym pokryciem gleby *Elymus repens* (L.) Gould. Wzrost populacji tego gatunku chwastu przyczynił się natomiast do istotnego ograniczenia udziału powierzchni gleby pokrytej darnią koniczyny białej oraz roślinami aksamitki rozpierzchłej.

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