Acta Sci. Pol. Hortorum Cultus 22(4) 2023, 79-90

https://czasopisma.up.lublin.pl/index.php/asphc ISSN 1644-0692 e-ISSN 2545-1405 https://doi.org/10.24326/asphc.2023.4172

ORIGINAL PAPER

Accepted: 23.04.2023
Issue published: 31.08.2023

APPLICATION OF LIVING MULCH IN ROWS OF THE APPLE TREES ON SEVERAL ROOTSTOCKS – LONG-TERM EVALUATİON

Maria Licznar-Małańczuk ✉, Iwona Kwiecińska

Department of Horticulture, Wroclaw University of Environmental and Life Sciences, Grunwaldzki sq. 24a, 50-363 Wrocław, Poland

ABSTRACT

The long-term influence of several living mulches on apple tree growth, nutrient status, yield, and fruit quality concerning the year of cover crop sowing in tree rows was evaluated in the Lower Silesia region in the southwestern part of Poland. The estimation was conducted in six apple tree 'Ligol' populations differentiated by the rootstock: M.26, M.9, P 60, P 2, P 16, and P 22. In experiment no. 1, one-year-old nursery stock was planted, and perennial living mulches were sown: colonial bent grass (*Agrostis vulgaris* With.) and white clover (*Trifolium repens* L.) in the same year and blue fescue (*Festuca ovina* L.) in the following year. In experiment no. 2, which involved two-year-old stock, the sowing of blue fescue was delayed until the second, third, fourth, and fifth years following orchard planting.

The presence of the cover crop significantly affected young tree growth when one-year-old trees were planted. The sowing of the living mulch in the first or the second year after tree planting led to a significant reduction in the cumulative yield obtained from the young trees. The living mulch improved the red coloration of the fruit skin in the young orchard, but it caused a reduction in the mean fruit weight and size. However, it also contributed to decreased nitrogen concentration in the leaves of the apple trees, the tree tolerance to living mulch increased as the orchard aged. A choice of semidwarf rootstock, postponed sowing of cover crop, and high-quality nursery stock were recognized as the most important factors for fostering apple tree tolerance to living mulches in tree rows.

Key words: orchard floor management, cover crop, fescue, colonial bent grass, clover

INTRODUCTION

Floor management under fruit tree crowns free of weeds positively influences trees' water and nutrient status, leading to favorable conditions for their growth [Gut et al. 1996]. In commercial orchards, this is attained by maintaining herbicide fallow in tree rows, while the remaining area is occupied by permanent grass sod [Granatstein and Sánchez 2009]. Environmentally friendly alternatives to chemicals for weed control are focused on different orchard floor management practices, including living mulch [Mia et al. 2020]. Nonleguminous and leguminous cover crops employed as living mulch in young tree rows will inevitably compete with fruit trees for living space and water [Hoagland et al. 2008] and reduce fertilizer use efficiency [TerAveste et al. 2010]. The presence of grass-living mulches was not neutral for the nutrient status of tree leaves [Merwin and Stiles 1994, Tahir et al. 2015]. Their presence hinders the

✉ maria.licznar-malanczuk@upwr.edu.pl

growth and cropping of trees [Yao et al. 2005, Atucha et al. 2011], particularly young trees [Mika et al. 1998, Hogue et al. 2010]. Reduced fruit mass and size were observed due to living mulch competition [Tworkoski and Glenn 2012]. On the other hand, fruit color was not impaired by cover crop presence [Granatstein and Mullinix 2008, Tahir et al. 2015].

The adverse effects of living mulch presence must be accounted for during orchard establishment. The delay in mulch sowing up to several years after planting the trees can mitigate the drawbacks of this floor management system. Some authors who evaluated living mulches in orchards recommended postponing their sowing until a few years after tree planting [Harrington et al. 2005, Hoagland et al. 2008]. The adverse effects of a green cover crop for fruit trees are also determined by the employed rootstock [Granatstein and Sánchez 2009]. Vigorous apple trees grafted on the strong growth 'Antonovka' seedling, still encountered in European orchards in the middle of the 20th century, did not exhibit a negative response to permanent sward in the rows after they reached an age of a few years [Kłossowski and Lechman 1976]. On the other hand, the yield of young trees on seedlings was low [Shribbs and Skroch 1986]. Dwarfing rootstocks replaced the seedlings in the second half of the last century as part of the fruticulture transition to increase production efficacy [Robinson et al. 1991]. It coincided with the widespread use of herbicides under the crowns of fruit trees. Several decades later, Granatstein and Sánchez [2009] highlighted the necessity of further research on rootstocks that could improve fruit tree tolerance to the presence of a living mulch, which replaced herbicide fallow in the tree rows.

The study aimed to evaluate the influence of cover crops on 'Ligol' cultivar vigor, nutrient status, yield, and fruit quality concerning the living mulch sowing year and rootstock choice.

MATERIAL AND METHODS

Two long-term experiments with the apple tree 'Ligol' were conducted at the Fruit Experimental Station in Samotwór (51°06'12"N, 16°49'52"E) of the Wroclaw University of Environmental and Life Sciences (southwestern part of Poland) in 2004–2014 and 2009–2019. Trees were always planted with a spacing of 3.5 × 1.2 m (2380 trees ha^{-1}) on haplic luvisol characterized as silty light loam (pH 7.0, soil organic matter 1.1%). Experiments were established following a modified split-plot design with four replications. The main-plot factor was an orchard floor management system in tree rows. The subplot factor was the rootstock variety. Each main plot (18 × 1 m) was divided into three subplots (6 × 1 m) with five trees grafted on one of the three tested rootstocks. The planting pattern for the trees on separate rootstock followed the randomized block design with four replications.

Experiment no. 1 was established in the spring of 2004. It was carried out on one-year-old unbranched trees grafted on the rootstocks P 2 (semidwarf), P 16 (dwarf), and P 22 (superdwarf). In the same year, three cover crops used as living mulches were sown in 1 m wide rows of trees after tree planting. The white clover (*Trifolium repens* L.) of the 'Sonja' represented the perennial living mulches. (10 kg ha^{-1}) and colonial bent grass (*Agrostis vulgaris* With.) of the 'Frasek' (34 kg ha^{-1}). The annual cover crop is dwarf nasturtium (*Tropaeolum majus nanum* L.) 'Empress of India' (26 kg ha^{-1}). The perennial cover crop blue fescue (*Festuca ovina* L.) of the 'Edolana' was sown in spring 2005 (30 kg ha^{-1}) to replace nasturtium because of insufficient soil surface cover under its plants. In experiment no. 2, two-year-old feathered trees grafted on dwarf M.9, semidwarf M.26, and semidwarf P60 rootstocks were planted in the spring of 2009. During the four subsequent vegetation seasons, extending over the 2010–2013 period, the living mulch of blue fescue of the 'Noni' and 'Sima' (50 kg ha^{-1} in the 1 : 1 cultivars ratio) was established in the tree rows in the second – 2010, third – 2011, fourth – 2012, and fifth – 2013 years following tree planting. After four years of living mulch sowing, a complete set of experimental treatments was obtained.

In both experiments, the control treatment was an herbicide fallow. It was maintained every year, with two (sometimes one) applications of mixed glyphosate (1.44–1.96 kg ha^{-1}) and MCPA (2-methyl-4-chlorophenoxyacetic acid, 0.60 – 1.00 kg ha^{-1}). The herbicides were applied on each side of 1.0 m wide tree rows in strips of 0.5 m wide. A backpack sprayer with a capacity of 12 L, working pressure of 500 kPa, and an output of 1.5 L per minute. In addition, black woven polypropylene fabric (Agro 84F-170 Tkanina PP, 94 g m^{-2})

was used to cover the rows of trees as a separate treatment only in experiment no. 1. The polypropylene fabric was 1.2 m wide. It was spread on 1.0 m wide main plots immediately after planting the trees. The excess parts of the polypropylene fabric, approximately 10 cm on both sides of the row, were dug into the soil. This synthetic mulch remained in the tree rows until the end of the research period. Permanent mixed grass sod was sown in the drive alleys – not belonging to the experimental plot in the orchard. It was mowed several times per year. Usually, 50 kg N per ha was spread in orchards. The trees were trained into the form of a slender spindle. Plant protection followed the recommendation for commercial growers. More details about agrotechnical methods applied in the first years after tree planting were described by Licznar-Małańczuk [2012, 2015]. The weather conditions were favorable for apple tree cultivation throughout the experimental period. Exceptions were during spring 2007 (–3°C, recorded on May 1) and 2011 (–2°C, May 3), when a late-spring frost caused partial flower damage, and on July 19, 2015, and July 10, 2017, when fruits were wounded by hail.

The yield per subplot was measured in experiments no. 1 and no. 2 in 2005–2014 and 2010–2019, respectively. The fruit mass was evaluated as the mean weight of 20 apples per subplot. A sample of approximately 30 kg of fruits per subplot was sorted into classes over ¾ of the red skin surface area. The same sample was divided into three classes of fruit diameter: less than 7.5 cm, 7.5−8.5 cm, and over 8.5 cm. In the 'Results and Discussion,' only the results for two classes are presented. The fruit quality was evaluated in experiment no. 1 in 2005−2014 and in experiment no. 2, only in the full-cropping orchard, when all treatments were yielded (2014, 2016, and 2018). In the years with low cropping levels due to hail damage or a deficient cropping level because of the biannual bearing of trees, fruit quality evaluations were omitted. Tree growth was determined by trunk cross-sectional area (TCSA) by measuring trunk diameters on two sides (north-south and east-west direction) or trunk circumference, in the case of older trees, 30 cm above the grafting point. The measure was determined at the orchard establishment in spring and then every autumn. The crop efficiency coefficient (CEC) was computed as a ratio of the total yield of young trees or the total yield from all cropping years to the TSCA in the last year of tree measurement in the young orchard or full cropping orchard, separately. The number of dead trees was recorded every year.

Twenty-five leaves from the apple tree were collected for macroelement analysis in a young orchard (experiment no. 1) on each subplot in two out of four replications in 2005–2008. The exact number of leaves was picked up on full cropping trees after all treatments had been introduced in experiment no. 2 on subplots in each repetition in 2015 and 2017. The samples were collected from the middle part of shoots at the end of July or in the first days of August. The leaves were dried at 45–50°C and ground. Nitrogen was determined after the mineralization of the samples (Kjeldatherm KB20) – [Adamski et al. 1997]. The phosphorus content was determined using the colorimetric method with ammonium molybdate [Adamski et al. 1997] and, in the case of magnesium, with titanium yellow [Adamski et al. 1997]. The concentrations of potassium and calcium were determined using the flame photometric method [Adamski et al. 1997]. According to Sobiczewski [2020], the elements' content in apple leaves were estimated.

All data were evaluated statistically using two-way analysis of variance (ANOVA) for the split-plot design to identify the effects of floor management, rootstock, and the interaction of these two factors on the variables. Prior to the statistical analysis, to fulfill the assumptions of analysis of variance, exponential transformations were applied to some of the continuous data (cumulative yield, TCSA, and its increase, CEC, mean fruit weight, and content of separate microelements). The discrete data (% share of fruit with blushing, diameter over 8.5 cm, and lower than 7.5 cm) were transformed angularly by the Bliss function. In exceptional, sporadic cases, transformations of variables provided only an approximation of the variance analysis assumptions. Duncan's multiple test calculated significant differences between treatment means ($p < 0.05$)

RESULTS AND DISCUSSION

The tree growth and yield of the six studied Ligol populations differed depending on the rootstock employed (Tabs 1 and 2). The research confirmed the significant effect of the rootstock on the growth of trees, which was consistent with the research of Czynczyk

Table 1. The growth, mortality, yield, and crop efficiency coefficient (CEC) of the apple tree 'Ligol' cv. grafted on three different rootstocks depending on orchard floor management in 2004–2014

Specification		Trunk cross-sectional area (cm^2) increase spring 2004–autumn 2008	Trunk cross-sectional area (cm^2) increase autumn 2008-autumn 2014	Trunk cross-sectional area (cm^2) 2008	Trunk cross-sectional area (cm^2) 2014	Dead trees up to the end of 2014 (%)	Cumulative yield (kg tree^{-1}) 2005–2008	Cumulative yield (kg tree^{-1}) 2009–2014	Cumulative yield (kg tree^{-1}) 2005–2014	CEC (kg cm^{-2}) 2008	CEC (kg cm^{-2}) 2014
rootstock P 2											
Herbicide fallow		7.1 a	22.3 a	7.9 a	30.2 a	–	17.3 a	81.8 a	99.1 a	2.2 b	3.2 a
Black woven		13.0 a	32.9 a	13.7 a	46.7 a	–	21.8 a	94.1 a	116.0 a	1.7 b	2.6 a
Blue fescue		5.2 a	28.6 a	6.0 a	34.6 a	5	10.1 a	73.1 a	83.1 a	1.8 b	2.4 a
Colonial bent grass		3.5 a	27.7 a	4.3 a	32.0 a	5	7.0 a	74.7 a	81.7 a	1.7 b	2.4 a
White clover		0.9 a	×	1.6 a	×	25	1.7 a	×	×	1.0 a	×
rootstock P 16											
Herbicide fallow		3.0 a	6.3 a	3.8 a	10.0 a	20	10.7 a	32.1 a	42.7 a	2.9 c	4.2 a
Black woven		4.2 a	8.9 a	5.0 a	13.8 a	–	13.1 a	33.1 a	46.2 a	2.7 c	3.4 a
Blue fescue		2.7 a	16.4 a	3.5 a	19.8 a	25	4.8 a	50.8 a	55.6 a	1.3 b	2.8 a
Colonial bent grass		1.7 a	15.6 a	2.4 a	18.0 a	30	3.6 a	57.5 a	61.1 a	1.5 b	3.3 a
White clover		0.9 a	×	1.6 a	×	60*	1.2 a	×	×	0.6 a	×
rootstock P 22											
Herbicide fallow		3.7 a	8.6 a	4.4 a	13.1 a	25	10.2 a	34.3 a	44.5 a	2.3 c	3.5 a
Black woven		4.6 a	10.0 a	5.4 a	15.4 a	20	12.6 a	41.3 a	53.9 a	2.4 c	3.5 a
Blue fescue		2.5 a	15.3 a	3.4 a	18.7 a	–	5.8 a	38.6 a	44.4 a	1.7 bc	2.3 a
Colonial bent grass		2.2 a	10.5 a	3.0 a	13.6 a	–	5.3 a	37.0 a	42.3 a	1.6 b	2.9 a
White clover		0.9 a	×	1.6 a	×	75*	1.5 a	×	×	1.0 a	×
average across all rootstocks											
Herbicide fallow		4.6 c	12.4 a	5.4 c	17.7 a	×	12.7 c	49.4 a	62.1 a	2.5 c	3.6 c
Black woven		7.3 d	17.3 a	8.0 d	25.3 a	×	15.9 d	56.2 a	72.0 a	2.2 c	3.2 bc
Blue fescue		3.5 bc	20.1 a	4.3 bc	24.4 a	×	6.9 b	54.1 a	61.0 a	1.6 b	2.5 a
Colonial bent grass		2.4 b	18.0 a	3.2 b	21.2 a	×	5.3 b	56.1 a	61.7 a	1.6 b	2.9 ab
White clover		0.9 a	×	1.6 a	×	×	1.5 a	×	×	0.9 a	×
average across all floor managements											
Rootstock	P 2	5.9 b	27.9 b	6.7 b	35.8 b	×	11.6 b	80.9 b	95. 0 b	1.7 a	2.7 a
	P 16	2.5 a	11.8 a	3.2 a	15.4 a	×	6.7 a	43.4 a	51.4 a	1.8 a	3.4 b
	P 22	2.8 a	11.1 a	3.6 a	15.2 a	×	7.1 a	37.8 a	46.3 a	1.8 a	3.0 ab

× – without estimation
* – up to the end of 2008
Within individual columns, the means for separate rootstock marked with varied letters differ significantly according to Duncan's test at a confidence level of 95%

et al. [2009]. The least vigorous trees on the superdwarf P 22 and dwarf P 16 rootstocks in experiment no. 1 yielded significantly less than trees grafted on semidwarf P 2. Similarly, the weak-growing trees on the dwarf rootstock M.9 obtained a significantly lower cropping level concerning the semidwarf trees on P 60 in 2010–2013 and also the M.26 rootstock in the following years of conducting experiment no. 2.

The tree trunk cross-sectional area and its increase were significantly lower in the floor management with living mulches: white clover, and colonial bentgrass than in the herbicide fallow and black woven in the first

Table 2. The growth, mortality, yield, and crop efficiency coefficient (CEC) of the apple tree 'Ligol' cv. grafted on three different rootstocks, depending on the year of blue fescue sowing, in 2009–2019

Specification		Trunk cross-sectional area (cm^2)				Dead trees up to the end of 2019 (%)	Cumulative yield (kg tree^{-1})			CEC (kg cm^{-2})	
		increase									
		spring 2009– autumn 2013	autumn 2013– autumn 2019	2013	2019		2010–2013	2014–2019	2010–2019	2013	2019
rootstock P 60											
Herbicide fallow		20.6 a	30.8 a	23.4 a	54.2 a	–	38.1 a	125.0 a	163.1 a	1.6 a	3.0 a
Year	2nd (2010)	15.6 a	23.9 a	18.1 a	42.0 a	–	24.5 a	110.4 a	134.9 a	1.3 a	3.3 a
of blue	3rd (2011)	18.8 a	27.5 a	21.4 a	48.9 a	–	33.3 a	112.3 a	145.6 a	1.5 a	3.0 a
fescue	4th (2012)	19.4 a	24.4 a	22.0 a	46.5 a	–	41.9 a	110.6 a	152.5 a	1.9 a	3.3 a
sowing	5th (2013)	19.6 a	25.1 a	22.4 a	47.5 a	–	38.2 a	106.7 a	144.8 a	1.7 a	3.1 a
rootstock M.26											
Herbicide fallow		18.1 a	30.3 a	20.6 a	50.9 a	–	38.6 a	124.8 a	163.4 a	1.9 a	3.2 a
Year	2nd (2010)	14.2 a	27.4 a	16.5 a	43.9 a	–	19.2 a	110.1 a	129.4 a	1.2 a	3.0 a
of blue	3rd (2011)	20.4 a	29.8 a	22.6 a	52.5 a	–	26.9 a	121.8 a	148.8 a	1.2 a	2.9 a
fescue	4th (2012)	18.8 a	24.6 a	21.3 a	45.9 a	–	37.1 a	102.6 a	139.7 a	1.8 a	3.1 a
sowing	5th (2013)	19.6 a	27.0 a	22.0 a	49.0 a	–	33.0 a	97.7 a	130.7 a	1.5 a	2.7 a
rootstock M.9											
Herbicide fallow		13.6 a	26.5 a	16.0 a	42.5 a	–	43.7 a	118.8 a	162.4 b	2.8 a	3.9 a
Year	2nd (2010)	10.4 a	21.3 a	12.9 a	34.2 a	5	22.4 a	90.5 a	112.8 a	1.7 a	3.3 a
of blue	3rd (2011)	14.5 a	23.3 a	17.1 a	40.4 a	–	29.0 a	103.3 a	132.3 a	1.7 a	3.3 a
fescue	4th (2012)	11.8 a	17.9 a	14.2 a	32.1 a	–	34.6 a	89.3 a	123.9 a	2.5 a	3.9 a
sowing	5th (2013)	12.8 a	22.4 a	15.5 a	37.9 a	5	33.3 a	94.1 a	127.5 a	2.2 a	3.4 a
average across all rootstocks											
Herbicide fallow		17.4 a	29.2 a	20.0 a	49.2 a	×	40.1 b	122.9 b	163.0 b	2,1 c	3.4 a
Year	2nd (2010)	13.4 a	24.2 a	15.8 a	40.0 a	×	22.0 a	103.7 a	125.7 a	1.4 a	3.2 a
of blue	3rd (2011)	17.9 a	26.9 a	20.4 a	47.2 a	×	29.7 ab	112.5 ab	142.2 ab	1.5 ab	3.1 a
fescue	4th (2012)	16.7 a	22.3 a	19.2 a	41.5 a	×	37.9 b	100.8 a	138.7 ab	2.1 c	3.4 a
sowing	5th (2013)	17.3 a	24.8 a	20.0 a	44.8 a	×	34.8 b	99.5 a	134.3 a	1.8 bc	3.0 a
average across all floor managements											
Rootstock	P 60	18.8 b	26.3 b	21.5 b	47.8 b	×	35.2 b	113. 0 b	148.2 b	1.6 a	3.1 a
	M.26	18.2 b	27.8 b	20.6 b	48.4 b	×	31.0 a	111.4 b	142.4 b	1.5 a	3.0 a
	M.9	12.6 a	22.3 a	15.1 a	37.4 a	×	32.6 a	99.2 a	131.8 a	2.2 b	3.6 b

× – without estimation
Within individual columns, the means for separate rootstock marked with varied letters differ significantly according to Duncan's test at a confidence level of 95%.

years after planting the trees (2004–2008) – Table 1. The mortality of the trees mulched with white clover on the dwarf P 16 and superdwarf P 22 rootstocks was high (60–75%) and precluded further data collection. The high competitiveness of the white clover and two grass living mulch was also revealed by the lower yield of young trees (2004–2008) compared to trees in herbicide fallow or mulched with synthetic black woven. It resulted from living mulch sowing already in the year of orchard establishment. In the case of blue fescue, it did not have such a negative impact on limiting tree growth. Unlike the other living mulches, this perennial grass was sown in the second year of the study to replace the annual dwarf nasturtium maintained for one year. This sequence of cover crops mitigated the negative influence of the perennial grass on the young trees. Nonetheless, the presence of blue fescue caused a significant decrease in foliar nitrogen up to a low level (Tab. 3). In the case of colonial bent grass, it decreased down to a deficit compared to

Table 3. Content of macroelements in leaves of the young apple tree 'Ligol' cv. grafted on three different rootstocks, depending on the orchard floor management, mean for 2005–2008

Specification		Macroelement (% d.m.)				
		N	P	K	Mg	Ca
rootstock P 2						
Herbicide fallow		2.45 a	0.22 a	1.41 a	0.27 a	0.56 a
Black woven		2.29 a	0.33 a	1.53 a	0.25 a	0.55 a
Blue fescue		1,88 a	0.39 a	1.82 a	0.33 a	0.68 a
Colonial bent grass		1.81 a	0.41 a	1.58 a	0.27 a	0.55 a
White clover		2.05 a	0.28 a	1.50 a	0.31 a	0.61 a
rootstock P 16						
Herbicide fallow		2.50 a	0.27 a	1.52 a	0.20 a	0.60 a
Black woven		2.17 a	0.26 a	1.53 a	0.23 a	0.57 a
Blue fescue		1.84 a	0.39 a	1.71 a	0.23 a	0.59 a
Colonial bent grass		1.73 a	0.54 a	1.74 a	0.19 a	0.51 a
White clover		2.34 a	0.21 a	1.40 a	0.23 a	0.57 a
rootstock P 22						
Herbicide fallow		2.51 a	0,27 ab	1.48 a	0.24 a	0.53 a
Black woven		2.40 a	0.30 ab	1.45 a	0.28 a	0.51 a
Blue fescue		1.97 a	0.47 bc	1.58 a	0.26 a	0.53 a
Colonial bent grass		1.80 a	0.51 c	1.66 a	0.25 a	0.53 a
White clover		2.36 a	0.24 a	1.35 a	0.30 a	0.61 a
average across all rootstocks						
Herbicide fallow		2.49 c	0.25 ab	1,47 a	0.24 a	0.56 a
Black woven		2.29 bc	0.39 ab	1.51 a	0.25 ab	0.54 a
Blue fescue		1.90 ab	0.42 bc	1.70 a	0.27 b	0.60 a
Colonial bent grass		1.78 a	0.49 c	1.66 a	0.24 a	0.53 a
White clover		2.25 bc	0.24 a	1.41 a	0.28 b	0.60 a
average across all floor managements						
Rootstock	P 2	2.10 a	0.33 a	1.57 a	0.29 c	0.59 a
	P 16	2.11 a	0.33 a	1.58 a	0.21 a	0.57 a
	P 22	2.21 a	0.36 a	1.50 a	0.27 b	0.54 a

Within individual columns, the means for separate rootstock marked with varied letters differ significantly according to Duncan's test at a confidence level of 95%

trees grown in herbicide fallow, which had a high level of this element in their leaves. This effect has already been described for dwarf orchards mulched with Poaceae species [Merwin and Stiles 1994, Andersen et al. 2013, Tahir et al. 2015]. In experiment no. 1, the magnesium leaf supply in all tested floor management practices was optimal and even high in phosphorus and potassium in the grass living mulch and the black woven. The application of the grass-living mulch did not significantly worsen the nutrient status with these elements and calcium compared to herbicide fallow. The examined rootstocks also had no adverse effect on the supply of nutrients to the trees. The only exception was the significantly lower magnesium content in the leaves of the trees grafted on the superdwarf P 22 and dwarf P 16 rootstocks compared to the semidwarf P 2.

The study of Licznar-Małańczuk [2012, 2020] showed that another aspect of growing trees in living mulch relates to mulch weed infestation. The weed communities of experiment no. 1 showed a successive increase in the couch grass (*Elymus repens* (L.) Gould) in white clover and, to a lesser extent, in colonial bent grass sod relative to blue fescue. This species contributes to tree growth by reducing soil moisture in the spring, just two years after planting the trees [Licznar-Małańczuk 2012]. The conditions for the growth and development of trees, especially in the white clover mulch, became different from the planned conditions and, as a consequence, negatively impacted young apple trees.

The living mulch competitiveness in the orchard was also related to the quality of planted trees – nursery stock quality – as a determinant of young trees' growth and cropping level [Bielicki et al. 2002]. In experiment no. 1, the trees were planted as one-year-old unfeathered maidens, similar to the trial of Hornig and Bünemann [1995] with dwarf apple trees on M.9. The authors reported a significant reduction in tree vigor and initial yield caused by living mulches: white clover and a mix of perennial grasses. Two-year maintenance of annual bluegrass (*Poa annua* L.) and white clover infested with couch grass sufficed to impair the performance of apple trees on the semidwarf M.26 rootstock for many years [Mika et al. 1998]. In experiment no. 1, the impact of the grass living mulches was significant on the yield of the young trees, but older trees yielded similar results (Tab. 1). According to Czynczyk et al. [2009], similar to the present research, the cropping level of 'Ligol' on semidwarf rootstocks was significantly higher than that on superdwarf P 22. Such dependency did not apply to the crop efficiency coefficients of trees grafted on P 2 and P 22 rootstocks in 2008 and 2014.

High-quality two-year-old apple tree nursery stock was planted in experiment no. 2 (Tab. 2). Trunk cross-sectional area, and its increase did not differ significantly across the semidwarf rootstocks M.26 and P 60 (Tab. 2). However, dwarf trees on the M.9 rootstock grew slower during the 10-year experiment, and they also yielded lower yields in 2014–2019 and 2010–2019 than trees on the two semidwarf rootstocks. Significantly weaker growth on the M.9 rootstock contributed to the high crop efficiency coefficient concerning trees on the M.26 and P60 rootstocks. Floor management did not influence the growth of the trees, but the yield was affected by the presence of blue fescue and its sowing year. However, simultaneously in three presented fruiting periods of trees, cumulative yields were always significantly impaired compared to herbicide fallow, only where the blue fescue was sown in the second year (2010) following the orchard establishment. Hogue et al. [2010] noted a performance drop of young apple trees on the M.9 rootstock in the presence of various living mulches introduced in the year of orchard planting. The sum of the first five crops was significantly lower than in herbicide fallow. However, Tahir et al. [2015] postponed sowing a grass mixture augmented with white clover seed until the tenth year after planting. Cover crop competition still negatively affected the growth and yield of trees on the M.9 rootstock. In contrast, in experiment no. 2, trees with delayed sowing of blue fescue, at least until the third (2011) year after the establishment of the orchard, yielded as in the herbicide fallow in the first years of cropping (2010–2013). A significant crop efficiency coefficient reduction in 2013 occurred only when the herbicide fallow was replaced with blue fescue in the second (2010) or third (2011) year following the orchard establishment. Floor management did not significantly affect the crop efficiency coefficient of trees after 10 years of cropping (2019).

The nutrient status of tree supply determined floor management and rootstock (Tab. 4). The competition from blue fescue showed significantly lower leaf nitrogen status (low or optimum) compared with high-level nitrogen concentration from trees in herbicide fallow. However, this was not confirmed when the blue fescue was introduced in the second year after planting (2010). Tahir et al. [2015] observed a similar pattern in trees on the M.9 rootstock, even when living mulch was introduced 10 years after the trees were planted. In experiment no. 2, the nitrogen concentration reduction was accompanied by increased potassium. The content of this element in all estimated floor management practices was high; however, it was significantly different. A negative correlation between nitrogen and potassium was described by Shribbs and Skroch [1986] based on a study on applying grasses as living mulch in an orchard with apple trees grafted on vigorous seedling rootstocks. It was not confirmed by Tahir et al. [2015] during the testing of trees on the M.9 rootstock. In experiment no. 2, the phosphorus leaf supply in tree leaves from the tested floor management practices was optimal or high; in the case of magnesium, it was optimal or low. The tested factor had no significant effect on their concentration in leaves, similar to the case of calcium. The rootstock had such an effect, but the results differed significantly between the three tested rootstocks.

Table 4. Content of macroelements in leaves of the full cropping apple tree 'Ligol' cv. grafted on three different rootstocks, depending on the year of blue fescue sowing, mean for 2015 and 2017

Specification		Macroelement (% d.m.)				
		N	P	K	Mg	Ca
rootstock P 60						
Herbicide fallow		2.36 a	0.20 a	2.07 a	0.19 a	0.91 a
Year of blue fescue sowing	2nd (2010)	2.28 a	0.24 a	1.78 a	0.23 a	0.96 a
	3rd (2011)	2.15 a	0.29 a	1.92 a	0.21 a	0,91 a
	4th (2012)	2.12 a	0.24 a	1.96 a	0.20 a	0.87 a
	5th (2013)	2.03 a	0.28 a	2.39 a	0.19 a	0.85 a
rootstock M.26						
Herbicide fallow		2.51 a	0.21 a	2.09 a	0.22 a	0.79 a
Year of blue fescue sowing	2nd (2010)	2.34 a	0.26 a	1.70 a	0.23 a	0.77 a
	3rd (2011)	2.31 a	0.29 a	2.15 a	0.23 a	0.81 a
	4th (2012)	2.11 a	0.25 a	2.15 a	0.21 a	0.72 a
	5th (2013)	2.15 a	0.33 a	2.57 a	0.20 a	0.70 a
rootstock M.9						
Herbicide fallow		2.44 a	0.17 a	1.81 a	0.20 a	0.90 a
Year of blue fescue sowing	2nd (2010)	2.29 a	0.23 a	1.55 a	0.22 a	0.87 a
	3rd (2011)	2.05 a	0.26 a	2.11 a	0.21 a	0.76 a
	4th (2012)	2.02 a	0.27 a	2.01 a	0.22 a	0.79 a
	5th (2013)	2.02 a	0.23 a	2.30 a	0.18 a	0.77 a
average across all rootstocks						
Herbicide fallow		2.44 c	0.19 a	1.99 b	0.20 a	0.87 a
Year of blue fescue sowing	2nd (2010)	2.30 bc	0.24 a	1.67 a	0.23 a	0.87 a
	3rd (2011)	2.17 ab	0.28 a	2.06 b	0.22 a	0.83 a
	4th (2012)	2.08 a	0.25 a	2.04 b	0.21 a	0.79 a
	5th (2013)	2.06 a	0.28 a	2.42 c	0.19 a	0.77 a
average across all floor managements						
Rootstock	P 60	2.19 ab	0,25 ab	2.02 a	0.20 a	0.90 c
	M.26	2.29 b	0.26 b	2.13 a	0.22 b	0.76 a
	M.9	2.16 a	0.23 a	1.96 a	0.21 a	0.82 b

Within individual columns, the means for separate rootstock marked with varied letters differ significantly according to Duncan's test at a confidence level of 95%

The mean fruit weight depended on the rootstock and floor management but also on the interaction of these factors in experiment no. 1 (Tab. 5). In the first years of the assessment (2005–2008), the presence of three living mulches significantly reduced the mean fruit weight compared to herbicide fallow and black woven mulches. White clover stimulated an increase in small fruits (<7.5 cm) compared to herbicide fallow, black woven, or blue fescue mulch. However, those trees' cumulative yield (2005–2008) was significantly lower than in the herbicide fallow and black woven (Tab. 1). In a similar experiment involving the other dwarf M.9 rootstock, apple trees cultivated in rye and white clover ground covers exhibited simultaneous significant fruit yield and mean fruit weight reduction relative to herbicide fallow (Hogue et al. 2010). Sowing of a grass mix contributed to a decreased first-quality class yield with 7.0–8.0 cm apple size [Andersen et al. 2013]. In experiment no. 2, the tested floor management practices and their interaction with rootstocks did not significantly affect the quality of the fruit (Tab. 6). Tahir et al. [2015] employed M.9 rootstock, and they

Table 5. The fruit quality of the apple tree 'Ligol' cv. grafted on three different rootstocks, depending on the floor management in the young orchard (2005–2008) and in the full cropping orchard (2009–2014)

Specification		Mean fruit weight (g)		Fruit with blush > ¾ of skin area (%)		Fruit with diameter (%)			
						>8.5 cm		<7.5 cm	
		2005–2008	2009–2014	2005–2008	2009–2014	2005–2008	2009–2014	2005–2008	2009–2014
rootstock P 2									
Herbicide fallow		199 a	171 a	30 a	23 a	30 a	22 a	34 a	45 a
Black woven		206 a	162 a	33 a	28 a	46 a	16 a	22 a	44 a
Blue fescue		177 a	201 b	84 a	21 a	21 a	35 a	49 a	32 a
Colonial bent grass		145 a	174 a	74 a	38 a	5 a	22 a	59 a	43 a
White clover		112 a	×	64 a	×	×	×	79 a	×
rootstock P 16									
Herbicide fallow		183 a	139 a	27 a	17 a	30 a	12 a	38 a	69 a
Black woven		199 a	137 a	28 a	33 a	30 a	17 a	26 a	55 a
Blue fescue		156 a	182 b	82 a	29 a	17 a	15 a	40 a	46 a
Colonial bent grass		137 a	180 b	84 a	39 a	1 a	20 a	70 a	44 a
White clover		83 a	×	63 a	×	×	×	90 a	×
rootstock P 22									
Herbicide fallow		185 a	150 a	30 a	22 a	33 a	18 a	40 a	59 a
Black woven		207 a	156 a	31 a	29 a	40 a	19 a	34 a	61 a
Blue fescue		181 a	181 b	79 a	30 a	21 a	35 a	46 a	39 a
Colonial bent grass		165 a	162 ab	67 a	39 a	10 a	17 a	51 a	55 a
White clover		106 a	×	64 a	×	×	×	83 a	×
average across all rootstocks									
Herbicide fallow		189 d	153 a	29 a	20 a	31 a	17 a	37 a	58 c
Black woven		204 e	152 a	31 a	30 bc	39 a	17 a	27 a	53 bc
Blue fescue		171 c	188 b	82 b	27 ab	20 a	28 a	45 a	39 a
Colonial bent grass		149 b	172 b	75 b	39 c	5 a	20 a	60 ab	47 ab
White clover		100 a	×	64 b	×	×	×	84 b	×
average across all floor managements									
Rootstock	P 2	167 b	177 b	57 a	28 a	26 a	23 a	48 a	41 a
	P 16	152 a	160 a	57 a	30 a	19 a	16 a	53 a	54 b
	P 22	169 b	162 a	54 a	30 a	26 a	22 a	51 a	54 b

× – without estimation
Within individual columns, the means for separate rootstock marked with varied letters differ significantly according to Duncan's test at a confidence level of 95%

did not report a negative influence of grass with white clover on mean fruit weight after postponing cover crop sowing by ten years relative to apple tree planting. In experiment no. 1, the mean fruit weight was more prominent on the older trees cultivated in living mulch in 2009–2014 than herbicide fallow and black woven.

The share of fruits with a large red skin area was influenced by floor management but not the rootstock in experiment no. 1 in 2005–2008 (Tab. 5). The fruit class with blush over ¾ of the skin area was significantly lower in the herbicide fallow and black woven mulch treatments compared to living mulches. Sosna et al. [2009] reported a similar effect in a semidwarf young orchard on the P 60 rootstock after replacing herbicide fallow with annual cover crops. In a single-year study of apple trees on M.26, the overcolor was similar across all floor management treatments,

Table 6. The fruit quality of the apple tree 'Ligol' cv. grafted on three different rootstocks depending on the year of blue fescue sowing in the full cropping orchard (mean for 2014, 2016, and 2018)

Specification		Mean fruit weight (g)	Fruit with blush (%) > ¾ of skin area	Fruit with diameter (%)	
				>8.5 cm	<7.5 cm
rootstock P 60					
Herbicide fallow		202 a	9 a	22 a	28 a
Year of blue fescue sowing	2nd (2010)	215 a	9 a	31 a	24 a
	3rd (2011)	191 a	16 a	14 a	43 a
	4th (2012)	185 a	15 a	19 a	32 a
	5th (2013)	186 a	14 a	14 a	42 a
rootstock M.26					
Herbicide fallow		206 a	10 a	12 a	34 a
Year of blue fescue sowing	2nd (2010)	198 a	15 a	24 a	36 a
	3rd (2011)	219 a	13 a	32 a	21 a
	4th (2012)	184 a	20 a	22 a	44 a
	5th (2013)	185 a	22 a	11 a	42 a
rootstock M.9					
Herbicide fallow		190 a	10 a	20 a	42 a
Year of blue fescue sowing	2nd (2010)	187 a	19 a	19 a	48 a
	3rd (2011)	180 a	11 a	8 a	58 a
	4th (2012)	164 a	22 a	6 a	71 a
	5th (2013)	169 a	17 a	7 a	56 a
mean for rootstock					
Herbicide fallow		199 a	9 a	18 a	35 a
Year of blue fescue sowing	2nd (2010)	200 a	15 a	25 a	36 a
	3rd (2011)	196 a	13 a	18 a	41 a
	4th (2012)	177 a	19 a	16 a	49 a
	5th (2013)	180 a	18 a	11 a	47 a
mean for rootstock					
Rootstock	P 60	196 b	13 a	20 b	34 a
	M.26	198 b	16 a	20 b	35 a
	M.9	178 a	16 a	12 a	55 b

Within individual columns, the means for separate rootstock marked with varied letters differ significantly according to Duncan's test at a confidence level of 95%

perhaps because the cultivar was 'Red Delicious' [Granatstein and Mullinix 2009]. In the presented studies, the importance of the influence of floor management on red blushing decreased when the trees were older and reached the period of full bearing of the trees (Tabs 5 and 6). The results differed from those obtained by Tahir et al. [2015] with older apple trees on M.9 after replacing row tillage with grass with white clover mulch, which fostered the red apple coloration. The anthocyanin concentration in the fruit's skin determines the appearance of red-colored apples. However, excessive shoot elongation inhibits pigment synthesis if nitrogen is high [Treutter 2001]. Competitive intake of this nutrient by living mulch restricts nitrogen availability to trees [TerAveste et al. 2010]. Slatnar et al. [2014] confirmed this relationship based on separate one-year testing of 'Ligol' apples obtained from trees on the P 2 rootstock in experiment no 1. The authors demonstrated that living mulch stimulated anthocyanin synthesis.

Granatstein and Sánchez [2009] recommended orchard management with living mulch based on low-

-maintenance cover crops combined with trees grafted on the more vigorous rootstocks. Such a choice will allow trees to tolerate or compensate for living mulch competition. The semidwarf apple trees rootstocks, such as P 2, P 60, and M.26, employed in the present study also conform to the advice for orchards formulated by Hoagland et al. [2008]. They emphasized the necessity of fostering vigorous tree growth in the first years after planting it. The recommendation also included postponing living mulch introduction by a few years for the tree's sake. A long-term study in the Lower Silesia region demonstrated that using semidwarf rootstocks is a good solution and delaying the sowing of living mulches until the third year after orchard establishment in apple tree cultivation. However, the statistical analysis of the growth parameters, tree yield and, in experiment no. 2, fruit quality did not confirm the significant interaction of rootstock and floor management. The careful choice of high-quality nursery stock was critical for shifting fruit tree cultivation toward living mulch application and away from herbicide fallow.

CONCLUSIONS

Reduced tree vigor and impaired yield are the most apparent effects of living mulch competing with a young apple tree. Tree tolerance to additional plants growing in the tree rows increases as the orchard ages, and growth, yield, and fruit quality differences between trees cultivated in living mulch decrease relative to herbicide fallow.

Based on a 10-year analysis of yield and fruit quality, it can be concluded that the grass-living mulch did not harm several-year-old apple trees. However, to ensure the best conditions for the growth and development of young trees, the choice of semidwarf rootstock, postponed sowing of cover crops, and high-quality nursery stock are among the most important factors for fostering fruit tree tolerance to living mulches.

Fruit blushing improves in a young orchard with living mulch. However, mean apple weight and size are reduced if it is present in the initial period following tree planting. The contribution of cover crops, as a factor determining fruit quality, decreases with orchard age.

SOURCE OF FUNDING

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

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