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Effect of Living Mulch on Soil Conditions and Morphometrical Indices of Sweet Cherry Trees

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Abstract: In order to maintain natural biocenosis and to create optimal conditions for reproducing soil fertility, it is necessary to keep the soil under living mulch in organic orchards. But the effect of the living mulch on soil properties and biometric indices of trees has not yet been fully investigated. This work aimed at examining the effects of living mulch (compared with standard mechanical cultivation) on soil moisture, soil temperature and biometric indices of sweet cherry trees in the arid conditions of the Southern Steppe of Ukraine. The work was conducted from 2014 to 2019 in the Southern Steppe of Ukraine in Zelene village near the city of Melitopol (46°46'N, 35°17'E). In organic sweet cherry (*Prunus avium L./Prunus mahaleb*) orchard standard mechanical cultivation (MC) was compared with living mulch - spontaneous vegetation cover (LM). The soil moisture at 20 cm depth was significantly greater under LM (an average of 3,9%), the soil temperatures under LM plots were lower (an average of 1.5°C over 6 years of research), in comparison to MC. It was established that the trunk cross sectional area of sweet cherry trees was significantly reduced under LM - by 1.2-2.1 times. However, LM contributed to an increase in the shoot growth efficiency – by 1.5-2.9 times, compared to MC. The ratio of total leaf area to the trunk cross sectional area was also significantly greater in conditions of LM, since 2015 by 1.3-2.5 times. The weather conditions of the year significantly influenced the formation of the biometric indices of the trees - Year×orchard floor management system interactions were significantly throughout all years of research. Investigated sweet cherry cultivars (Valery Chkalov and Dilemma) respondend to the floor management systems in a similar way – their biometric indices did not differ significantly.

Keywords: *Prunus avium L.*, *Prunus mahaleb*, Organic Orchard, Biometric Indices, Soil Moisture, Soil Temperature

1. Introduction

Conscious attitude to life, awareness of environmental problems, encourage farmers to switch to organic technologies. But the issue of optimal orchard floor management system in an organic orchard has not been sufficiently studied, especially in the arid conditions of the Southern Steppe of Ukraine. In recent years, there is an increasing interest for use of living mulches in orchards.

Natural herbs can serveas a living mulch, improving the water regime, the physical condition of the soil [1, 2] and protecting it from erosion [3-5]; herbs have their own rhizosphere, which enriches the soil with organic matter [6-8], supplies plants with nitrogen (through symbiotic and associative bacteria) [9-11], phosphorus (through bacteria-phosphatesolubilizers) [12, 13]; flowering grasses attract pollinating insects [14, 15] and provide nutrition to beneficial insects [16, 17]; volatile compounds that produce herbs (especially medicinal plants) can disorient pests and have a fungicidal effect [18].

It was reported that living mulches influence soil properties and tree performance in an organic apple orchard in northern Patagonia and disking is not a recommended practice because it may decrease the concentration of soil organic matter and leads to poor tree vigor that corresponds to low fruit bearing

potential [19]. However, living mulches may reduce yield and tree size [5]. There are also reports that tree productivity does not depend on the orchard floor management system in an organic orchard [20-22]; or the treatment effect ceased to be significant, once the trees reached full production [23].

Thus, in order to maintain natural biocenosis and to create optimal conditions for reproducing soil fertility, it is necessary to keep the soil under living mulch in organic orchards. But the effect of the living mulch on biometric indices of trees has not yet been fully investigated. Little is known about the effects of living mulches on soil properties in organic sweet cherry orchards.

This work aimed at examining the effects of living mulch (compared with standard mechanical cultivation) on soil moisture, soil temperature and biometric indices of sweet cherry trees in the arid conditions of the Southern Steppe of Ukraine.

2. Materials and Methods

The work was conducted from 2014 to 2019 in the Southern Steppe of Ukraine in Zelene village near the city of Melitopol (46°46'N, 35°17'E). The soil cover of the investigated area is

the chestnut soils, which are very low-humus. Soils have a weakly alkaline reaction of soil solution (pH varies within 7.1-7.4). On the background of a light granulometric composition, the humus content in the upper humus horizon is 0.6%. The analysis of aqueous extraction revealed that the total content of water-soluble salts does not exceed 0.015-0.024%.

The long-term mean air temperature is +10.6°C. The summer months (June, July and August) have an average daily air temperature of 21-23°C. Winters are warm with frequent thaws. The coldest months are January and February. During these months mean annual air temperature ranges minus 3.7-4.3°C, but the minimum temperature is reduced to minus 26°C. Mean annual precipitation for the last 10 years was approximately 481 mm.

The analys of weather conditions over the years of the studies (Table 1) show that climate is warming - the average annual temperature was 0.8-1.6°C warmer relative to long-term normals. Winter conditions were more favorable, which can be seen in the coldest month - January (the air temperature was 0.3-1.6°C higher than long-term normals, with the exception of January 2016 and 2017).

Table 1. Weather conditions during 2014–19 relative to long-term normals as measured at the Melitopol weather station.

| Mean monthly temp (°C) | | | | | | | | | | | | |
Yr	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Now.	Dec.	Average annual
2014	+0.3	+1.5	+3.5	+0.8	+1.9	-0.5	+1.3	+1.6	+1.3	-0.9	-1.3	+0.2	+0.8
2015	+0.9	+2.4	+2.3	-0.9	+0.3	+0.7	0	+2.0	+4.4	-1.3	+2.7	+2.3	+1.3
2016	-1.1	+5.2	+3.0	+2.5	-0.3	+1.4	+1.1	+2.6	+0.1	-1.9	-0.2	-2.0	+0.8
2017	-0.9	+0.5	+3.7	-1.5	-0.4	+0.9	-0.1	+3.2	+2.9	+0.3	+1.2	+5.3	+1.2
2018	+1.2	+1.1	-1.5	+3.0	+3.0	+2.2	+1.1	+2.6	+1.5	+2.9	-1.1	+0.6	+1.3
2019	+1.6	+2.4	+0.7	+1.0	+1.5	+4.1	-0.6	+0.4	+0.7	+1.4	+2.3	+3.8	+1.6
Precipitation (%)												
2014	+27	-79	-71	+41	+40	+89	-39	-51	+164	-52	-50	+64	+13
2015	-4	-7	+126	+87	-48	+15	+18	-97	-98	-46	+88	-72	-4
2016	+36	+22	-28	-11	+82	-48	-22	-49	+55	-22	+2	-39	-1
2017	+4	-16	-63	+76	-73	-23	+36	+22	+30	+4	-52	-57	-11
2018	+21	+39	+96	-84	-52	-40	+81	-82	+104	-44	-3	+74	+10
2019	+19	-68	+6	+44	+107	-73	-5	+61	-67	-42	-48	-26	-8

Table 2. Hydrothermal coefficient (HTC).

Yr	Apr.	May	June	July	Aug.	Sept.	Oct.
2014	1.4	1.2	1.6	0.4	0.2	1.9	nm
2015	nm	0.5	0.9	0.7	0	0	nm
2016	0.8	1.7	0.4	0.5	0.2	1.2	nm
2017	nm	0.3	0.6	0.8	0.5	0.8	1.0
2018	0.1	0.4	0.5	1.1	0.1	1.4	0.5
2019	1.4	1.8	0.2	0.6	0.8	0.2	0.5
Long-term normals	1.1	0.9	0.9	0.6	0.5	0.8	1.0

nm denote 'not measured': hydrothermal coefficient is not determined if the average monthly air temperature is less than 10°C.

The average annual precipitation was not significantly different from long-term normals, but rainfall was distributed unevenly each year - occurring as wetting (mainly in January and September, with the exception of September 2015 and 2019) and drought (mainly in June and August). This is clearly seen in Table 2. For the estimation of the meteorological conditions we used Hydrothermal coefficient (HTC), which

established as the ratio of the sum of precipitation (mm) during the period with average daily air temperatures above 10°C to the sum of temperatures at the same time, reduced by 10 times [24]. HTC characterizes not only the profitable part of the water balance (precipitation), but also the unproductive consumption of moisture (evaporation from the soil surface, vegetation). The criteria that characterize the intensity of droughts by the HTC are established: HTC < 0.5 - sharp lack of precipitation, severe drought; HTC=0.6–0.7 - insufficient moisture (very dry); HTC=0.8–0.9 - arid (non-severe drought); HTC=1.0–1,2 - insufficient humidity; 1,3-1,6 - moderate humidity; HTC > 1.7 - excess humidity [25].

Drought is a common occurrence in the Southern Steppe of Ukraine, especially in summer months. It was abnormally arid in August and September 2015, when only 0.9 and 0.5 mm precipitation. The hottest month of August was very dry during all years of research, except in 2019, when 56 mm of precipitation fell and the hydrothermal coefficient was higher than the long-term norm.

The experiment was conducted in an organic sweet cherry orchard of Valery Chkalov and Dilemma cultivars (*Prunus avium L.*)/*Prunus mahaleb*) planted in 2011 at 7×5 m. Orchard rows were oriented north to south. Trees were trained as central leader.

The experiment was designed as a randomized complete block with two treatments, in triplicate. Each experimental plot consisted of 36 trees, spanning 3 rows with 12 trees per row. The 10 central trees of the middle row were used for measurements, and the other 26 were guard trees. Each experimental plot for soil analysis had an area of 210 m^2 (7m×30m).

Since 2013 the experimental orchard has been maintained with two different orchard floor management systems (OFMS): standard mechanical cultivation – one discing at a 15 cm depth + manual weeding during the growing season (MC) was compared with living mulch - spontaneous vegetation cover (LM). The natural vegetation of grasses was mowed 4 times during the growing season and the clippings were left on the ground for decomposition. Any other management was identical in each treatment. Synthetic fertilizers and chemical plant protection products were not used.

Soil conditions were measured annually at the first decade of August. The soil was sampled to a depth of 20 cm at 5 randomly established locations in each plot. The soil water content was determined gravimetrically by oven drying (105°C) until constant weight. Soil temperature at 20 cm depth was determined using a digital thermometer with a probe 125 mm long (Range: −20° to 200°C).

Biometric indices of sweet cherry trees were determined according to generally accepted methods [26]: total annual vegetative growth was evaluated as product of number and length of new shoots per tree; trunk diameter at 0.3 m above the graft union was measured annually at mid-October and used to calculate trunk cross sectional area (TCSA). Shoot growth efficiency (SGE) was calculated as the ratio of total annual vegetative growth to the trunk cross sectional area. Leaf surface area was determined gravimetrically and used to calculate the total leaf area (TLA) given the number of leaves on the tree. Leaves for analysis were collected at the first decade of August, with the full development of the leaf surface. Leaf samples were collected from mid-shoot on the new growth found in the middle of the tree. Leaf efficiency (LE) was calculated as the ratio of TLA to the trunk cross sectional area.

Treatment means were compared using Minitab 19 software (Minitab Inc., State College, PA). Statistical analyses were undertaken using the general linear model and two-way normal ANOM procedure. A treatment effect significant at $P \leq$ 0.05 was further analyzed with the Tukey mean separation test at a significance level of $P \leq 0.05$.

3. Results and Discussion

Our studies showed a positive effect of LM on the Soil temperature and soil water content (Table 3). The soil temperatures under LM plots were lower, compared with the soil temperatures under MC plots.

Table 3. Effect of year×OFMS interactionon on soil conditions.

Soil temperature at a depth of 20 sm (mean), °C						
	2014 Yr	**2015 Yr**	**2016 Yr**	**2017 Yr**	**2018 Yr**	**2019 Yr**
Orchard Floor Management Systems (OFMS)						
Living Mulch (LM)	23.5	22.1	23.4	23.3	26.8	21.1
Mechanical Cultivation (MC)	25.9	23.6	24.8	24.3	27.7	23.0
Significance	*	*	*	*	*	*
Significance (Yr×OFMS)	*	NS	NS	*	*	*
Soil water content at a depth of 20 cm (mean), %						
Living Mulch (LM)	18.8	20.4	17.7	28.7	17.8	30.4
Mechanical Cultivation (MC)	13.9	16.4	14.7	23.9	16.0	25.7
Significance	*	*	*	*	*	*
Significance (Yr×OFMS)	*	NS	*	*	*	*

* denote P ≤ 0.05, or nonsignificantly different (NS).

Effects of floor management systems on soil conditions were significant during all 6 years of research. Year×orchard floor management systems interactions for soil temperature was significant in 2014 and in 2017-2019 years. Reductions in soil temperature under the LM treatment averaged 1.5°C (ranged from 0.9 to 2.4°C) as compared to the MC treatment. The live mulch probably acted as an insulator - the presence of LM on the soil surface insulates the soil from the air temperatures. Lower soil temperature under LM has mostly been attributed to the reduced solar energy reaching the soil during hot period. Similar effects have been described in the scientific literature: the soil temperature in the surface 0-20cm layer under live grass clover mulching treatment in the citrus garden was lower than control treatment without any cover;

the soil water content was higher under live grass clover mulching treatment [27].

Living mulch increased soil water content, in comparison to MC (1.8 to 4.9%). Similar effects have been described by Simões [22]: the effects of natural vegetation mowing with those of tillage on soil water content and resistance to penetration was compared over an 8-year period, in a Mediterranean rainfed olive orchard. Soil water was higher in natural vegetation mowing, particularly in mid-summer and after the first autumn rains (1 to 2%). Living mulch of the cover crop in apple orchards enhanced the soil water content by approximately 28%, compared with conventional approach, where no cover crop was planted and natural weeds were controlled every month [28]. In the conventional system

(tillage, no recycling of pruning material) the occurrence soil crusting and of compacted layers along the profile hindered infiltration and percolation of rainfall water influencing the soil water content below the 100 cm layer. The sustainable system (no-tillage, spontaneous vegetation cover, annual recycling of pruning material) was able to better store water from rainfall, received during the autumn-winter period, especially in the deepest soil layer (from 100 to 200 cm). Water amounts stored by sustainable system were 45 and 17% higher than those retained by the conventional system [29].

This effects probably entirely due to increased organic matter and activity of soil biota by living mulch. The positive impact of live mulch on soil micro-ecology and soil quality has been confirmed by many studies [6, 28, 30].

Year×OFMS interactions for soil water content was significant throughout all years of research, with the exception of 2015. Anomalous drought in August 2015 (as can be seen from tables 1 and 2) was likely to cause this deviation (precipitation was 98% less than the annual average). Probably under such extreme conditions, the soil water content is more influenced not by the weather conditions, but by other factors. The drawback of our research is the lack of data on soil biological activity that could explain the trends identified.

Our studies have shown that the difference in trunk cross sectional area was insignificant both between OFMS and between cultivars in 2014 year, as can be seen from table 4. However, starting from 2015, a significantly larger TCSA should be noted for MC, and in the following years the difference between OFMS increased (from 1.2 to 2.1 times).

Similar results have been reported in many scientific sources: live mulch adversely affects the growth processes of fruit trees through competition for water and nutrients [5].

The difference in TCSA between cultivars became significant, starting in 2016, when the TCSA for 'Valery Chkalov' was larger than 1.6 cm^2 to 'Dilemma'. But, starting from 2017, 'Dilemma' exceeded 'Valery Chkalov' by this indic (from 4.6 to 2.3 sm^2). Year×OFMS interactions for TCSA was significant throughout all years of research, with the exception of 2017. Year×cultivar interactions for TCSA was nonsignificantly throughout all years of research. It should be noted that the studied cultivars are similar in phenological characteristics.

The shoot growth efficiency of cherry trees in 2014 did not differ significantly under the conditions of LM compared to MC (Table 5). But, starting from 2015, this indic began to grow under the conditions of LM, and was significantly higher compared to MC from 2015 to 2019 - 1.5, 2.6, 2.9, 2.6, 2.3 times, respectively.

A significant difference between the studied cultivars by the shoot growth efficiency was observed in 2014: this indic was significantly larger for 'Valery Chkalov' - 1.5 times, compared to 'Dilema'. But in 2016, SGE was significantly higher for 'Dilema' - 1.4 times, compared to 'Valery Chkalov'. In 2015, 2017-2019 there was no significant difference between the studied cultivars by SGE.

Throughout all the years of research, we have observed an increase in total leaf area under the conditions of LM compared to MC. Accordingly, leaf efficiency was larger - 1.3-2.5 times (Table 6).

Table 4. *Effects of year×OFMS and year×cultivar interactions on trunk cross sectional area for 'Valery Chkalov' and 'Dilema' sweet cherry.*

Trunk cross sectional area (sm^2)						
	2014 Yr	2015 Yr	2016 Yr	2017 Yr	2018 Yr	2019 Yr
Orchard Floor Management Systems (OFMS)						
Living Mulch (LM)	3.1	5.5	8.7	15.8	19.5	25.1
Mechanical Cultivation (MC)	3.1	6.7	13.8	23.9	37.1	52.2
Significance	NS	*	*	*	*	*
Significance (Yr×OFMS)	*	*	*	NS	*	*
Cultivar (CV)						
Valery Chkalov	3.3	6.2	12.1	17.2	26.5	37.5
Dilema	3.0	6.0	10.5	21.8	30.1	39.8
Significance	NS	NS	*	*	*	NS
Significance (Yr×CV)	NS	NS	NS	NS	NS	NS

* denote P ≤ 0.05, or nonsignificantly different (NS).

Table 5. *Shoot growth efficiency for 'Valery Chkalov' and 'Dilema' sweet cherry.*

Shoot growth efficiency=ratio of total annual vegetative growth to the trunk cross sectional area ($m×sm^{-2}$)						
	2014 Yr	2015 Yr	2016 Yr	2017 Yr	2018 Yr	2019 Yr
Orchard Floor Management Systems (OFMS)						
Living Mulch (LM)	1.3	4.7	8.0	8.5	6.1	2.7
Mechanical Cultivation (MC)	1.4	3.2	3.1	2.9	2.3	1.2
Significance	NS	*	*	*	*	*
Significance (Yr×OFMS)	*	*	*	*	*	*
Cultivar (CV)						
Valery Chkalov	1.1	3.7	4.6	6.1	4.3	1.9
Dilema	1.6	4.2	6.4	5.3	4.1	2.0
Significance	*	NS	*	NS	NS	NS
Significance (Yr×CV)	NS	NS	*	*	NS	NS

* denote P ≤ 0.05, or nonsignificantly different (NS).

Table 6. Leaf efficiency for 'Valery Chkalov' and 'Dilema' sweet cherry.

Leaf efficiency=ratio of total leaf area to the trunk cross sectional area ($m^2 \times sm^{-2}$)						
	2014 Yr	2015 Yr	2016 Yr	2017 Yr	2018 Yr	2019 Yr
Orchard Floor Management Systems (OFMS)						
Living Mulch (LM)	0.8	2.4	3.7	3.1	3.3	2.7
Mechanical Cultivation (MC)	1.4	1.8	1.8	1.4	1.6	1.1
Significance	*	*	*	*	*	*
Significance (Yr×OFMS)	*	*	*	*	*	*
Cultivar (CV)						
Valery Chkalov	1.2	2.1	2.4	2.2	2.6	1.8
Dilema	1.0	2.1	3.1	2.3	2.3	2.0
Significance	*	NS	*	NS	NS	NS
Significance (Yr×CV)	NS	NS	*	NS	NS	NS

* denote P ≤ 0.05, or nonsignificantly different (NS).

Weather conditions significantly influenced the shoot growth and formation of leaf surface: year×OFMS interactions for SGE and LE was significantly throughout all years of research.

The tendency to increase SGE and LE under the conditions of LM, compared with MC, shows that trees gradually overcome competition with natural herbs. As previously reported, according to the results of many years of research [31]: trees are overcoming competition with herbs in five to ten years. Here we show for the first time how sweet cherry trees overcome competition with herbs in the conditions of the Southern Steppe of Ukraine.

As can be seen from table 3, LM stores moisture in the soil. Based on the reduction of the cross-sectional area of the sweet cherry trees (Table 4), it could be concluded that the LM uses the stored moisture only on its own, and the trees suffer from drought. Instead, in our study the annual growth and leaf area under the conditions of LM are increasing (as can be seen from tables 5 and 6). That is, in this case, we have a more complex interaction of natural grasses and trees than competition. Annual growth can be influenced by both environmental factors (soil moisture content, temperature) and internal factors - the composition and activity of enzymes, hormones. We can assume that the reason here is the activity of soil microorganisms that exist in the rhizosphere of trees and natural herbs, first of all, plant growth promoting rhizobacteria and mycorrhizal fungi that can supply trees with moisture, nutrients, hormones, enzymes [8]. This may be the cause of the increase the annual growth and leaf area under the conditions of living mulch (compared with standard mechanical cultivation).

It is also possible that cherry trees of studied cultivars on the drought-tolerant rootstock are well adapted to the drought and under the conditions of LM form an alternative hydraulic architecture compared to the conditions of the MC. New growth and branches at the distal end of a plant maintain a constant flow rate and velocity of water [32]. It is shown that drought-resistant species can increase shoot growth and leaf area under drought conditions [33, 34].

It should be noted that research in horticulture should continue for many years, our research will be continued, and the final conclusions will be obtained in 5-10 years. Future research should focus on the impact living mulch have at soil microorganisms and productivity of sweet cherry trees.

4. Conclusions

Our study demonstrated substantial impacts of floor management systems on soil conditions: living mulch reduced soil temperature in the surface 0-20cm layer on averaged 1.5°C and increased soil water content on 1.8 to 4.9%, compared with standard mechanical cultivation.

Under conditions of living mulch trunk cross sectional area of cherry trees significantly decreased - by 1.2-2.1 times, compared with standard mechanical cultivation.

Dynamics of shoot growth and leaf surface area depended on weather conditions, but the general tendency of increase of shoot growth efficiency and leaf efficiency under conditions of living mulch is observed - by 1.5-2.9 and 1.3-2.5 times, compared with standard mechanical cultivation.

Year×OFMS interactions for trunk cross sectional area, shoot growth efficiency and leaf efficiency was significantly throughout all years of research.

Investigated sweet cherry cultivars (Valery Chkalov and Dilemma) respondend to the floor management systems in a similar way – their biometric indices did not differ significantly.

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