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INVITED PAPERS

CHANGES IN SOIL CHARACTERISTICS AND PROPERTIES OF BLACK CURRANT USING DIFFERENT CULTIVATION SYSTEMS

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ABSTRACT

Mulching is an important agricultural technique that is not widely used in perennial fruit orchards, especially not in black currant plantings. Therefore, the aim of this study was to compare two mulched (sawdust and black foil) and un-mulched soils (bare fallow) in black currant orchard. The research determined soil physical and chemical characteristics and some properties of black currant (bush volume, yield per unit area, berry weight, soluble solids content). During five-year research, it was found that in all cultivation systems, there were changes in soil characteristics, as well as in the tested properties of black currant. Mulching with sawdust had a stimulating effect on nutrient content (humus, N, P_2O_5 and K_2O) in soil and resulted in a stable soil water regime and steadily low soil temperatures throughout the growing season compared to the other two cultivation systems, which directly led to an increase in the bush volume and yield per unit area. On the other hand, moderate soil temperature and low soil moisture during the growing season, as recorded on bare fallow, promoted the increase in berry weight. In contrast, the soil covered with foil had a positive effect on improved soil mechanical properties, especially an increase in silt fractions and contributed to higher soil temperature and moisture, which caused higher accumulation and synthesis of soluble solids in berries. Generally, the present results suggested that cultivation systems significantly influenced soil characteristics and certain properties of black currant, which should be considered when choosing an appropriate location for establishing black currant orchards.

Key words: *Ribes nigrum, mulching, soil characteristics, black currant properties*

INTRODUCTION

Black currant (*Ribes nigrum* L.) is a modest plant that can grow on a wide range of soil types and under different soil cultivated systems. Under the agro-environmental conditions of Serbia, the most common soil cultivation system is bare fallow. More recently, mulching has been increasingly used in orchard floor management for black currants. Mulching is an important agricultural technique that covers the soil with different organic (sawdust, straw, leaves, compost, peat, etc.) or synthetic material (paper, polyethylene film, foil, etc.). Different materials have a variable influence on soil characteristics. Organic mulch delays the onset of soil warming in spring, contributes to reducing the rate of initial cooling, reduces temperature fluctuations and maintains the water holding capacity (Larsson, 1997; Kumar and Lal, 2012; Kuotsu et al., 2014). According to Robinson (2008), organic mulch (sawdust, wood chip) has a favourable effect on plants due to lower variations in soil temperature (lower during the day and slightly higher at night) and reduced water loss through evaporation. Also, Sinkevičienė et al. (2009) reported that organic mulches increase soil organic matter content, improve soil characteristics, and maintain good water-holding capacity. On the other hand, the use of inorganic mulches, especially foil mulch affects the earlier warming of the soil, increases soil temperature during the growing season, conserves soil moisture, and controls weeds (Al-Kayssi, 2009; Liu et al., 2014; Amare and Desta, 2021). In general, mulching affects the soil's physical, chemical and biological properties, which are a vital aspect of soil fertility (Pervaiz et al., 2009; Inbar et al., 2014; Jones et al., 2020). Regarding the effect of mulching on the biological properties of black currant, numerous studies have shown that soil mulching in black currant orchards favours bush growth and development, yield and fruit quality (Kivijarvi et al., 2005; Kaldmae et al., 2013; Paunović et al., 2020).

Global market trends and demand for high-quality berry products dictate the introduction of modern cultivation technology. With this in mind, the objective of the experiment was to provide a comparative analysis of the effect of different soil cultivation systems (sawdust mulch, black foil mulch and bare fallow) on soil characteristics and some properties of black currant.

MATERIAL AND METHODS

The present study was conducted in a black currant orchard of the Fruit Research Institute, Čačak, Western Serbia, during 2015-2019. The black currant orchard was established in the spring 2011 using two-year-old plants of the cultivar 'Čačanska Crna'. Black currants were grown as bushes at a spacing of 3 m between rows and 1 m in the row. Three cultivation systems were used: bare fallow (no mulch treatment), sawdust mulch and black foil mulch treatment. The experiment was laid out in a randomized block design, (10 bushes × 3 soil cultivation systems × 3 replications), giving a total of 90 black currant bushes. Standard cultural practices (pruning, fertilisation and drip irrigation) were used for all treatments.

Soil sampling was performed before the experiment and at the end of the experimental period. Agrochemical analyses were conducted using the following methods: pH value was determined potentiometrically with a combined glass electrode, by mixing soil with 1M KCl solution (ratio 1:2.5) (CyberScan pH 510, Eutech Instruments, Singapore); humus levels were measured by the Kotzmann method; nitrogen content was determined by the Kjeldahl method (Bremner and Mulvaney, 1982); readily available phosphorus was assessed colorimetrically, and readily available potassium was measured by flame photometry (the AL method according to Egner et al., 1960).

The analysis of soil mechanical properties involved testing the percentage of silt and clay fractions by sieving, disaggregation with 4% $Na_4P_2O_7x10H_2O$ and pipetting method. Soil textural classes were determined using the textural triangle method of the WRB (2014).

Soil temperature and moisture were measured at ten-day intervals starting from the beginning of the growing season (March) until the end of the growing season (October). Soil temperature at 0–30 cm depth was determined by a thermometer with a measuring range -20ºC –+50ºC (Figure 1), and soil moisture was measured by a WatermarkTM sensors tensiometer (measurement range from 0 – water-saturated soil to 200 – extremely dry) (Figure 3). Temperature and moisture at the soil surface were measured by a P330 thermo-hygrometer with a measuring range of -40ºC–+70ºC for temperature and 0–99% for moisture (Figures 2 and 4, respectively).

The following properties of the studied black currant cultivar were evaluated: 1. Bush volume was calculated using the truncated cone formula and is expressed in m^3:

$$V = \frac{\pi \times H}{3} \times \left(R^2 + R \times r + r^2\right)$$

H - bush height (*m*)
R - radius of the bush at the top (*m*)
r - radius of the bush at the base (*m*).

2. Yield per unit area was the result of multiplying yield per bush by number of bushes per hectare; 3. Berry weight was determined on a Mettler 0.01 g precision scale (Switzerland). Berries were selected visually at the same development stage, during June at full ripeness from similar locations in the bushes. 4. Soluble solids content was determined by a digital refractometer (Kruss, Germany)

The experimental data for properties of black currant obtained during the five-year research period were subjected to statistical analysis using Fisher's three-factor analysis of variance - ANOVA. The significance of differences between the mean values of the tested factors and the interaction means was determined by LSD test at $P \leq 0.05$ significance levels.

RESULTS AND DISCUSSION

The physico-chemical properties of the soil before black currant orchard establishment and at the end of the experimental period are presented in Table 1. The soil before the beginning of the experimental period was classified as sandy clay loam. After the experiment period, in all cultivation systems, there were changes in soil mechanical and agrochemical properties. Sawdust mulch led to a decrease in silt by 1.52% and clay by 3.70% contents, while foil mulch caused an increase in silt by 3.12% and a decrease in clay by 6.81% contents. This ratio of silt and clay fractions under foil mulch favoured the formation of more loose and friable soil, which is in agreement with the findings of Inbar et al. (2014), who reported that higher soil temperature under foil causes dehydration of clay in the soil, leading to strong interactions among the clay particles which in turn yield less clay and more silt in the soil. Changes in soil mechanical properties were also found in bare fallow, where it was recorded that the silt and clay contents decreased (0.96% and 3.15%, respectively), but changes were minimum than sawdust and foil mulch. At the end of the experiment, the soil under sawdust mulch and bare fallow remained sandy clay loam, whereas the soil under foil mulch, due to changes in soil mechanical characteristics, was classified as sandy loam.

In terms of agrochemical characteristics, before the orchard establishment, the soil was slightly acid and moderately supplied with humus and N, and had high levels of P_2O_5 and K_2O. During the five-year experiment, sawdust mulch caused a decrease in soil pH by 0.56, and an increase in humus content by 1.13% and N levels by 0.07%. As regards P_2O_5 and K_2O contents, the soil mulched with sawdust during the growing season had a stimulating effect on increasing the content of P_2O_5 by 7.35 mg/100 g and K_2O by 9.73 mg/100 g compared to the soil before the orchard establishment. These data are consistent with the results of numerous authors, who observed that organic mulches are effective in reducing nutrient leaching, improving the nitrogen balance, and increasing the levels of available phosphorus and potassium in the soil during decomposing organic materials, but they affect decreasing the soil pH (Broschat, 2007; Pervaiz et al., 2009; Kumar and Lal, 2012).

Table 1. Soil mechanical and agrochemical properties before black currant orchard establishment and at the end of the experimental period

Soil properties		Soil mechanical properties		Soil agrochemical properties				
		Silt % 0.02–0.002 mm	Clay % <0.002 mm	pH	Humus %	N %	P_2O_5 mg/100 g	K_2O mg/100 g
before orchard establishment		24.25	25.50	5.48	3.64	0.18	25.72	27.65
at the end of the experimental period	Bare fallow	23.29	22.35	4.63	2.86	0.13	23.49	25.94
	Sawdust mulch	22.73	21.82	4.92	4.77	0.25	33.07	37.38
	Foil mulch	27.37	18.69	4.75	2.95	0.15	21.38	24.05

With respect to soil mulched with foil, the study demonstrated that the soil under foil mulch showed a decrease in the soil pH by 0.73, humus by 0.69% and N by 0.03% contents. Also, foil mulch exhibited a greater decrease in the content of P_2O_5 by 4.34 mg/100 g and K_2O by 3.60 mg/100 g than in the soil before orchard establishment. Numerous studies have reported that high soil moisture and temperature under foil mulch lead to the reduction of the soil pH by increasing organic acids, affecting in that way a significant reduction in soil nutrients, especially N, P_2O_5 and K_2O, due to an increase in the decomposition of organic matter (Lalitha et al., 2010; Hegan et al., 2015; Jones et al., 2020). At the end of the experiment, the soil under bare fallow also showed a decrease in all tested parameters: pH by 0.85, humus content by 0.78%, N levels by 0.05%, P_2O_5 by 2.23 mg/100 g and K_2O by 1.71 mg/100 g. In general, bare fallow exhibited a greater reduction in pH, humus and N contents, whereas the levels of P_2O_5 and K_2O were higher than the soil covered with foil. Compared to sawdust mulch, the soil under bare fallow and foil revealed a higher decrease in all tested soil mechanical and agrochemical properties.

Cultivation systems during the growing season had a significant effect on the soil temperature and moisture. At the beginning of the growing season (March) and at its end (October), temperature differences between bare fallow and mulched soil were the lowest (Figures 1 and 2). Foil mulch increased soil temperature faster than other cultivation systems. From March until October, soil temperature at the root growth zone under foil was higher by 1.9°C on average and on the foil surface by 2.0°C on average compared to bare fallow temperature. The temperature difference between bare fallow and foil mulch at 0–30 cm depth was highest during June (2.9°C), whereas the highest difference at the soil surface was recorded during July (3.1°C). A high-temperature difference at the root growth zone was also observed during July (2.5°C) and August (2.2°C), while at the soil surface, a high difference was recorded during June (2.4°C) and August (2.7°C). It can be assumed that foil due to its ability to absorb sunlight and transmit radiation to deeper soil layers, directly increases soil temperature throughout the growing season. In contrast, sawdust mulch reduced soil temperature during the growing season. Sawdust mulched soil at 0–30 cm depth was colder by1.3°C on average, while soil surface temperature was reduced by 1.5°C on average compared to bare fallow temperature. The highest temperature difference between bare fallow and sawdust mulch at the root growth zone was recorded in June (2.2 °C), and the highest difference at the soil surface was in July (2.5 °C).

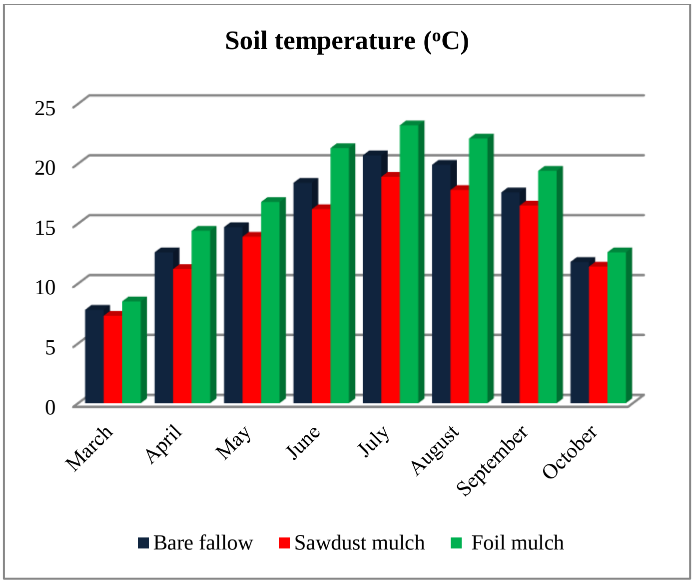

Figure 1. Soil temperature at 0–30 cm depth

Moreover, a high-temperature difference at 0–30 cm depth and on the sawdust surface was also observed during August (2.1°C and 2.4°C, respectively). From August until October, there was a gradual decrease in soil temperature difference in all cultivation systems; at the end of the growing season (October), the temperature difference between bare fallow and foil mulch was 0.8°C at 0–30 cm depth and 1.0°C at the soil surface, while the difference between bare fallow and sawdust mulch was 0.4°C at 0–30 cm depth and 0.7°C at the soil surface.

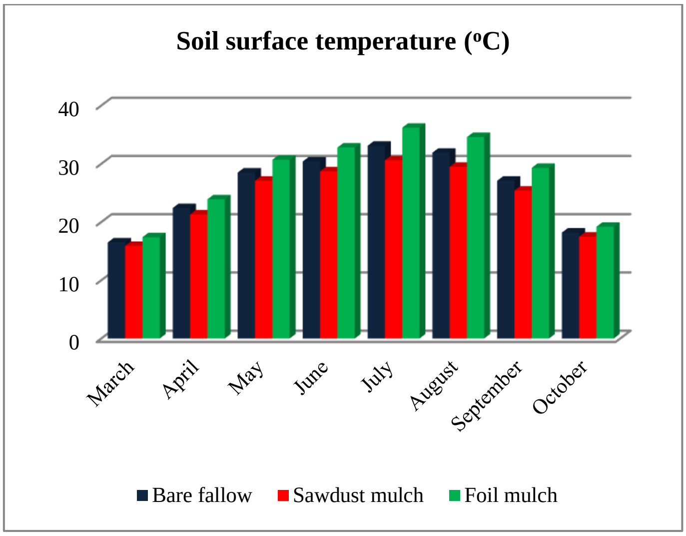

Figure 2. Soil surface temperature

The results are consistent with the results of Shiukhy et al. (2015) and Amare and Desta (2021), who reported that foil mulch directly increases soil temperature modifying the balance between absorbed and reflected radiation transmitted through foil mulch. Also, Larsson (1997) found that organic mulches, including sawdust delay the onset of heat transfer through the soil, minimise the diurnal temperature variation, lower the maximum temperature reached and reduce the initial cooling rate.

With regard to soil moisture, the study demonstrated that cultivation systems significantly influenced soil moisture (Figures 3 and 4). Soil moisture content was higher by 15.4 kPa on average under black foil mulch compared to bare fallow, due to foil ability to preserve moisture in the soil and reduce evaporation from the soil surface, thereby increasing the amount of water stored in the soil profile. The highest difference in moisture between bare fallow and foil mulch was found in August (26.1 kPa), and the lowest was in March (0.4 kPa). Also, a high soil moisture difference was recorded in July (24.2 kPa).

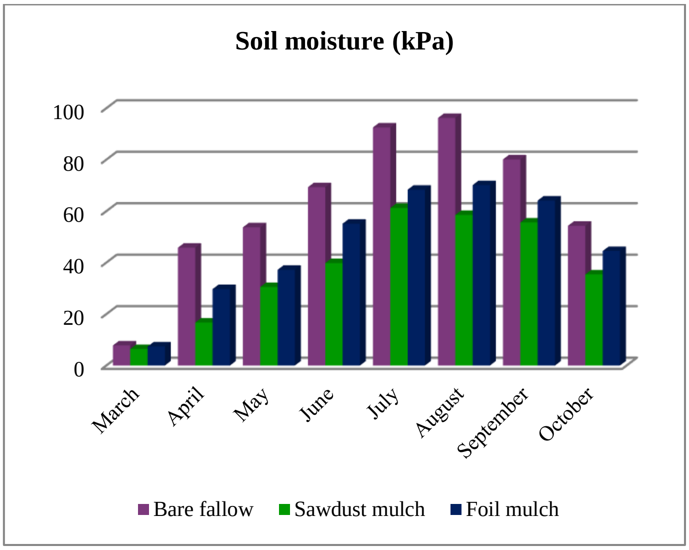

Figure 3. Soil moisture at 0–30 cm depth

During the growing season, moisture at the foil surface was lower by 5.1% on average compared to bare fallow. The highest surface moisture difference between bare fallow and foil mulch was measured during summer (June - 11.2% and July - 7.2%) and the lowest during May (2.0%), as can be attributed to the direct effect of foil in reducing water loss through evaporation. According to Al-Kayssi (2009), foil facilitates the retention of soil moisture i.e. prevents its evaporation by providing a physical barrier to vapour flow between the soil and the atmosphere and causing a return flow of water after condensation under the mulch, thus improving soil moisture retention and increasing temperature on soil surfaces. Likewise, Abu-Awwad (2008) reported that soil surface covers significantly increase transpiration compared to open soil treatments, due to the elimination of evaporation, which increases water available in the soil. In general, many studies supported the obtained results (Kumar and Lal, 2012; Liu et al., 2014; Bakshi et al., 2015). Soil moisture under sawdust at 0–30 cm depth, from March until October, was higher by 24.4 kPa on average compared with bare fallow. The maximum difference in soil moisture at the root zone between bare fallow and sawdust mulch was found in August (37.7kPa), and the minimum in March (1.39 kPa). A high moisture difference was also observed during June (29.5 kPa) and July (31.3 kPa). The difference in soil surface moisture between bare fallow and sawdust mulch was higher by 3.0% on average during the growing season. The highest difference was measured during summer (July – 6.5%), while the lowest values were recorded at the beginning of the growing season (March – 1.7%), confirming the previously established finding by Kuotsu et al. (2014) and Pandey et al. (2016), who observed that soil moisture content and water infiltration rate in mulched soil is significantly higher than in soil without mulch.

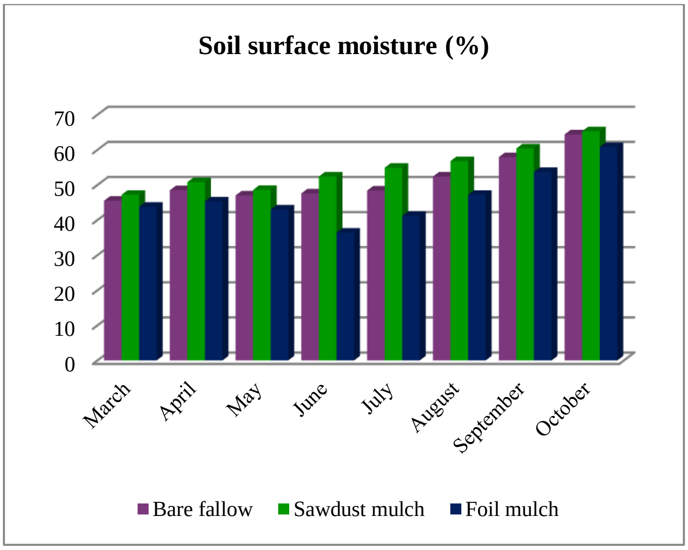

Figure 4. Soil surface moisture

The relationship of soil properties of different cultivation systems in currants had a significant effect on bush volume, yield per unit area, berry weight and soluble solids content in black currant berries.

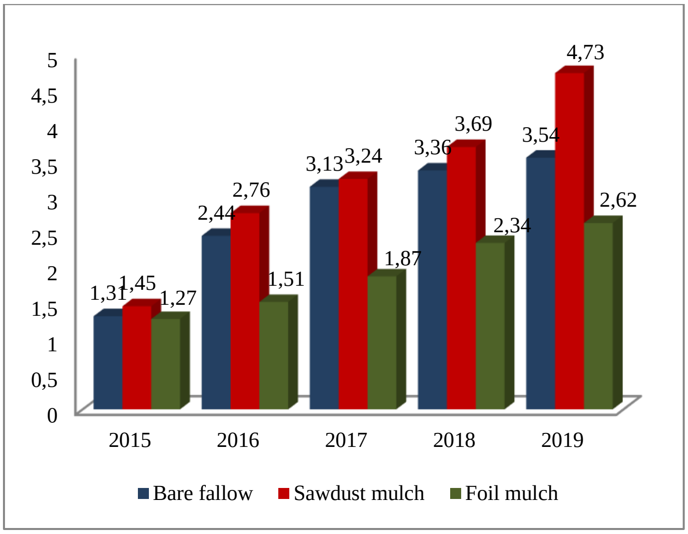

Figure 5. Bush volume (m^3) as dependent on cultivation systems

During the experimental period, sawdust mulch decreased soil temperature and temperature variations in the soil during spring and summer and ensured lower soil moisture, and also stimulated an increase in nutrient levels in the soil, which directly led to an increase in bush volume and yield per unit area in black currant, as compared to foil and bare fallow (Figures 5 and 6). Bush volume under sawdust mulch ranged from 1.45 m^3 (2015) to 4.73 m^3 (2019), while yield per unit area varied from 3.53 t (2015) to 14.7 t (2019). The difference between bare fallow and sawdust mulch in bush volume was 11.2% on average, while the difference between bare soil and foil mulch was larger at 36.2% on average. In terms of yield per unit area, the average difference between bare fallow and sawdust mulch was 5.53%, and the difference between bare fallow and foil mulch was 12.4%.

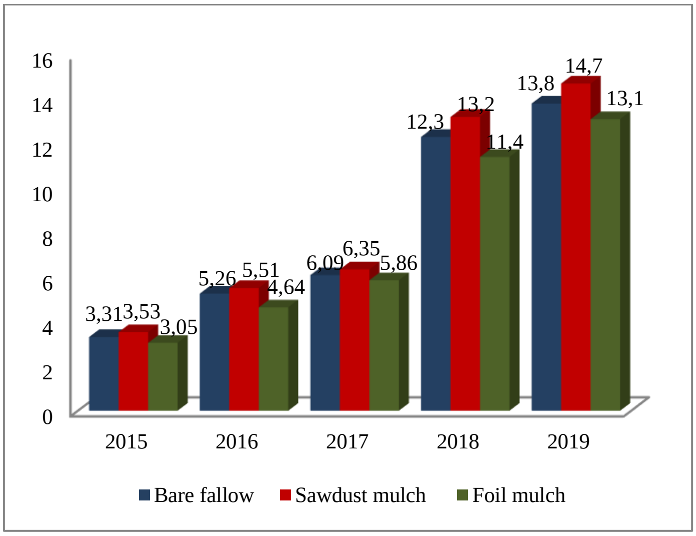

Figure 6. Yield per unit area (t) as dependent on cultivation systems

Moderate soil temperature and the lowest moisture throughout the growing season influenced a greater berry weight in black currants grown under bare fallow, while the lowest berry weight was recorded in currants grown under foil (Figure 7). Black currants under bare fallow had berry weight from 1.03 g to 1.39 g, and currants under foil from 0.86 to 1.25 g. The results on the growth and yield of black currant are comparable to those obtained by Larsson (1997), who reported that sawdust has the potential to improve the physical, chemical and biological properties of the soil, leading to an increase in growth and yield of black currant, but had not a positive effect on the fruit size. However, the same author pointed out that prolonged use of sawdust mulches resulted in decreased bush growth and yield in later years of planting life. Paunović et al. (2020) found that mulching with sawdust is an effective method for increasing the yield and bush growth of black currants, considering that sawdust has the potential to improve the physical, chemical and biological properties of the soil. According to Robinson (2008), sawdust mulch has a direct effect in increasing bush size by 30-40% compared to foil mulch and un-mulched soil. Also, Pedersen (2002) stressed that there was intense bush growth, but lower yields in black currants grown under different types of mulches, while Wang et al. (2015) revealed that mulch in peach markedly increased yield by 29.0% and 27.9% compared to the control. As regards berry weight, Starast et al. (2005) concluded that foil as mulch did not have good effects on blueberry in terms of berry weight, because it contributed to a significant reduction in berry weight compared to the control treatment and the treatment with sawdust. In contrast, Libek et al. (2008) and Kaldmae et al. (2013) obtained higher values in cultivars grown on foil-mulched soil than bare fallow, which is not in agreement with the results of the present research.

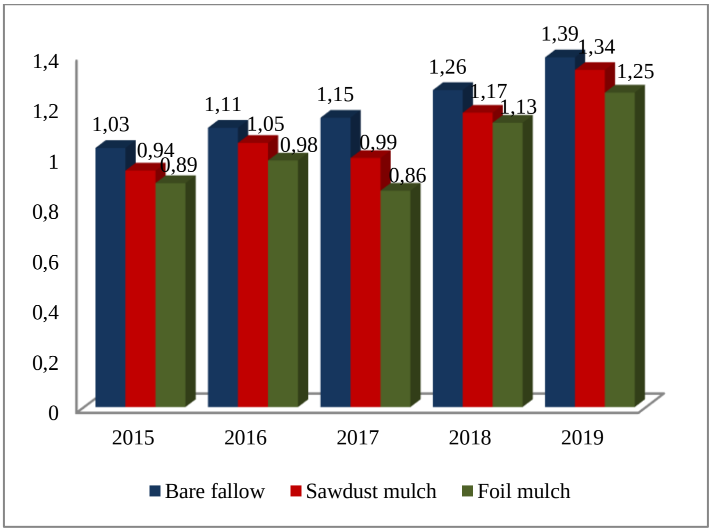

Figure 7. Berry weight (g) as dependent on cultivation systems

Fruit quality is determined by the content of primary metabolites, which largely contribute to fruit taste, flavour and appearance. Soluble solids content in fresh fruits is one of the most important indicators of the quality and technological convenience of black currant berries.

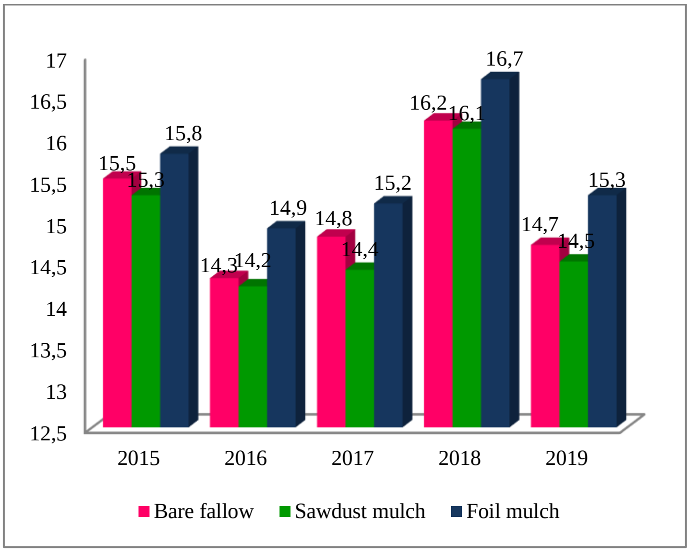

Figure 8. Soluble solids content (%) as dependent on cultivation systems

Mulching had a significant effect on the synthesis and accumulation of soluble solids in the berries. Under the agro-environmental conditions of Čačak, black foil mulch allowed early soil warming, increased soil temperature, prevented evaporation and ensured higher soil moisture, which favoured the accumulation and synthesis of soluble solids (Figure 8). Soluble solids content in the berries of black currants grown under foil mulch ranged from 14.9 to 16.7% and was higher by 3.09% and 4.39%, respectively, than in the berries grown on bare fallow (14.3-16.2%) and sawdust-mulched soil (14.2-16.1%). Between bare fallow and sawdust mulch, there was no significant difference in the soluble solids content. The present results are comparable with the findings of Pedersen and Andersen (2012) and Kaldmae et al. (2013), who reported higher values for soluble solids under foil mulch compared to other cultivation systems. Vagiri et al. (2013) evaluated the contents of soluble solids in organically grown black currant on foil-mulched soil and recorded higher values for soluble solids. Also, many other fruit species, such as strawberries, blackberries, raspberries, apples, and plums, grown on soil mulched with foil reported higher values of soluble solids compared to un-mulched soil (Pande et al., 2005; Vool et al., 2007; Kaur and Kaundal, 2009; Bakshi et al., 2014; Pandey et al., 2015).

CONCLUSION

The obtained results showed that the use of mulches modification of soil microclimate, resulting in different effects that have an impact on yield and berries quality. Therefore, when selecting the soil cultivation systems to be used in black currant plantings in lowland regions, priority should be given to sawdust over foil, considering that sawdust influenced improved soil properties and directly led to an increase in bush growth and yield of black currants. Generally, to intensify the production of black currants, and in accordance with the principles of modern growing technology, the application of sawdust mulch might be effective in promoting mulching in black currant orchards, as an important agricultural practice, especially as growers transition towards gaining new knowledge and experience in the use of different cultivation systems.

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