SOIL SCIENCE ANNUAL
2021, 72(2), 140644

https://doi.org/10.37501/soilsa/140644

Organic mulch materials improve soil moisture in vineyard

Alice Čížková[1]*, Patrik Burg[1], Patrik Zatloukal[1], Michaela Vaidová[1]

[1]Mendel University in Brno, Faculty of Horticulture, Department of Horticultural Machinery, Valtická 337, 691 44, Lednice, Czech Republic

* Ing. A. Čížková, alice.cizkova@mendelu.cz, ORCID iD: https://orcid.org/0000-0003-1743-7754

Received: 03.09.2020
Accepted: 30.07.2021
Associated editor: W. Szymański

Keywords

Vineyard
Mulch materials
Soil moisture
Grape yield

Abstract

The research paper deals with an evaluation of the effect of three types of organic mulch materials - cereal straw, wood chips and compost on soil moisture maintenance in vineyard in the Czech Republic in years 2017–2019. For comparison, the variant without mulch coverage "black fallow" was also monitored (control variant). The experiment was based on an experimental site in the village of Rakvice in the South Moravia Region. The three year results of the experiment demonstrate that the use of these three organic materials has a positive effect on the increase of soil moisture compared to the control variant. The best results are achieved by the variant with cereal straw, where the highest values of soil moisture were measured. At the same time, the yield of grapes and their qualitative parameters from individual variants were evaluated. Used organic mulching materials showed a significant statistical difference in the quality of the grapes compared to the control variant. These differences were demonstrated in the YAN content and in the variant with cereal straw also in the titratable acidity. The results of the experiment demonstrate that what might otherwise be agricultural waste, can be used to improve soil moisture and it represents an important agrotechnical treatment in vineyards contributing to the protection of soils and the environment in viticulture in Czech Republic and central Europe.

1. Introduction

According to reports and models conducted by the Intergovernmental Panel on Climate Change (2013), agriculture is perhaps the most significantly affected by climate change of all sectors of human activity. Actual climate change brings important challenges to viticulture. Some of the major risks may be driven by the projected rise in air temperatures and the decrease in soil water availability (Fraga et al., 2016; Santos et al., 2017).

According to data (OIV, 2018) there are approximately 6 million ha of vineyards in the world, what means, that vineyards represent one of the most important crops in terms of income and employment from global perspective. Despite the fact that the vine belongs to a deep-rooted plant species, numerous studies have shown that its cultivation in the coming period will be significantly affected by increasing global climate change (Chaves et al., 2007; Keller et al., 2011).

The forescated warming and unbalanced rainfall distribution will have a detrimental impact on the physiology of the grapevine and ultimately on the yield of grapes (IPCC, 2013).

It has been shown that these factors can be inhibited and even counteracted by certain management practices that can be applied by growers (Keller, 2010; Fraga et al., 2016). One potential adaptation measure that needs to be considered and further studied is the application of mulches (Chan et al., 2010). Mulches are organic or inorganic products that may be placed on the soil surface. Mulching reduces soil compaction, protects the soil surface against erosion, regulates soil temperature, reduces evaporation and increases soil moisture (Chen et al., 2007). In addition to saving water, organic mulching improves soil quality and increases its organic matter content (Ji and Unger, 2001). Mulches may also be beneficial for combating pests and stopping weed development, thus reducing water competition (Guerra and Steenwerth, 2012). Moreover, vineyards with mulch tend to suffer less from heat and water stresses (Cerdŕ et al., 2015; Mahdavi et al., 2017). Previous studies showed that by means of mulching, it is possible to decrease water requirement and to maintain yield, even under adverse climatic conditions (Bahar and Yasasin, 2010; Chan et al., 2010; DeVetter et al., 2015).

The aim of this study is to evaluate the effects of different organic mulch materials on soil moisture retention in vineyard, yield of grapes and their qualitative parameters.

2. Materials and methods

2.1. Characterization and location of the experimental area

Experimental measurements were carried out in the period from 2017 to 2019, in a 16 years old vineyard, with the planting of the Grüner Veltliner variety on the rootstock of Kober 5BB. In the vineyard, plants spacing is 2.4 x 0.9 m and a manner of growing is on a higher line with a cut per one twig.

The vineyard is located in the South Moravia Region in the "Velké Pavlovice" wine-growing sub-region, in the area of "Rakvice" and on the land called "Kozí Horky" (Latitude: 48°51'29"N, Longitude: 16°48'48" E). The site is in a corn production area, a very warm and dry climate region with an altitude of 164 m a. s. l. The slope of the land is up to 5%. The soils on which the experiment was conducted are classified according to Czech soil classification system as a Pelic Chernozems developed from very fine substrates (clays, marls, Carpathian flysch and tertiary sediments). According to the WRB classification (IUSS Working Group WRB, 2015) the studied soils are classified as Chernozems. Content of a soil rock fragments (fraction > 2 mm) is up to 10%, content of humus is 3.49% and pH value 7.4.

The climate is continental. According to Czech Hydrometeorological Institute (2019), long-term average annual air temperature from the period of 1981–2010 is 8.9°C. Long-term average annual precipitation is 559 mm with the highest rainfall occurrence in summer (from June to July: 35% of the annual total precipitation) and a minimum in winter (from January to March: 15% of the annual total precipitation).

2.2. Character of the mulching materials and experiment variants

For the purpose of experimental measurements, the soil surface in the rows of vineyards was covered with three different types of mulch material of organic origin: cereal straw (in amount of 1.2 kg·m^{-2}, volume weight 100 kg·m^{-3}), wood chips (in amount of 4 kg·m^{-2}, volume weight 400 kg·m^{-3}) and compost (in amount of 2 kg·m^{-2}, volume weight 560 kg·m^{-3}). The doses of materials were used following the multiannual mulch values based on initial experiments in Germany, reported by Ziegler (2012). The control variant represents a cultivated interlayer without covering material. The initial application of mulching materials was on 2nd January 2017 and was renewed in the following years. Each of the experimental variants was established in 3 replicates and the area of each variant was 24 m^2.

2.3. Collection and analysis of soil samples

Undisturbed soil samples were taken to Kopecky cylinders made of stainless steel, of a volume of 100 cm^3 and a height of 5 cm. Sampling were performed from three layers of soil profile (i.e. in depths of 0.1 m, 0.2 m and 0.3 m). Above each sampling depth the top layer of soil was removed with a trowel and Kopecky cylinder (3 cylinders per each sampling soil layer) were placed on the flattened surface. The cylinder was pushed into the ground evenly and after pushing 5–10 mm under surface it was carefully removed from the soil by a spade. Then the Kopecky cylinder was cleaned and packed in a plastic bag. There were determined current bulk density, porosity, maximal capillary capacity and minimal air capacity of undisturbed soil samples in laboratory. Soil samples were always taken in the spring of the experimental year. Table 1 provides an overview of average values in individual years.

2.4. Measuring of the meteorological data and soil moisture

A weather station (AMET, Czech Republic) was installed in the experimental vineyard, which recorded data on air temperature and rainfall. In all experimental variants, the soil moisture values were measured by "VIRRIB" humidity meters (AMET, Czech Republic), located at a depth 0.3 m in 3 treatments per variant. The soil moisture was recorded during a growing season every day at regular fifteen-minute intervals using the "VIRRIBLOGGER" recording unit.

2.5. Evaluation of yields and qualitative parameters of grapes

The grapes were harvested separately for the individual experiment variant (11 plants per variant in 3 replicates), weighed using KERN KB 10 000 laboratory scale (Kern & Sohn GmbH, GERMANY) and the average yield of grapes (per 1 plant) was determined, which was subsequently converted to the average yield of grapes expressed in tonnes per a hectare of vineyard.

At harvest, the juice of each variant was analyzed for pH, density of sugar in juice were determined by refractometry (°ČNM), titratable acidity and Yeast Assimilable Nitrogen (YAN) by titration with NaOH using TITROLINE EASY (SI Analytics GmbH, GERMANY). All measurements were performed three times per variant.

2.6. Statistical analysis

Results were reported as averages and standard deviation. Multivariate analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) tests were conducted to determine the differences among averages, using the software package "Statistica 12.0" (ver. 12.0, 2017). Multivariate analysis of vari-

Table 1
Average values of selected physical properties of soil

Year	Bulk density (g·cm^{-3})	Porosity (%)	Volume		Maximum capillary capacity	Minimal air capacity
			Water	Air		
			(% volume)		(% volume)	
2017	1.19	54.71	25.33	29.38	40.13	14.58
2018	1.39	46.96	24.69	22.27	35.78	11.19
2019	1.23	53.12	31.29	21.84	40.69	12.43

ance was conducted, and the results were compared using Tukey's multiple range assay at a significance level of α = 0.05.

3. Results and discussion

The results of the physical properties of the soil obtained over a three-year period do not indicate a significant effect of different organic mulching materials on the soil properties (Table 1). Slight differences in individual years were influenced by agrotechnical tillage and the total rainfall in the observed period. The values given in Fig. 1 show average values of air temperature and distribution of rainfall during the year. The total annual rainfall was 480 mm in 2017, 513 mm in 2018 and 713 mm in 2019. These data were obtained from a weather station located at the experimental site. The stated amount of rainfall in the mentioned years had a significant effect on the soil moisture under the individual organic mulch materials and also in control variant, when the increasing amount of rainfall also increased the soil moisture (Fig. 2–4). The best results were achieved in the monitored period by the variant with cereal straw, for which the highest values of soil moisture were recorded. This fact can be explained by the slower outflow of surface water during rain, the absorption of water by the cereal straw itself and thus easier penetration into the soil profile. Sarkar and Singh (2007) reported the beneficial effect of organic mulch materials on the retention of soil moisture after rain. They also found that mulched soil is able to hold 19 to 21 mm more soil moisture in the profile up to 1.2 m than soil without mulch cover. This effect enabled grapevines to better resist extreme drought stress during the growing season and positively influence the course of physiological processes (Fraga et al., 2016).

In the monitored period 2017–2019, the obtained values of soil moisture at the experimental sites suggest a positive effect of used organic mulching materials on soil moisture in comparison with uncovered control variant. While in 2017 the soil moisture was significantly higher only for the variant with cereal straw, in the following two years all variants with organic mulch materials exhibited significantly higher soil moisture than control variant. Figs 2–4 show the values of volume moisture of the soil for individual experimental variant. The highest average moisture values were measured for cereal straw mulch (26.65% vol. in 2017, 32.33% vol. in 2018 and 37.57% vol. in 2019). Prosdocimi et al. (2016) stated that straw mulch in small doses from 75 g·m^{-2} can positively affect soil moisture conditions. On average, it reduces water loss from soil by 14%, and this effect occurs immediately after the application of cereal straw. The results obtained from experimental measurements confirm that cereal straw can be a very suitable organic material for retaining water in the soil profile.

Variants with wood chips and compost also confirm a positive effect on maintaining soil moisture, as their obtained average soil moisture values from three years period are in 2018 and 2019 higher than control variant. DeVetter et al. (2015) stated that mulch materials improved soil moisture likely by reducing an evaporation from the soil surface and indirectly through suppression of weed competition for soil water. The lowest soil moisture was measured in variant with compost (21.88% vol. in 2017) and in the control variant (21.91% vol. in 2018 and 23.12% vol. in 2019). The average values of all experimental variants are given in Table 2.

Table 3 shows the average values of grapes yield for the Grüner Veltliner variety, which were determined for individual experimental variants. The results show that the efficiency of mulch materials is reflected in an increase in the yield of grapes in the longer term. While in 2017 there was no statistically significant difference in yields between the evaluated variants, in the following two years the difference was proved in benefit of variants with organic mulch materials on soil surface compared to control. The best results were achieved with the use of cereal straw mulch, where the yield was 12.1–19.4% higher compared to the control variant. Fraga et al. (2016) states that the use of mulch materials can reduce by 10–25% the yield loss of grapes caused by water stress and by reducing nutrient availability in the soil. They point out at the same time, that this strategy alone may not be sufficient to completely mitigate yield losses and other additional treatments should be applied (e.g. optimization

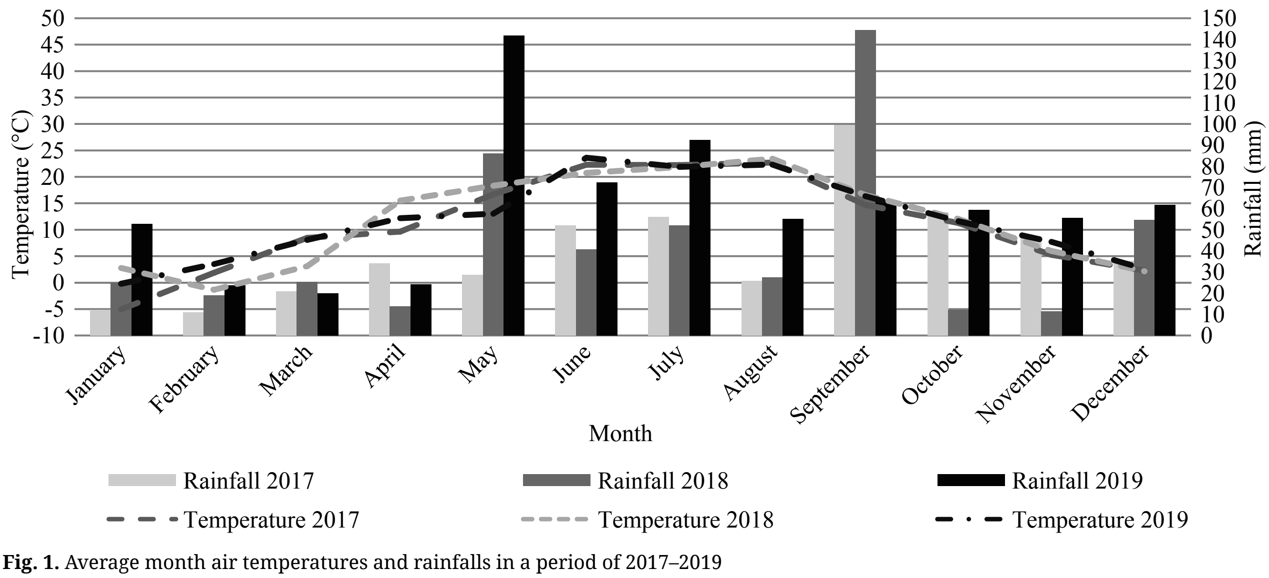

Fig. 1. Average month air temperatures and rainfalls in a period of 2017–2019

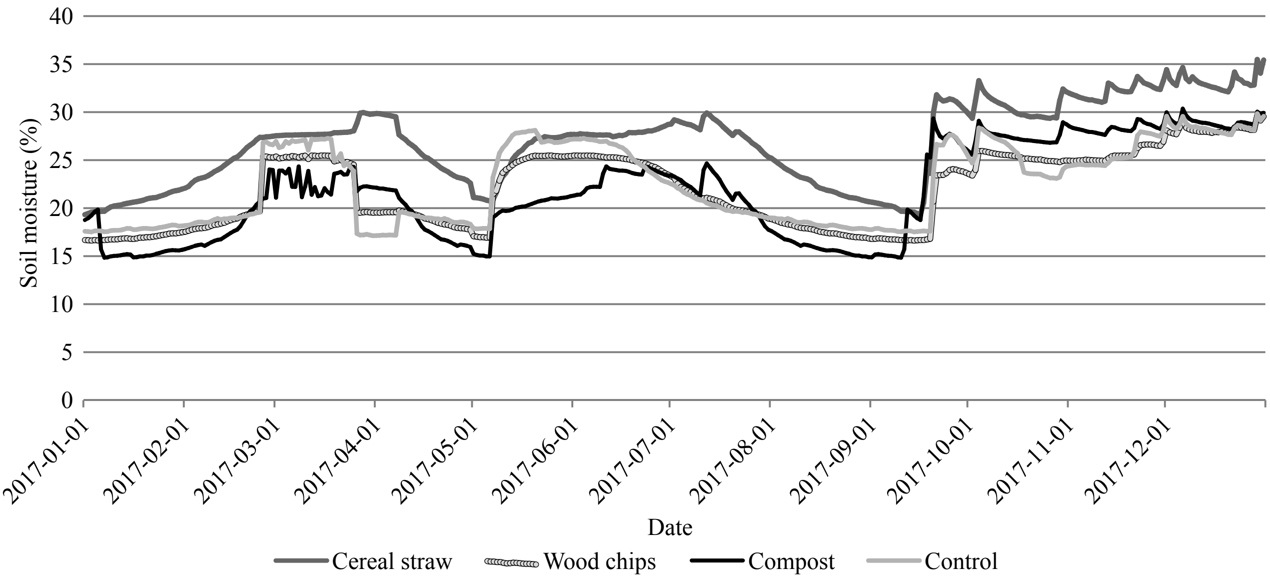

Fig. 2. Average values of volume soil moisture during the year 2017

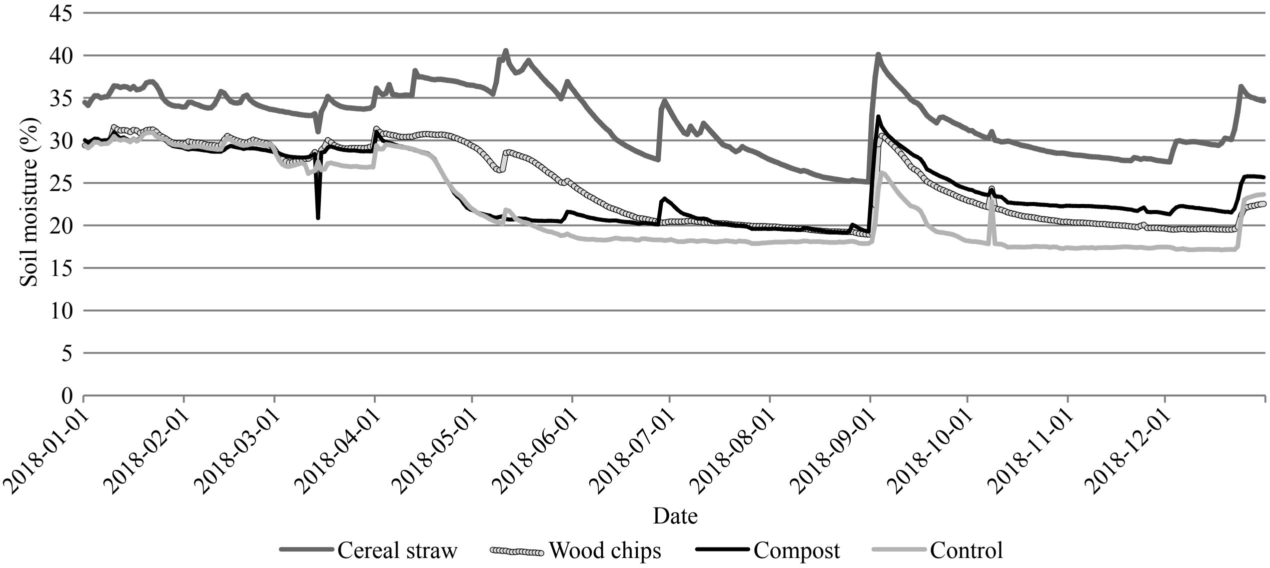

Fig. 3. Average values of volume soil moisture during the year 2018

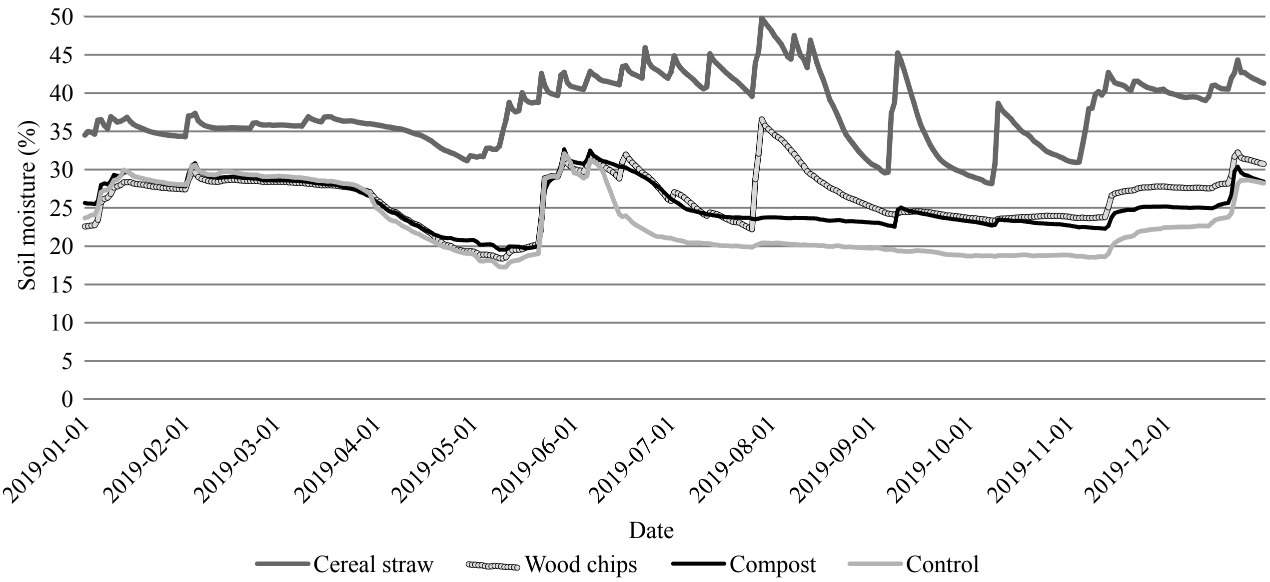

Fig. 4. Average values of volume soil moisture during the year 2019

Table 2
The average moisture values and their statistics for the whole studied period (2017–2019)

Experimental variant	Year of experiment		
	2017	2018	2019
	Average soil moisture values (% vol.)		
Cereal straw	26.65 ±0.42^{d}	32.33 ±0.03^{f}	37.57 ±0.03^{d}
Wood chips	22.04 ±0.03^{a}	24.62 ±0.05^{c}	26.35 ±0.04^{c}
Compost	21.88 ±0.11^{a}	24.35 ±0.04^{c}	25.38 ±0.11^{e}
Control	22.60 ±0.05^{b}	21.91 ±0.09^{a}	23.12 ±0.03^{a}

Note: Mean values in one column followed by the same letter were not significantly different from each other by Tukey's test at P < 0.05.

Table 3
The average yield of grapes for the observed period (2017–2019)

Experimental variant	Year of experiment		
	2017	2018	2019
	Average yield of grapes ($t \cdot ha^{-1}$)		
Cereal straw	10.73 ±0.11^{abc}	12.42 ±0.09^{ef}	13.22 ±0.09^{g}
Wood chips	10.67 ±0.10^{ab}	12.01 ±0.03^{d}	12.66 ±0.13^{f}
Compost	10.65 ±0.08^{a}	11.85 ±0.06^{d}	12.19 ±0.09^{d}
Control	10.55 ±0.08^{a}	11.08 ±0.10^{c}	11.07 ±0.16^{bc}

Note: Mean values in one column followed by the same letter were not significantly different from each other by Tukey's test at P < 0.05.

of cut and nutrition of plants, supplementary irrigation). Ramos and Martínez-Casasnovas (2006) stated that mulching with organic matter can therefore not only be a means of improving soil moisture conditions, but it can also have a beneficial effect on the quantity of yield and quality of grapes. However, the results of the analyses focused on the evaluation of selected qualitative parameters of grapes show that no statistically significant difference in the sugar content of the grapes was demonstrated in the individual experimental variants (Table 4). For the three-year averages was the sugar content slightly higher in the variant covered with cereal straw (22.94°ČNM) and compost (22.83°ČNM). This situation was similar for the pH of the must, the highest value of which was measured in the experimental variant covered with wood chips. Jackson (2008) states that the optimal pH values for musts are in the range of 3.1–3.7. These values create a good prerequisite for the future chemical and biological stability of wines. Acids in must are, in addition to sugar content, one of the most important qualitative parameter. Acids in musts and wines are evaluated as titratable acidity by measuring the value of all titratable acids. The optimal acid content during grape ripening is moving in the range of 5–8 $g \cdot l^{-1}$ (Ribéreau-Gayon et al., 2006). The determined values show that the optimal amount of titratable acids was achieved in all evaluated variants. The highest content was determined for the variant covered with cereal straw (5.24 $g \cdot l^{-1}$). An equally important parameter is a yeast assimilable nitrogen (YAN). Its essential importance is to provide nutrition for the yeast so that the sugars contained in the must are converted into ethanol during the fermentation process. For an ideal fermentation process, the minimum content of yeast assimilable nitrogen should be 150–200 $mg \cdot l^{-1}$ (Ribéreau-Gayon et al., 2006). The obtained results show that the determined values of yeast assimilable nitrogen correspond to the technological needs of the three experimental variants. In the case of a variant covered with wood chips, it is necessary to increase the YAN content by supplementary nutrition for yeast before fermentation. In addition to mulching materials, the final quality of the grapes is affected by several factors (e.g. the vintage, the amount of nutrients in the soil).

Table 4
The average of qualitative parameters of grapes in period (2017–2019)

Experimental variant	Qualitative parameters of grapes			
	Density of sugar (°ČNM)	pH	Titr. acidity ($g \cdot l^{-1}$)	YAN ($mg \cdot l^{-1}$)
Cereal straw	22.94 ±1.72^{a}	3.54 ±0.09^{a}	5.67 ±0.24^{b}	153.44 ±0.16^{c}
Wood chips	22.55 ±1.79^{a}	3.69 ±0.25^{a}	5.24 ±0.18^{a}	124.84 ±1.21^{a}
Compost	22.83 ±1.73^{a}	3.45 ±0.11^{a}	5.20 ±0.01^{a}	161.66 ±0.41^{d}
Control	22.22 ±0.90^{a}	3.31 ±0.08^{a}	5.21 ±0.10^{a}	151.64 ±0.43^{b}

Note: Mean values in one column followed by the same letter were not significantly different from each other by Tukey's test at P < 0.05.

4. Conclusions

Regarding the results of measurements carried out over a three-year period, the use of organic mulch materials of inter-row of vineyards can be described as a promising agrotechnical treatment that has a positive effect on soil moisture. Organic materials not only help maintain higher soil moisture, but these factors also have a positive effect on the resulting quality and yield of the grapes. In particular, it was an increase in the content of yeast assimilable nitrogen in variants with cereal straw and compost, and also higher content of titratable acidity in variant with cereal straw. The results show that of the three organic materials used, the most promising is the use of cereal straw, which retains the most moisture in the soil. This agrotechnical treatment can be designated as a promising treatment that growers (small farmers or large companies) can easily take in the short term, taking into account economic and agri-environmental aspects. Its advantage is also the possibility of combination with other appropriate treatments or strategies, that will generally support the sustainability of viticulture in the future. The increasing lack of natural rainfall, especially during growing period, which occurs in the wine-growing regions due to climate change, necessarily creates a need for appropriate adaptation treatments and therefore these experimental measurements are still ongoing to demonstrate the longer-term positive effect of organic mulch materials.

Acknowledgement

This study was supported by the project IGA-ZF/2019–DP001 "Evaluation of water surface runoff and water infiltration into the soil using rain simulation method" and by the project CZ.02.1.01/0.0/0.0/16_017/0002334 Research Infrastructure for Young Scientists, co-financed by Operational Programme Research, Development and Education.

References

Bahar, E., Yasasin, A.S., 2010. The yield and berry quality under different soil tillage and clusters thinning treatments in grape (Vitis vinifera L.) cv. Cabernet-Sauvignon. African Journal of Agricultural Research 5(21), 2986–2993.

Cerdà, A., Gonzalez-Pelayo, O., Gimelnez-Morera, A., Jordan, A., Pereira, P., Novara, A., Brevik, E.C., Prosdocimi, M., Mahmoodabadi, M., Keesstra, S.D., Garcia Orenes, F., Ritsema, C.J., 2015. The use of barley straw residues to avoid high erosion and runoff rates on persimmon plantations in Eastern Spain under low frequency – high magnitude simulated rainfall events. Soil Research 54, 154–165. https://doi.org/10.1071/SR15092

Chan, K.Y., Fahey, D.J., Newell, M., Barchia, I., 2010. Using composted mulch in vineyards-Effects on grape yield and quality. International Journal of Fruit Science 10(4), 441–453. https://doi.org/10.1080/15538362.2010.530135

Chaves, M.M., dos Santos, T.P., Souza, C., Ortuno, M.F., Rodrigues, M.L., Lopes, C.M., Maroco, J.P., Pereira, J.S., 2007. Deficit irrigation in grapevine improves water-use efficiency while controlling vigour and production quality. Annals of Applied Biology 150(2), 237–252. https://doi.org/10.1111/j.1744-7348.2006.00123.x

Chen, S.Y., Zhang, X.Y., Pei, D., Sun, H.Y., Chen, S.L., 2007. Effects of straw mulching on soil temperature, evaporation and yield of winter wheat: field experiments on the North China plain. Annals of Applied Biology 150(3), 261–268. https://doi.org/10.1111/j.1744-7348.2007.00144.x

Czech Hydrometeorological Institute, 2019. http://portal.chmi.cz/informace-pro-vas/rocni-vyhodnoceni/meteorologicka-pozorovani# and http://portal.chmi.cz/historicka-data/pocasi/uzemni-srazky#

DeVetter, L.W., Dilley, C.A., Nonnecke, G.R., 2015. Mulches reduce weeds, maintain yield, and promote soil quality in a continental-climate vineyard. American Journal of Enology and Viticulture 66(1), 54–64.

Fraga, H., García de Cortázar-Atauri, I., Malheiro, A.C., Santos, J.A., 2016. Modelling climate change impacts on viticultural yield, phenology and stress conditions in Europe. Global Change Biology 22(11), 3774–3788. https://doi.org/10.1111/gcb.13382

Guerra, B., Steenwerth, K., 2012. Influence of Floor Management Technique on Grapevine Growth, Disease Pressure, and Juice and Wine Composition: A Review. American Journal of Enology and Viticulture 63(2), 149–164.

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IUSS Working Group WRB. 2015. World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Jackson, R.S., 2008. Wine Science: Principles and Applications, 3rd edition. Academic Press, USA.

Ji, S., Unger, P.W., 2001. Soil Water Accumulation under Different Precipitation, Potential Evaporation, and Straw Mulch Conditions. Soil Science Society of America Journal 65(2), 442–448. https://doi.org/10.2136/sssaj2001.652442x

Keller, M., 2010. Managing grapevines to optimise fruit development in a challenging environment: a climate change primer for viticulturists. Australian Journal of Grape and Wine Research 16(s1), 56–69. https://doi.org/10.1111/j.1755-0238.2009.00077.x

Keller, M., Mills, L.J., Harbertson, J.F., 2011. Rootstock effects on scion vigor and fruit and wine composition in a dry climate. American Journal of Enology and Viticulture 62(3), 388A.

Mahdavi, S.M., Neyshabouri, M.R., Fujimaki, H., Heris, A.M., 2017. Coupled heat and moisture transfer and evaporation in mulched soils. Catena 151, 34–48.

OIV, 2018. OIV Statistical Report on World Vitiviniculture. 2018 World Vitiviniculture Situation. http://www.oiv.int/public/medias/6371/oiv-statistical-report-on-world-vitiviniculture-2018.pdf

Prosdocimi, M., Jordán, A., Tarolli, P., Keesstra, S., Novara A., Cerdà A., 2016. The immediate effectiveness of barley straw mulch in reducing soil erodibility and surface runoff generation in Mediterranean vineyards. Science of The Total Environment 547, 323–330.

Ramos M.C., Martínez-Casasnovas J.A., 2006. Nutrient losses by runoff in vineyards of Mediterranean Alt Penedčs region (NE Spain). Agriculture Ecosystems & Environment 113, 356–363.

Ribéreau-Gayon, P., Glories, Y., Maujean, A., Dubourdieu, D., 2006. Handbook of Enology. Volume 2., The Chemistry of Wine – Stabilization and Treatments. John Wiley & Sons.

Santos J.A., Costa R., Fraga H., 2017. Climate change impacts on thermal growing conditions of main fruit species in Portugal. Climatic Change 140(2), 273–286.

Sarkar S., Singh S., 2007. Interactive effect of tillage depth and mulch on soil temperature, productivity and water use pattern of rainfed barley (Hordeum vulgare L.). Soil and Tillage Research 92, 79–86.

Ziegler B., 2012. Bodenpflege im Weinbau. Abteilung Weinbau & Oenologie (Gruppe Weinbau), Broschürenreihe des Dienstleistungszentrums Ländlicher Raum Rheinpfalz, WEINBAU-INFORMATIONEN / Ausgewählte Themen für die Praxis, Neustadt an der Weinstraße 72 Seiten.