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Soil properties and grape yield of vineyard as affected by sawdust addition in a semi-arid region

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Abstract

Due to its high organic matter content, sawdust can be used for soil amendment. This study investigated the effect of sawdust obtained from a furniture industry (Yildiz Integre Akhisar flakeboard) on grape yield and loam texture soil (Typic Xerofluvent) properties of a vineyard located in Saruhanlı District, Manisa, Turkey. In the trial, three groups with dry sawdust (10 t ha^{-1}, 20 t ha^{-1}; 30 t ha^{-1}) was added to plots of vineyard while 0 t ha^{-1} or without sawdust addition was set up as a control group. All the 4 treatments were replicated three times (4×3). Sawdust addition resulted in significant increase ($p < 0.05$) of soil organic matter, total nitrogen, electrical conductivity (EC), available Na, Ca, Mg, Fe, Zn, P, K, and Mn contents, moisture, saturation percentage, field capacity, wilting point, available water and aggregation percentage values compared with control group. Also, the soil pH, bulk density, and dispersion percentage significantly decreased with sawdust addition. However, there was no significant change in lime, available Cu contents, structure stability index, aggregate stability of the soil with sawdust addition. Compared with control group, addition of 20 t ha^{-1} and 30 t ha^{-1} of dry sawdust significantly increased the grape yield of the vineyard. The highest yield of 4.23 t ha^{-1} was recorded with 30 t ha^{-1} sawdust addition. Sawdust can be used as a soil amendment given its positive effects on some soil properties and grape yield of the vineyard. It is suggested that nitrogen immobilization from the soil by microorganisms due to sawdust's high C/N ratio is a key consideration for its future use.

Keywords: Grape yield, loam texture soil, sawdust, semi-arid region.

Introduction

The benefits of soil organic matter (SOM) have been largely explored by many studies (Krull et al., 2004). Organic matter (OM) is known to improve soil structure, supply macronutrients, and micronutrients, and limit soil erosion. Also, it has the potential to increase soil water holding capacity that is a prominent aspect, particularly, in semi-arid regions (Medrano et al., 2015). The effect of organic matter on soil properties is related to its amount (Murphy, 2014).

The organic matter content in Turkey's soils, especially Egean region is generally low (Eyüpoğlu, 1999). Many studies carried out in the Egean region in Manisa districts (Alaşehir, Salihli, Akhisar-Gölmarmara) revealed that organic matter content of vineyard soils is less than 1% (Merken and Önder, 2014; Çoban et al., 2016; Yağmur and Okur, 2018). Thus, it appears relevant to increase its amount in the soil to obtain the expected benefits. Increasing the amount of SOM, and thereby the water holding capacity could lead to a reduction of irrigation water use that is generally limited in semi-arid regions (Medrano et al., 2015). Moreover, Yagmur et al. (2014) showed that irrigation water for vineyards in Alasehir, a district of Manisa, could present salinity and boron problems. Therefore, the use of organic materials to optimize water use is of great importance.

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Several organic materials (e.g., sawdust, rice bran, cocoa husk) are used to increase SOM (Olayinka and Adebayo, 1985; Moyin-Jesu, 2007). Sawdust consists of the dust and small pieces of wood resulting from woodworking operations and it has a very high carbon to nitrogen ratio (more than 100) (Allison, 1965). Large loads of wood chip are produced in the world. For instance, nearly 58 million metric tons of wood waste were produced in the United States in 2011 making a cumulative amount of about 3.5 billion metric tons (EPA, 2018). There is wood industry in almost every province of Turkey (Yildirim, 2012). The resulting sawdust is generally sent to pellet fuel plants, chipboard, and flooring product factories. Utilization of unused sawdust in agricultural sector can be beneficial to the soil and plant thus, contribute to a circular economy by closing the nutrients loop (Hannah, 2007).

The use of sawdust in agriculture goes back to several years ago. It can be used as animal bedding or be applied to the field as mulch or soil improver (Allison and Anderson, 1951). The sawdust can be applied to field in different forms: as compost after being processed with other materials (Aggelides and Londra, 2000), as ash (Awodun, 2007; Moyin-Jesu, 2007), or simply in its raw form, very often, supplemented with inorganic fertilizers or manure (Turk, 1943; Olayinka and Adebayo, 1985; Tran, 2005; Gali, 2011). This supplementation takes into account the high C/N ratio of sawdust that may lead to N immobilization from soil by microorganisms for the mineralization purpose (Sawada et al., 2015). The C/N ratio and the amount of other elements present in sawdust depend on the wood from which it is derived (Viljoen and Fred, 1924; Allison, 1965). Many studies emphasized the increase of crop yield and improvement of soil physical and chemical properties due to addition of sawdust and its derived products either alone or in combination (Olayinka and Adebayo, 1985; Aggelides and Londra, 2000; Chiroma et al., 2006; Awodun, 2007). These effects are more pronounced over a long period.

In most studies, the crops assessed are generally annual (e.g., okra, barley, beans, etc.). Few studies have been carried out to explore the benefits of sawdust addition to perennial crops such as vineyards, less in a semi-arid context. According to FAOSTAT (2019), Turkey ranked 5th and 6th worldwide in vineyards area and production of grapes, respectively. Almost half of the country's vineyards are located in the semi-arid Aegean region, particularly in Manisa province. Therefore, the current study investigated the effect of fine sawdust addition on soil properties and grape yield of a vineyard in Saruhanlı district of Manisa province.

Material and Methods

Experimental field and sawdust

The experiment was carried out in a vineyard of about 2000 m^2 belonging to a local farmer in Saruhanlı district of Manisa province. Saruhanlı district has a warm and temperate climate. There is more rainfall in the winter than in the summer. According to the Köppen-Geiger climate classification, it can be called Csa (Mediterranean climate with warm winter, very hot and dry summers). The average annual temperature and rainfall in the region is 16.6 ° C and 665 mm, respectively (Climate, 2019). The soil was loam texture slightly alkaline. Pre-trial soil analysis of some properties in the study field are shown in Table 1.

Table 1. Soil characteristics at the start of the experiment

Parameters		Units	Value
pH		-	7.52
Electrical conductivity		µmhos cm^{-1}	875.33
Lime		%	9.50
Organic matter (OM)		%	1.62
Sand		%	37.12
Clay		%	36.72
Silt		%	26.16
Total N		%	0.11
Available	P	mg kg^{-1}	23.92
	K	mg kg^{-1}	461.94
	Ca	mg kg^{-1}	5583.33
	Mg	mg kg^{-1}	541.00
	Mn	mg kg^{-1}	18.10
	Fe	mg kg^{-1}	4.28
	Cu	mg kg^{-1}	4.73
	Zn	mg kg^{-1}	1.06
	Na	mg kg^{-1}	58.88

The sawdust used in the trial was obtained from a flakeboard fabric industry (Yıldız Entegre Ağaç Sanayi ve Ticaret AŞ) located in Manisa-Akhisar. The sawdust had a fine structure since it was a waste of flakeboard processing. The sawdust used in the trial and its characteristics are shown in Figure 1 and Table 2, respectively.

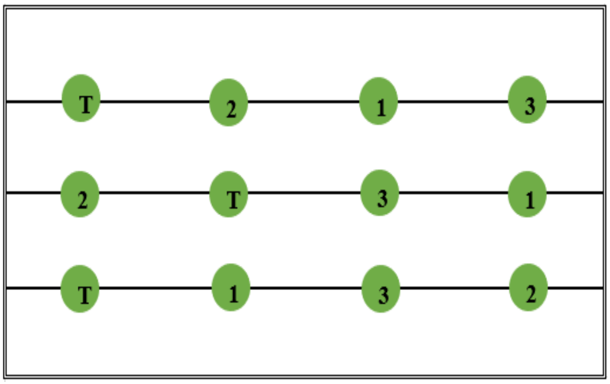
Figure 1. Sawdust used in the experiment

Table 2. Characteristics of the sawdust

Parameters		Units	Value
pH		-	7.76
Electrical conductivity		µmhos cm^{-1}	1611.00
Lime		%	3.73
Organic matter		%	67,59
C/N		-	71,28
Available	P	mg kg^{-1}	6.00
	Na	mg kg^{-1}	806.00
	K	mg kg^{-1}	1129.00
	Ca	mg kg^{-1}	8820.00
	Mg	mg kg^{-1}	712.00
	Fe	mg kg^{-1}	51.76
	Cu	mg kg^{-1}	7.05
	Zn	mg kg^{-1}	50.82
	Mn	mg kg^{-1}	13.22
Total	N	%	0.55
	B	mg kg^{-1}	28.30
	P	mg kg^{-1}	655.00
	Na	mg kg^{-1}	1032.00
	K	mg kg^{-1}	4365.00
	Ca	mg kg^{-1}	22295.00
	Mg	mg kg^{-1}	4530.00
	Fe	mg kg^{-1}	7035.00
	Cu	mg kg^{-1}	7.46
	Zn	mg kg^{-1}	147.00
	Mn	mg kg^{-1}	174.00

Experiment establishment

The sawdust was collected from the plant in Manisa Akhisar in April 2018. It was manually applied all around the plants in Manisa Saruhanlı on the same date. The treatments consisted of control without any application (0 t ha^{-1}, T), 10 t ha^{-1} (1), 20 t ha^{-1} (2), 30 t ha^{-1} (3) of dry fine sawdust. Applications were made after the vineyard was pruned (in February 2018) and the field was ploughed. After the sawdust was applied to the soil surface, it was covered with soil by the mean of a tractor. The trial was set up following a randomized complete block design (RCBD) with three replications as shown in Figure 2. Each plot was constituted of three grape trees. The variety of grape used was the seedless sultana. The sultana grape is known to be juicy, sweet and refreshing.



T: Control No application,

1: 10 t ha^{-1}, 2: 20 t ha^{-1}, 3: 30 t ha^{-1} of dry sawdust

Figure 2. View of the trial plan.

Soil analysis

Soil sampling was done at the start and approximately 6 months after addition of sawdust (September 2018) and collected at a depth of 0-15 cm. Pre- and post-trial soil analysis of available Fe, Zn, Cu, and Mn were determined by diethylenetriaminepentaacetic acid (DTPA) extraction method (Lindsay and Norvell, 1978). Determination of available Na, Ca, Mg, K was carried out by ammonium acetate (1 N NH_4 Oac pH:7) method (Kacar, 1995). Available P was analyzed using Olsen method (Olsen et al.,1954). Organic Carbon (OC) was determined by the procedure of Walkley and Black using the dichromate wet oxidation method (Nelson and Sommers, 1996). OM was calculated by multiplying OC content by 1.724. The modified Kjeldahl method was used for determination of total nitrogen (Bremner, 1965). Bulk density was estimated by cylinder method (Hunt and Gilkes,1992). Soil moisture and saturation percentage were obtained using oven drying method (Black, 1965) and pore space saturation method (Richards, 1954), respectively. A pressure plate was used to determine field capacity and wilting point at pF of 2.54 and 4.2, respectively. Available water was calculated by the difference between these two features (Richards, 1954). A pH meter was used for soil pH measurement (Jackson, 1967). The calcimetric method was applied for lime measurement. (Soil Survey Staff, 1951). Aggregation percentage, dispersion percentage, structure stability index, and aggregate stability were calculated using methods presented by Kemper and Roseneau (1986).

Determination of grape yield

The grape harvest was carried out in September 2018. The grape yield from the different plots was determined by weighing.

Statistical analysis

The collected data were subjected to variance analysis (ANOVA) using the R 3.5.1 version software. Comparison of means was performed with Duncan's multiple comparison test at a significance level of α = 0.05.

Results and Discussion

Effect of sawdust addition on soil chemical properties

In the study, sawdust application significantly affected soil chemical properties (p <0.05) (Table 3).

Table 3. Soil chemical properties at the end of the study

		0 t ha^{-1}	10 t ha^{-1}	20 t ha^{-1}	30 t ha^{-1}	
pH		7.60 ± 0.03 A	7.40 ± 0.05 AB	7.30 ± 0.04 B	6.80 ± 0.10 C	***
EC,µmhos/cm		878.30 ± 25.6 D	941.70 ± 22.5 C	981.70 ± 10.4 B	1033.30 ± 25.60 B	***
OM,%		1.70 ± 0.08 D	2.30 ± 0.15 C	2.80 ± 0.1 B	3.50 ± 0.30 B	***
Lime, %		9.75 ± 0.39 A	9.83 ± 0.60 A	9.52 ± 0.09 A	9.49 ± 0.02 A	ns
Total N, %		0.101 ± 0.01 C	0.113 ± 0.01 B	0.117 ± 0.01 B	0.131 ± 0.01 B	***
Available, mg.kg^{-1}	P	23.92 ± 5.13 B	29.18 ± 0.93 AB	31.59 ± 1.20 A	32.28 ± 1.59 A	*
	K	445.79 ± 19.38 B	465.17 ± 16.79 AB	471.63 ± 5.60 AB	484.70 ± 9.69 AB	*
	Ca	5583.3 ± 49.41 B	6059.60 ± 58.24 A	6092.5 ± 15.82 A	6130.10 ± 20.02 A	***
	Mg	514.2 ± 9.77 C	527.70 ± 6.03 BC	539.0 ± 2.89 AB	545.00 ± 4.69 AB	**
	Na	57.19 ± 5.83 C	63.92 ± 2.91 BC	68.97 ± 2.92 B	77.38 ± 5.83 B	**
	Fe	4.28 ± 0.26 C	5.10 ± 0.19 B	5.32 ± 0.26 B	6.49 ± 0.08 B	***
	Zn	1.06 ± 0.14 B	1.20 ± 0.02 A	1.24 ± 0.02 A	1.31 ± 0.03 A	*
	Cu	4.73 ± 0.50 A	4.99 ± 0.24 A	4.93 ± 0.66 A	5.05 ± 0.15 A	ns
	Mn	20.77 ± 0.31 C	22.69 ± 7.58 C	34.03 ± 4.40 B	45.24 ± 1.44 B	***

*, **, *** indicate significance at p ≤ 0.05, 0.01, and 0.001, respectively. ns is meant for « not significant » The means (n=3) ± standard deviations in each column followed by a different letter are significantly different according to Duncan's test at * p ≤ 0.05.

The soil organic matter (SOM) increased in parallel with increasing sawdust rates. The organic matter content ranged between 1.67% and 3.50% resulting in an increase of 110%. The highest and lowest values were obtained from plots with the highest rate (30 t ha^{-1}) and plots without any sawdust addition, respectively. Similar results were obtained in many other studies when organic materials were applied (Demir and Gülser, 2015; Delibacak and Ongun, 2016; Alvarenga et al., 2017). This result could be attributed to the high organic matter content of sawdust (approximately 68%) used in the experiment.

The impact of sawdust addition on soil electrical conductivity (EC) was similar to SOM. Soil EC increased with sawdust increasing rates reaching a value of 1033 µmhos cm^{-1} in plots that received the highest rate (30 t ha^{-1}). This could have resulted from the high electrical conductivity of the added sawdust (Table 2; 1611 µmhos cm^{-1}). Another reason could be attributed to the release of nutrients as a result of sawdust mineralization that affected the EC (Smith and Doran, 1997).

In comparison with the control, soil nutrients such as total nitrogen (N), available phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) iron (Fe) zinc (Zn) manganese (Mn) increased with sawdust addition. It appeared that the highest rate lead to more pronounced impact on soil nutrients. The increments due to addition of 30 t ha^{-1} compared with control reached 0.03%, 35%, 8.72%, 9.8%, 3.72%, 35.30%, 34%, 23.6%, 117% for total nitrogen, available P, K, Ca, Mg, Na, Fe, Zn respectively. For soil available P, K, Ca, Zn content, no significant statistical difference was found between the treatments 10 t ha^{-1}, 20 t ha^{-1}, 30 t ha^{-1} ($p < 0.05$). The increase of these nutrients in the soil can be explained by their presence in the sawdust as indicated in Table 2. In addition, mineralization process probably contributed to the increase of the available nutrients in the soil. However, it appears difficult to conclude since mineral nitrogen was not analyzed in this study.

Soil pH decreased from 7.6 in the control plots to 6.8 in plots with 3 t ha^{-1} sawdust addition. This is possible due to several organic acids and H^+ ions produced by organic matter decomposition. Moreover, the carbon dioxide (CO_2) that results from the decomposition could react with the water present in the soil to form a carbonic acid (H_2CO_3) that increases the acidity (Sağlam, 1997). Several studies have reported the decrease of the soil pH as a result of organic materials application to the soil (Candemir and Gülser, 2010; Tavali et al., 2013). No statistical difference was found out between treatments regarding lime and Cu content.

Effect of sawdust addition on soil physical properties

Changes in soil physical characteristics as affected by sawdust application are shown in Table 4.

Table 4. Soil physical properties at the end of the study

	0 t ha^{-1}				**10 t ha^{-1}**				**20 t ha^{-1}**				**30 t ha^{-1}**				
BD,g cm^{-3}	1.33	±	0.03	A	1.19	±	0.04	B	1.14	±	0.02	B	1.06	±	0.03	C	***
M,%	9.27	±	0.61	C	11.37	±	0.69	B	14.13	±	1.11	A	15.22	±	0.24	A	***
SP, %	45.60	±	1.54	C	48.80	±	0.36	B	50.10	±	0.30	B	52.30	±	0.95	A	**
FC, %	30.79	±	0.33	D	32.43	±	0.24	C	33.83	±	0.67	B	35.36	±	0.29	A	***
WP, %	16.20	±	0.79	B	17.20	±	0.40	A	17.70	±	0.17	A	18.10	±	0.28	A	*
AW, %	14.54	±	0.73	C	15.16	±	0.30	BC	16.10	±	0.59	AB	17.26	±	0.52	A	**
SSI, %	36.67	±	1.15	A	38.00	±	0.00	A	36.67	±	1.15	A	36.67	±	2.31	A	ns
AS, %	10.88	±	1.97	A	10.61	±	1.93	A	10.74	±	1.09	A	10.51	±	0.92	A	ns
DP, %	36.57	±	1.73	A	32.72	±	0.00	AB	33.52	±	0.69	AB	31.90	±	2.87	B	**
AP, %	63.43	±	1.73	B	67.28	±	0.00	AB	66.48	±	0.69	AB	68.10	±	2.87	A	*

BD: Bulk density, M: Moisture, SP: Saturation percentage, FC: Field capacity, WP: Wilting point, AW: Available water, SSI: Structural stability index, AS: Aggregate stability, DP: Dispersion percentage, AP: Aggregation percentage

*, **, *** indicate significance at $p \leq 0.05$, 0.01, and 0.001, respectively. ns is meant for « not significant » The means (n=3) ± standard deviations in each column followed by a different letter are significantly different according to Duncan's test at * $p \leq 0.05$.

Similar to soil chemical characteristics, sawdust addition led to statistically significant changes in soil physical properties. Both soil bulk density and dispersion percentage decreased following the sawdust addition. The bulk density was 1.33 and 1.06 (g cm^{-3}) in the control and 30 t ha^{-1} added plots, respectively representing a decrease of nearly 20%. The lower density of the fine sawdust incorporated into the soil could explain the soil bulk density decrease (Mylavarapu and Zinati, 2009). Furthermore, sawdust addition is associated with increase of soil aggregation and porosity (Eibisch et al., 2015).

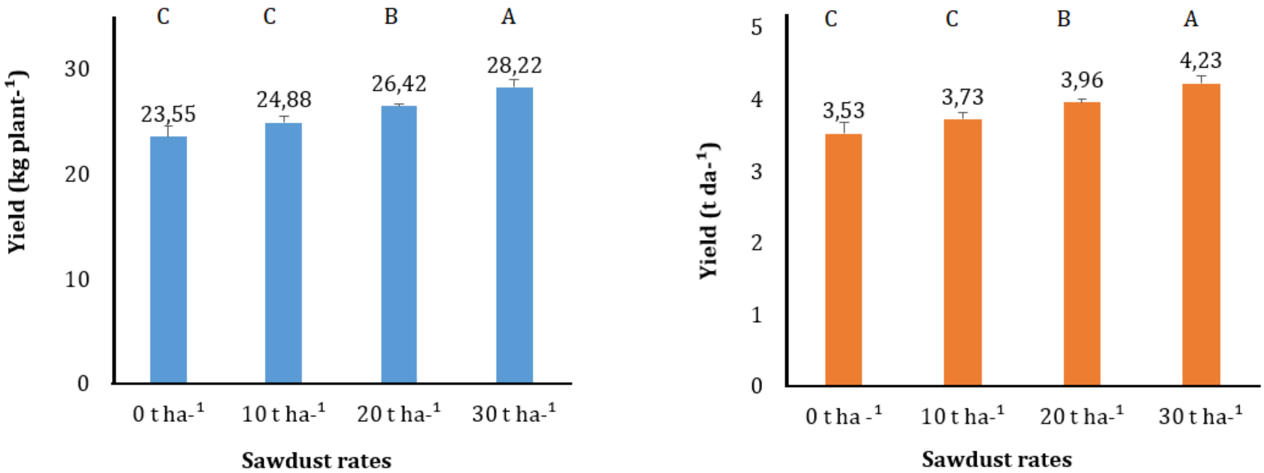
Regarding the dispersion percentage, the decrease recorded between the control and the treatments with 30 t ha^{-1} was approximately 13%. The decrease in the dispersion rate following application of organic materials has been reported by Turgut and Aksakal (2010). In our study, although the decrease was due to sawdust application, the dispersion rate in all plots varied between 31.90% and 36.57%, indicating that all of the soils remained sensitive to erosion. Soils with a dispersion percentage greater than 15 are likely to be eroded (Bryan, 1968).

Conversely, all characteristics related to soil water such as moisture, saturation percentage, field capacity, wilting point, and available water increased by 64%, 14%, 15%, 12%, 19%, respectively in the plots that received 30 t ha^{-1} of sawdust compared with control (0 t ha^{-1}). This increase may be attributed to the increase in total porosity of the soil with sawdust addition and thus more water retention of the soil (Khaleel et al., 1981). In addition, sawdust can hold moisture because of its hydrophilic properties (Stevenson, 1982). The soil water content is positively correlated to the amount of organic matter (Barzegar et al., 2002; Khan et al., 2006). Available water is the water held in soil between its field capacity and permanent wilting point (Romano and Santini, 2002). Also, as the increase of field capacity with sawdust is higher than the increase in the wilting point, there is an increase in the available water values.

The effect of sawdust addition on aggregation percentage was found to be statistically significant (P <0.05). The percentage of aggregation of the soil was 63.43% and 68.10% in control and 30 t ha-1 sawdust added plots, respectively. The effect on the structure stability index and the aggregate stability of the soil was not statistically significant (P <0.05). However, it has been reported that organic matter increases the structural stability index of the soil and aggregate stability (Cercioglu et al., 2014). Since organic matter acts as a cementing agent in the soil, it promotes the flocculation of soil particles and stable aggregate. But given that our trial period was not long enough, sawdust could not significantly affect the structural stability index and the aggregate stability of the soil.

Effects of sawdust addition on grape yield

The grape yield was affected by sawdust addition as shown in Figure 3.



Error bars are meant for standard deviations. Bars with similar letter(s) are not significantly different at P≤ 0.05 using Duncan's test.

Figure 3. Yield variation according to the sawdust rates

The grape yield increased with an increasing sawdust rate. However, no statistical significance was found between the control and 10 t ha^{-1} treatments. Yields of 3.96 t ha^{-1} and 4.23 t ha^{-1} were recorded with 20 t ha^{-1} and 30 t ha^{-1} treatments representing an increase of nearly 12 and 17%, respectively compared with control. Johnson (1944) reported tomato yield increase with sawdust addition. Also, Gali (2011) observed an increase of shoot dry matter of maize due to 5 t ha^{-1} and 10 t ha^{-1} sawdust application on sandy soil in the short term. The improvement of physical and chemical soil properties driven by the applied sawdust positively affected plant development and grape yield. The addition of sawdust more likely supplied the available nutrients resulting in a yield increase as compared with unamended plot. It appeared difficult to figure out the soil characteristics that impacted the most the yield since neither the subsurface soil where the roots of trees can reach nor the plant itself could be analyzed in this study. However, the increase of soil water content driven by sawdust could be an important aspect, particularly in this semi-arid study area where around 5 mm of rainfall is recorded in two fructification months, July and August. Data could not allow assessing the mineralization dynamic on the study period (about 6 months). However, the addition of nitrogen may be necessary in the future to promote its decomposition in the soil by microorganisms.

Conclusion

The effect of fine sawdust waste on loamy soil properties and grape yield was explored in this study. Sawdust addition led to improvement of soil properties and grape yield. In terms of the chemical properties, sawdust significantly increased the SOM, total nitrogen, EC, available Na, Ca, Mg, Fe, Zn, P, K, and Mn content. Conversely, a decrease in soil pH was recorded with sawdust addition. The lime and available Cu content of the soil did not show a statistically significant change. Regarding the soil physical properties, sawdust addition statistically increased the soil moisture, saturation percentage, field capacity, wilting point, aggregation percentage, and available water. An inverse effect was observed on the soil bulk density and dispersion percentage. Soil stability index aggregate stability was not statistically significant. Grape yield increased with sawdust addition compared with control group (without sawdust addition). The highest grape yield was determined in 30 t ha^{-1} sawdust addition. There was no statistical difference between the control and 10 t ha^{-1} treatment for grape yield. The use of sawdust as a soil amendment appears an interesting management. Nevertheless, its high C/N ratio could lead to negative effects if nitrogen is not supplemented in the soil.

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