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The effect of hazelnut husk applications on some properties of hazelnut orchard soil and hazelnut yield*

Fındık zurufu uygulamalarının fındık bahçesi toprağının bazı özelliklerine ve fındık verimine etkisi

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Keywords: Available nutrients, microbial biomass carbon, organic matter, penetration resistance, yield

Anahtar sözcükler: Besin elementi, mikrobiyal biyomas-C, organik madde, penetrasyon direnci, verim

ABSTRACT

Objective: The objective of this study was to determine the effect of hazelnut husk released after production on some physical and biological properties, nutrient content, and hazelnut yield of hazelnut orchard soil.

Material and Methods: In experiments, each hazelnut ocak was planted at a 4.0 m x 4.5 m distance to form a parcel; Hazelnut husk was applied at doses of 0, 25, 50, and 75 kg/ocak in a randomized block design with three replications. In the first, second, and third years following the application, soil samples were taken after the hazelnut harvest in order to determine some physical, chemical and biological properties, nutrient content, and hazelnut yields.

Results: Statistically, significant differences were determined in the organic matter (OM), penetration resistance (PR), bulk density (BD), soil respiration (SR), microbial biomass carbon (C_{mic}), total N, available P_2O_5, K_2O and hazelnut yields ($p<0.01$) of the soil depending on the hazelnut husk dose applications. Depending on the application dose, hazelnut husk application increased the organic matter content of the soil by an average of 29.84% as compared to the control.

Conclusion: As a result of the positive changes in the physical and biological properties of the soils, increases were obtained in the applied doses in the total N, available P_2O_5, K_2O, and hazelnut yields of the soils as compared to the control.

ÖZ

Amaç: Bu çalışmada, üretim sonrası açığa çıkan fındık zurufunun fındık bahçesi toprağının bazı fiziksel ve biyolojik özelliklerine, besin elementi içeriğine ve fındık verimine etkisi belirlenmiştir.

Materyal ve Yöntem: Denemede 4.0 m x 4.5 m aralıklarla dikilmiş her bir fındık ocağı bir parseli oluşturacak şekilde fındık zurufu 0, 25, 50 ve 75 kg/ocak dozlarında tesadüf blokları deneme desenine göre üç tekerrürlü olarak ocaklara uygulanmıştır. Uygulamayı takip eden birinci, ikinci ve üçüncü yılda fındık hasadı sonrası toprak örnekleri alınarak toprağın bazı fiziksel ve biyolojik özellikleri, besin elementi içeriği ve fındık verimler belirlenmiştir.

Araştırma Bulguları: İstatistiksel olarak fındık zurufu doz uygulamalarına bağlı olarak toprağın organik maddesi (OM), penetrasyon direnci (PD), hacim ağırlığı (HA), toprak solunumu (TS), mikrobiyal biyomas karbonu (C_{mic}), toplam N, alınabilir P_2O_5 ve K_2O ve fındık verimlerinde ($p<0.01$) önemli farklılıklar belirlenmiştir. Fındık zurufu uygulaması toprağın organik madde miktarını kontrole göre ortalama %29.84 artırmıştır.

Sonuç: Toprakların bu özelliklerindeki olumlu değişiklerin sonucu toprakların toplam N, alınabilir P_2O_5 ve K_2O ve fındık verimlerinde uygulanan dozlarda kontrole göre artışlar belirlenmiştir.

INTRODUCTION

As a world's leading hazelnut producer, Türkiye accounts for 63.51% of the total production, according to the 2021 FAO data (FAOSTAT, 2021). Türkiye is also the leading hazelnut exporter in the world, with its export reaching up to 61%. According to the Farmer Registration System in Türkiye, although hazelnut is produced in 43 provinces, almost all of the commercial production is carried out in Ordu, Samsun, Giresun, Sakarya, Düzce, Trabzon, Zonguldak, Kocaeli, Artvin, Bartın, Kastamonu, Sinop, Gümüşhane, Rize, Bolu and Tokat (TMO, 2017). Even though the hazelnut is produced in larger lands as compared to other top hazelnut producers. But the yield is much lower than the other producers. While France ranks first with 225 kg/da in world hazelnut yield in 2019, China ranks second with 212 kg/da and Greece ranks third with 212 kg/da. Looking at the average yield of the last five years, Armenia ranks first with 238 kg/da, the USA ranks second with 221 kg/da and China ranks third with 207 kg/da. Türkiye's hazelnut yield in 2019 was 106 kg/da and the average yield of the last five years is 96 kg/da (Anonymous, 2021). The emergence of new hazelnut producers and the increase in the production of other hazelnut-producing countries have caused Türkiye's share in world hazelnut exports to decrease over time. While Türkiye has been exporting hazelnuts in a relatively uncompetitive environment in production for many years, it may have to compete severely with other countries in terms of quality and price in the coming years unless necessary precautions are taken. Türkiye, therefore, has to reduce the cost of hazelnut production and increase the quality to the optimum level in a short time. To reduce the production cost and increase the yield of hazelnut, it is highly important and necessary to pay attention to the chemical inputs used at the wrong time and in excessive amounts (Eryılmaz & Kılıç, 2019).

Lawandowski & Zumwinkle (1999) reported that fertile soil should have a high level of organic matter and biological activity, stable aggregates, an environment in which plant roots can easily move, and a soil structure where water can easily infiltrate on the surface. Soil organic matter affects soil functions by causing or mediating changes in soil properties and processes related to soil physical integrity, soil fertility and productivity, and environmental quality. Soil organic matter contributes to and is affected by biological productivity in natural and managed ecosystems (Herrick & Wande, 1997). The application of organic waste to the soil has the greatest effect on the organic matter content and nutritional values and also improves the soil structure, water and air balance, and microbiological activities (Chenu et al., 2000; Candemir & Gülser, 2010). These positive effects vary depending on the organic matter content and the quality of the organic matter (Ünsal et al., 2001). Sarker et al. (2018) reported that the chemical quality of organic matter plays an important role in the soil aggregation process. Gülser et al. (2015) implied that hazelnut husk (55% C:N ratio) has a higher C:N ratio than that of compost (22% C:N ratio) depending on the slower mineralization rate in the soil, having a greater impact on soil quality indices than does compost.

There is no specific soil management in hazelnut orchards other than surface applications of fertilizer. Therefore, hazelnut husk can be physically or chemically recycled as an organic matter source in hazelnut orchards with degraded soil conditions (Gülser et al., 2015). For producers, fertilizer has a significant share in important production cost for hazelnut production. It is of great importance to increase the amount of organic matter by adding organic material to the soil in reducing this cost and increasing the effectiveness of the fertilizer applied to the soil. The organic material applied may have positive effects on the physical, chemical, and biological properties of the soil, resulting in an increase in the effectiveness of the applied fertilizer and a decrease in the amount of fertilizer used. The fact that hazelnut husk is abundant and residual in the region as organic material to be applied to the soil is an issue that should be taken into consideration in economic terms. It is very important to use hazelnut husk, which becomes available during production, as a source of organic matter in the soils of the region in question, especially since hazelnut fields are difficult to reach.

In this study, the effect of hazelnut husk, which is released after production and has become an environmental problem, the majority of which cannot be evaluated, on some physical, chemical and biological properties of the hazelnut orchard soil was determined.

MATERIALS and METHODS

Materials

The experiment was set up in Muslubey Village of Salıpazarı District, Samsun Province (Figure 1). Some properties of soil and the hazelnut husk used in the experiment are given in Table 1. Accordingly, the trial garden has soil with a clay loam texture, with an organic matter value of 2.87%, and a bulk density of 1.12 g/cm^3. The hazelnut husk used in the experiment was kept covered for 75 days, releasing its bitter green juice. The C/N ratio of the hazelnut husk used was 15.51, the pH value was 7.86, the EC value was 0.62 dS/m, and the OC value was 34.55%.

Figure 1. Location map of the study area.

Şekil 1. *Çalışma alanının lokasyon haritası.*

The temperature and precipitation data for the years 2008, 2009, and 2010, when the experiment was conducted, and the long term are depicted in Figure 2. Given the long-term data, the lowest temperature was 6.7°C in February, and the highest temperature was 23.6°C in August. The highest precipitation was observed in October, with 90.9 mm.

Table 1. Some properties of soil and hazelnut husk used in the trial

Çizelge 1. *Deneme toprağının ve fındık zurufunun bazı özellikleri*

	soil	hazelnut husk
Sand (%)	20.2	-
Clay (%)	28.5	-
Silt (%)	51.3	-
Class	CL	-
Bulk density (g/cm^3)	1.12	-
pH	5.05	7.86
EC (dS/m)	0.30	0.62
OM (%)	2.85	60.9
Total N (%)	0.16	2.23
C:N	10.25	15.1

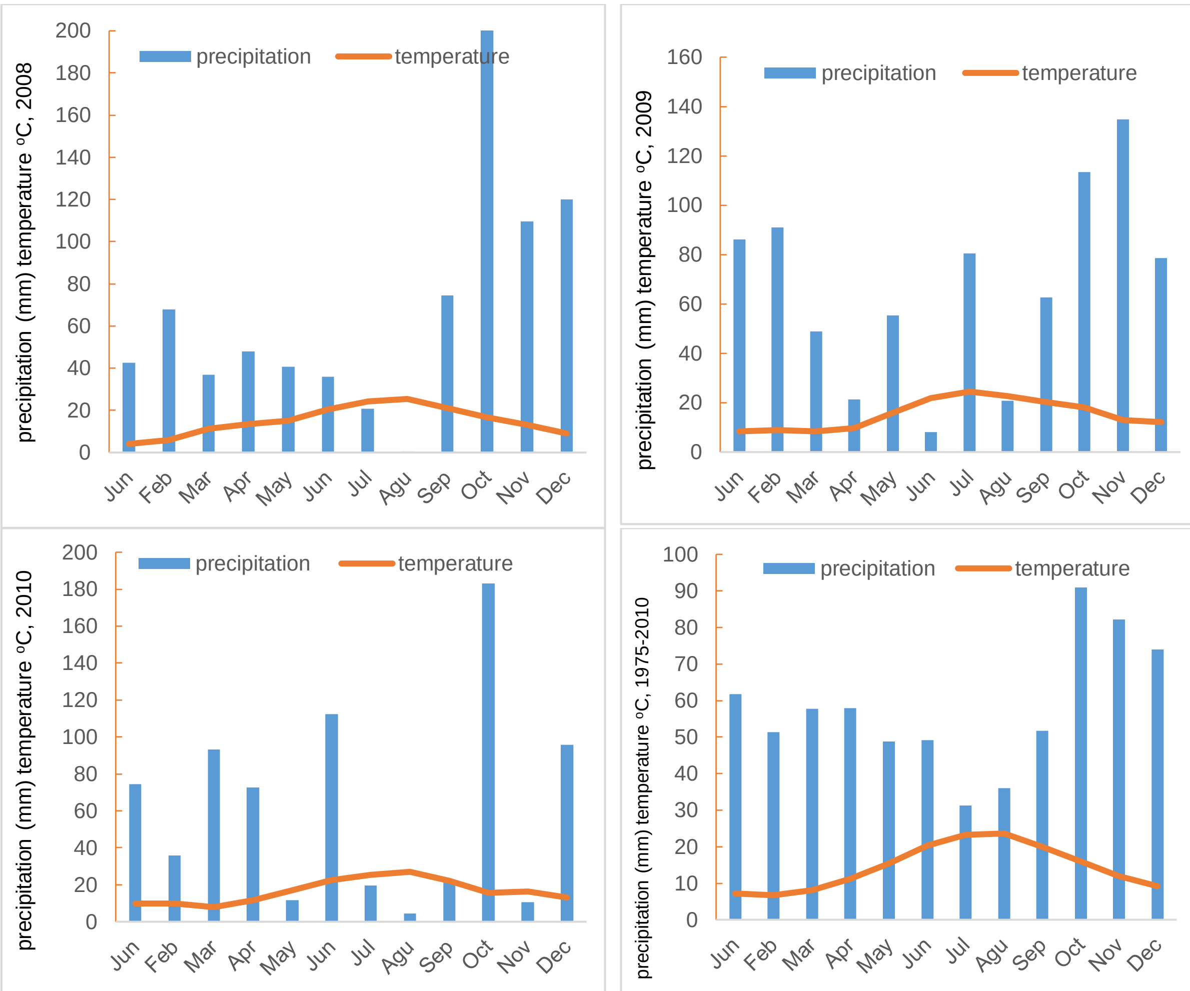

Figure 2. Temperature and precipitation values for research years and the long term (1975-2010).

Şekil 2. *Araştırma yıllarına ve uzun yıllara (1975-2010) ait sıcaklık ve yağış değerleri.*

Methods

Experiments were designed as a randomized block design with three replications. In the trials, each hazelnut ocak (in Turkish "ocak", which is consist of 8 single trunks together) planted at 4 m x 4.5 m intervals formed a parcel. An ocak was left unprocessed between the plots. Hazelnut husk was applied once in the trial plots in November 2007 as 0, 25, 50, 75 kg/ocak based on its dry weight (33%), and it was mixed with the soil. Based on the results of the soil analysis, half of the nitrogenous fertilizer and all of the phosphorus and potassium fertilizers were applied to all plots in March, and the other half of the nitrogenous fertilizer was applied as topdressing to ocaks in June and equally to each plot. Calcium ammonium nitrate (26 N%) was used as nitrogen fertilizer, diammonium phosphate (18 N%-46 P_2O_5%) as phosphorus fertilizer, and potassium sulfate (50%) fertilizer as potassium fertilizer. Again, since the soil in which the experiment was established was acidic, 363 kg/da lime was applied equally to each plot in the first year. Pruning was done in the autumn months, when the vegetation in the hazelnuts stops and the leaves fall to a large extent. Hazelnuts were harvested when ¾ of the existing fruits fell from the branch when the branches were shaken. Soil samples were taken from each plot after the hazelnut harvest in 2008, 2009 and 2010 (Although the data obtained are old, it is thought that the results give general information and are sufficient to provide up-to-date information). The organic matter (OM) of hazelnut husk was determined according to Kacar (1990), pH and electrical conductivity (EC) was determined according to Bayraklı (1987) in hazelnut husk : water (1/10) extraction. In soil samples; reaction (pH) and electrical conductivity (EC) in saturation paste, total nitrogen (N), available P_2O_5 and K_2O contents were determined according to the principles reported by Tüzüner (1990); soil texture and bulk density values were determined according to Demiralay (1993); aggregate stability(AS) was determined according to Kemper & Rosenau (1986); and penetration values(MPa) were determined with a conical tip Eijkelkamp model hand penetrometer with a surface area of 2 cm^2; the average of 6 measurement readings was calculated. Soil respiration was done as reported by Anderson (1982) and Microbial biomass carbon according to Anderson & Domsch (1978). The C_{mic}/C_{org} ratio was determined by the ratio of microbial biomass carbon to organic carbon. The data obtained from the experiments were evaluated according to the procedure as suggested by Yurtsever (1984). Three-year data were subjected to pooled analysis of variance in randomized blocks, and significant mean values were grouped by LSD multiple comparison.

RESULTS and DISCUSSION

The changes in soil penetration resistance, aggregate stability, and bulk density

The changes caused by hazelnut husk applied at increasing levels in the penetration resistance, aggregate stability, and bulk density values of the trial soils and the results of their variance analysis are tabulated in Table 2.

Penetration resistance is a commonly used parameter to evaluate soil compaction and the effects of soil management. Penetration resistance is a point measurement that varies greatly depending on time and area (O'Sullivan et al., 1987; Gülser et al., 2011). Increase in the penetration resistance in the soil or increase in the bulk density value as a result of compaction adversely affects the water-holding capacity and hydraulic conductivity properties of the soil, causing negative effects on the infiltration of water in the soil and the storage capacity of water that can be used by plants. Root growth of most agricultural crops slows significantly when penetration resistance in soil exceeds about 1.7 to 2 MPa (Bengough & Mullins, 1990; Canarache, 1990; Arshad et al., 1996). In this study, penetration values were found between 1.45-7.23 MPa (It is thought that this value is high because the hazelnut orchards are not tillage). According to the analysis of variance performed using penetration values, differences were determined between subjects ($p<0.01$) and years ($p<0.01$). The highest penetration value was obtained from the control subject, while the lowest value was obtained from the application of 75 kg/da hazelnut husk. Depending on the dose applications, reductions of 11.64%, 16.26%, and 36.04% were achieved compared to the control. Gülser & Candemir (2012) found that the penetration resistance decreased from 1.72 MPa to 0.91, 0.84, and 0.72 MPa 7 months after applying 2%, 4%, and 6% hazelnut husk to clay soil. Gülser et al. (2015) reported that there were significant negative correlations between penetration resistance and organic carbon and stated that penetration resistance decreased by 67% with hazelnut husk application as compared to the control. Aksakal et al. (2016) reported that the penetration resistance decreased significantly ($p<0.05$) with the increase in dose due to vermicompost application, and the lowest penetration value was obtained with the highest dose (4%) of vermicompost. Bandyopadhyay et al. (2010) found the penetration resistance in NPK + farmyard manure application up to a soil depth of 28 cm to be significantly lower than the control, stating that this might have resulted from the reduced bulk density due to the application of organic matter. Mujdeci (2011) applied organic matter (biosolid and manure, 30 tons ha^{-1}) to clay loam soil in an apple orchard and investigated its effect on penetration resistance. Penetration values in 2008 and 2009 were higher than in 2010. This variability may be caused by the differences in the bulk density depending on the moisture content of the soils and the hazelnut husk application. Penetration resistance is affected by some soil properties such as bulk density, texture, aggregation, cementation, organic matter content, mineralogy, and soil water content (Ribon & Tavares Filho, 2004; To & Kay, 2005; Dexter et al., 2007; Tavares Filho et al., 2012). Even though many soil properties affect penetration resistance, bulk density and especially soil water content has the greatest short-term effects on penetration resistance. Some studies have reported a direct relationship between penetration resistance and these variables, and this is usually described with an exponential model (Vaz et al., 2011, 2013).

According to the analysis of variance performed with the bulk density of the soil, significant differences at p<0.01 level were found between subjects and years. As compared to the control, an average of 16.36% reduction in bulk density value was achieved. Research has suggested that applying organic matter to soils reduces bulk density (Kılıç et al., 2000; Marinari et al., 2000; Özenç, 2004; Candemir & Gülser, 2010; Gülser, 2016; Gülser et al., 2017; Demir & Gülser 2021). Gülser (2022) stated that there is a significant negative relationship (-0.844**) between the organic matter content of the soils and the bulk density. Gülser et al. (2017) reported that hazelnut husk application reduced the bulk density of the soil compared to the control, stating that the lowest bulk density was determined with a 6% dose of hazelnut husk. Since organic materials possess low bulk density and higher porosity, the mixing of soils with denser mineral fractions causes a decrease in the bulk density of the soil (Martin & Stephens, 2001; Bronick & Lal, 2005). Celik et al. (2010) reported that the highest penetration resistance and bulk density values were found in control and mineral fertilizer applications, while the lowest values were obtained in organic applications. Researchers have evidently demonstrated that long-term applications of barnyard manure, compost, and mycorrhizal compost are important to prevent root growth, infiltration, runoff, erosion, hydraulic conductivity, aeration, mineralization rate, and soil compaction that limits biological activity. Bandyopadhyay et al. (2010) found the bulk density of the combined use of NPK and farm manure to be 5.6% and 9.3% lower than the application of NPK alone and control, respectively. They underlined that this reduction in bulk density may result from a higher organic carbon content of the soil, better aggregation, and increased root growth and biopores.

Table 2. The changes in soil penetration resistance, aggregate stability, and bulk density caused by hazelnut husk applied at increasing doses

Çizelge 2. *Artan dozlarda uygulanan fındık zurufunun toprakların penetrasyon direnci, agregat stabilitesi ve hacim ağırlığı değerinde meydana getirdiği değişimler*

	0 (Control)	**25 (kg/ocak)**	**50 (kg/ocak)**	**75 (kg/ocak)**	**Mean**
			Penetration Resistance (MPa)		
2008	7.23 a	6.04 b	5.79 c	3.21 e	**5.57 A**
2009	4.71 c	4.51c	4.14 c	3.96 cd	**4.33 B**
2010	1.71 e	1.51 e	1.49 e	1.45 e	**1.54 C**
Mean	**4.55 A**	**4.02 B**	**3.81 B**	**2.87 C**	
	F_{year}: 65.986**	$F_{subject}$: 22.952**	$F_{subject\ x\ year}$: 11.886**		
	Aggregate Stability (%)				
2008	62.08	58.78	51.36	51.38	**55.90 A**
2009	55.55	57.26	58.26	60.14	**57.80 A**
2010	43.90	46.85	45.91	43.94	**45.15 B**
Mean	**53.84**	**54.30**	**51.74**	**51.72**	
	F_{year}: 12.231**	$F_{subject}$: 0.348	$F_{subject\ x\ year}$: 1.017^{ns}		
	Bulk density (g/cm^3)				
2008	1.07	0.78	0.87	0.88	**0.90 B**
2009	1.11	1.00	0.98	0.96	**1.01 A**
2010	1.12	1.09	0.88	0.79	**0.97 AB**
Mean	**1.10 A**	**0.96 B**	**0.91 B**	**0.88 B**	
	F_{year}: 9.876**	$F_{subject}$: 7.481**	$F_{subject\ x\ year}$ 1.568^{ns}		

ns: not significantly different, *: Significant at P< 0.05, **: Significant at P <0.01.

Although the aggregate stability value was not statistically significant depending on the dose applications, an average increase of 2.32% occurred compared to the control. The highest aggregate stability values were obtained in 2009, but they were not statistically different from the values obtained in 2008. In 2010, however, there was a decrease in aggregate stability values. Candemir (2005) stated that residual (waste) applications increase aggregate stability and that the application that increases aggregate stability the most in sandy soil is hazelnut husk. Gülser (2016) reported that AS values have a significant positive correlation (0.667*) with soil OM and the aggregate stability of hazelnut husk application increased by 99% compared to the control. Improved aggregate stability by adding organic waste to the soil is the result of plant phenolic acid interactions released during the decomposition of the structural components of the waste and increased microbial activity due to carbohydrate metabolisms (Martens, 2000). Oades (1984) reported that the aggregate stability of the soil is affected by microorganisms in two aspects: the mechanical bonding of soil particles and the production of effective binders through the synthesis or decomposition of organic wastes. The increases were generally more pronounced in 25 kg/ocak applications. There were decreases in 50 and 75 kg/ocak applications compared to 25 kg/ocak applications. This decrease seen at high doses might have resulted from the fact that the hazelnut husk applied in increasing doses increases the microbial activity, the increased nutritional needs cannot be met due to this increase, and the humus, which provides aggregation, is used as a nutrient by microorganisms. As a matter of fact, in our study, the hazelnut husk application increased the organic matter of the soil as well as the microbial biomass carbon. Aşkın et al. (2000) and Candemir & Gülser (2007) also found similar results in their studies.

The changes in the OM, SR, C_{mic} and C_{mic}/C_{org} ratio values of the soils

The changes in organic matter, soil respiration, C_{mic} and C_{mic}/C_{org} ratios of the trial soils caused by hazelnut husk applied at increasing doses and their variance analysis results are shown in Table 3. Microbial biomass (C_{mic}), comprising only 1-3% of total soil carbon and about 5% of total soil (Smith & Paul, 1990), is an important component of soil organic matter. It comes in on the biogeochemical cycles of basic nutrients (C-N-P-S) and related energy flows (Meli et al., 2002; Kızılkaya et al., 2004). Basal soil respiration of soil microflora provides useful information about the physiological state of the pedo ecosystem, upon which there is still some controversy. This respiration activity refers to the energy use of microflora and demonstrates the efficiency of organic carbon degradation by soil microorganisms (Wardle & Ghani, 1995).

Table 3. The changes in the OM, SR, C_{mic} and C_{mic}/C_{org} ratio values of the soils caused by increasing doses of hazelnut husk

Çizelge 3. *Artan dozlarda uygulanan fındık zurufunun toprakların OM, TS, C_{mic} ve C_{mic}/C_{org} oranında meydana getirdiği değişimler*

	0 (Control)	**25 (kg/ocak)**	**50 (kg/ocak)**	**75 (kg/ocak)**	**Mean**
	OM (%)				
2008	3.11	3.64	4.17	4.71	**3.91**
2009	3.00	3.81	4.03	4.58	**3.85**
2010	3.34	3.96	3.89	4.03	**3.81**
Mean	**3.15 C**	**3.80 B**	**4.03 B**	**4.44 A**	
	F_{year}: 0.358^{ns}	$F_{subject}$: 35.553**	$F_{subject\ x\ year}$: 2.636^{ns}		
	Soil respiration (µg CO_2 100 g^{-1} dry soil 24h)				
2008	4.90 ef	5.53 def	7.46 cd	15.65 a	**8.38 B**
2009	3.53 f	7.56 cd	11.60 b	13.43 ab	**9.03 A**
2010	4.05 ef	6.45 cde	7.54 cd	8.85 c	**6.72 A**
Mean	**4.16 D**	**6.51 C**	**8.87 B**	**12.64 A**	
	F_{year}: 4.087*	$F_{subject}$: 56.543**	$F_{subject\ x\ year}$: 6.502**		
	C_{mic} (µg CO_2-C g^{-1} dry soil 24h)				
2008	23.90 c	27.21 bc	30.60 b	44.24 a	**31.49 A**
2009	18.28 de	24.23 c	27.45 bc	31.26 b	**25.31 B**
2010	13.55 e	14.86 de	15.50 de	18.95 d	**15.72 C**
Mean	**18.58 C**	**22.10 B**	**24.52 B**	**31.48 A**	
	F_{year}: 433.946**	$F_{subject}$: 34.390**	$F_{subject\ x\ year}$: 5.035**		
	C_{mic}/C_{org}				
2008	0.132	0.129	0.127	0.126	**0.138 A**
2009	0.105	0.110	0.117	0.117	**0.112 B**
2010	0.070	0.070	0.060	0.080	**0.070 C**
Mean	**0.102**	**0.103**	**0.101**	**0.120**	
	F_{year}: 96.998**	$F_{subject}$: 2.398^{ns}	$F_{subject\ x\ year}$: 1.253^{ns}		

ns: not significantly different, *: Significant at P< 0.05, **: Significant at P <0.01.

According to the analysis of variance achieved e with organic matter values, there was a significant difference between the subjects (P<0.01) in the OM value of the soils. While the lowest organic matter value was obtained in the control, the highest OM value was obtained from the 75 kg/ocak application, with an average of 29.84% increase compared to the control. Candemir & Gulser (2011), Ozenc (2004), and Candemir & Gülser (2007) emphasized that hazelnut husk applied as organic residue increases the OC values of the soil.

According to the analysis of variance with SR and C_{mic} values, differences were found between subjects (p<0.01), years (p<0.01), and subject-year interaction (p<0.01). The highest soil respiration and C_{mic} values were obtained from the highest dose application. It is evident that the hazelnut husk applied at an increasing level results in increase in the soil respiration and C_{mic} values of the soils by an average of 124.52% and 40.09%, respectively. High soil respiration and C_{mic} values determined at increasing application doses may result from the microbial decomposition of the high organic matter contained by the hazelnut husk applied to the soils over time, serving as a food source for microorganisms, and increasing the number of heterotrophic microorganisms. Meanwhile, the applied material may have provided suitable conditions for the development and reproduction of microorganisms by improving the physical properties of soil, such as soil aeration and water retention. As a matter of fact, it has been observed that the bulk density and penetration values of the soil decrease depending on the application of organic matter. Kaplan (2005) found that different organic residues (tobacco fabrication waste, wheat straw, tea waste, and hazelnut husk) added to sandy-loam soil increased SR and C_{mic} content. Kızılkaya & Gülser (2016) stated that organic wastes increase the C_{mic} and soil respiration of soils compared to the control, the C/N ratio of the wastes makes a difference in these soil parameters, and the low initial C/N ratio increases these parameters more. Gülser et al. (2016) reported that there is a significant positive correlation between OC and SR (0.864 at p<0.01). Candemir & Gülser (2011) stated that SR is increased by hazelnut husk application. Özenç et al. (2019) found that hazelnut husk application increased the SR and C_{mic} contents of the soils compared to the control. It was also stated that the application of organic waste to the soil increases the biological properties of the soil, and the increased soil organic matter content was reported to be generally positively correlated to the microbiological activity in the soil (Bayadilova et al., 2022).

The current study found that hazelnut husk application increased the C_{mic}/C_{org} ratio, although not statistically significant. A high C_{mic}/C_{org} ratio indicates an increase in C_{mic} in total organic C. Therefore, the organic material applied not only increased the organic carbon content of the soil but also increased the C_{mic} amount, suggesting that microorganisms can be effective for a longer time in terms of soil fertility and sustainability. Studies showed that the application of organic residues to soils increases both C_{mic} and total organic C (Monreo et al., 1999; Kaplan, 2005; Kızılkaya & Hepşen, 2007). Statistical analyses with the C_{mic}/C_{org} ratio revealed differences between years. As the year progressed, this rate decreased, which may be due to the loss of effect of the applied organic material over time.

The changes in the total N, available P_2O_5 and K_2O values of the soils

The changes in N, available P_2O_5, and available K_2O soils caused by hazelnut husk applied at increasing doses and their variance analysis results are shown in Table 4.

According to the analysis of variance with the total N values of the soils, differences were determined between subjects (p<0.01), years (p<0.01), and subject-year interaction (p<0.01). The highest N values were obtained from the application of 75 kg/ocak dose in 2008. According to the variance analysis made with the available P values of the soils, differences were determined between the subjects (p<0.01), and subject-year interaction (p<0.01). Compared to the control application, an increase of 42% was achieved in the 25 kg/ocak dose application, 116% in the 50 kg/ocak dose application, and 164% in the 75 kg/ocak dose application. The useful P has been found to decrease depending on the years. This decrease may result from the fixation of P by humus and clay minerals in the soil or the formation of compounds with Fe and Al in acidic soil. According to the analysis of variance with the available K values of the soils, differences were determined between subjects (p<0.01), years (p<0.01) and subject-year interaction (P<0.01). As compared to the control application, an increase of 63% was achieved in the 25 kg/ocak dose application, 99% in the 50 kg/ocak dose application, and 173% in the 75 kg/ocak dose application. It is evident that the available K increases depending on the years. Kacar & Katkat (1998) emphasized that hazelnut husk is an organic waste that draws attention with its high K content. Andrews et al. (2021) underlined that research has shown that potassium ions readily dissolve from plant material into soil solution due to their high mobility as a predominantly unbound monatomic cation in plant tissues. This study found that there was an increase in the microbial biomass of the soil due to the application of hazelnut husk. Therefore, due to the increased microbial biomass, the N, P, and K contents of the soils may have increased as a result of the decomposition of the hazelnut husk and the penetration of the nutrients it contained in it into the soil. Indeed, researchers state that microbial biomass is involved in the biogeochemical cycles of essential nutrients (C-N-P-S) and related energy flows (Meli et al., 2002; Kızılkaya et al., 2004). Özenç et al. (2019) reported that the application of hazelnut husk to the soil provides a 99% increase in the available phosphorus content and a 103% increase in the extractable potassium content compared to biochar. Kaur et al. (2005) reported that the application of farmyard manure, poultry manure, and sugarcane filter cake alone or in combination with chemical fertilizers improved organic C, total N, P, and K status in soil.

Table 4. The changes in the total N, available P_2O_5 and K_2O values of the soils caused by the hazelnut husk applied in increasing doses

Çizelge 4. *Artan dozlarda uygulanan fındık zurufunun toprakların toplam N, alınabilir P_2O_5 ve K_2O değerinde meydana getirdiği değişimler*

	0 (Control)	25 (kg/ocak)	50 (kg/ocak)	75 (kg/ocak)	Mean
			N (%)		
2008	0.17g	0.22c	0.26b	0.29a	**0.23 A**
2009	0.14h	0.18fg	0.19efg	0.18fg	**0.17 B**
2010	0.21cde	0.22cd	0.25b	0.20def	**0.22 A**
Mean	**0.17 C**	**0.20 B**	**0.23 A**	**0.22 A**	
	F_{year}: 72.731**	$F_{subject}$: 29.835**	$F_{subject\ x\ year}$: 11.611**		
			Available P_2O_5 (kg/da)		
2008	3.90 d	8.13 bc	8.50 bc	10.10 b	**7.66**
2009	5.43 d	5.97 cd	9.20 b	14.50 a	**8.78**
2010	4.90 d	6.12 cd	13.02 a	12.97 a	**9.25**
Mean	**4.75 D**	**6.74 C**	**10.24 B**	**12.52 A**	
	F_{year}: 1.6733	$F_{subject}$: 47.5070**	$F_{subject\ x\ year}$: 4.4780**		
			Available K_2O (kg/da)		
2008	30.0 e	63.3 b	64.7 b	129.0 a	**71.75 A**
2009	33.9 de	43.6 de	62.4 b	68.3 b	**52.03 B**
2010	29.9 e	46.2 cd	59.8 bc	59.2 bc	**48.78 B**
Mean	**31.28 D**	**51.03 B**	**62.26 C**	**85.50 D**	
	F_{year}: 15.14**	$F_{subject}$: 63.24**	$F_{subject\ x\ year}$: 13.00**		

ns: not significantly different, *: Significant at P< 0.05, **: Significant at P <0.01.

The changes in hazelnut yields

It is more appropriate to determine the effects of organic waste application on yield in the long term; that said, in the short term, the effects of organic waste on crop yield compared to mineral fertilizers and controls may vary depending on the characteristics of the organic material, soil properties, application rate, and climatic conditions (Franco-Otero et al., 2012). In this study, differences were determined between subjects (p<0.01), years (p<0.01) and subject-year interaction (p<0.01) according to the analysis of variance performed using yield values (Table 5). Given the interaction, it is apparent that the highest yield was obtained from the application of 75 kg/ocak in 2010. This study has found that positive changes in the physical, chemical, and biological properties of the soils due to the application of hazelnut husk increased the hazelnut yield values. Bandyopadhyay et al. (2010) stated that the combined use of farmyard manure and the recommended dose of chemical fertilizer resulted in increases in plant growth parameters and grain and stalk yields of soybean. Abedi et al. (2010) pointed out that wheat grain yield and yield components increased significantly with N fertilizer and compost application. The same researchers also stated that besides the positive effects of organic fertilizer on soil structure leading to better root growth and more nutrient uptake, compost not only slowly releases nutrients, but also prevents losses of chemical fertilizers through denitrification, evaporation and waste, and can increase the effectiveness of chemical fertilizers, thereby increasing yields and reducing the use of chemical fertilizers to maintain soil health and fertility.

Table 5. The changes in hazelnut yields caused by hazelnut husk applied at increasing doses

Çizelge 5. *Artan dozlarda uygulanan fındık zurufunun fındık verimlerinde meydana getirdiği değişimler*

	0 (Control)	**25 (kg/ocak)**	**50 (kg/ocak)**	**75 (kg/ocak)**	**Mean**
			Yield (kg/ocak)		
2008	2.13d	2.90c	3.07bc	3.20ab	**2.83A**
2009	1.47f	1.53ef	1.65ef	2.17d	**1.70 C**
2010	1.66ef	2.01d	1.75e	3.41a	**2.21B**
Mean	**1.75C**	**2.15B**	**2.15B**	**2.93A**	
	F_{year}: 40.160**	$F_{subject}$: 98.975**	$F_{subject\ x\ year}$: 8.616**		

CONCLUSIONS

The application of hazelnut husk, an important source of organic matter, to the soil after being withered for a certain period of time helped achieve positive changes in the organic matter of the soil and, accordingly, some biological and physical properties, as well as increases in the nutrient content and yield. Hazelnut husk, applied at increasing doses, increased the SR and C_{mic} values of the soil with clay loam texture thanks to the high organic matter in its structure. The application of hazelnut husk increased not only the OM value of the soils but also the microbial activity required in the soil to degrade and decompose the organic matter. Similarly, the HA values of the soil decreased depending on the application. Despite this decrease in BD, the PD value of the soil decreased. In addition, hazelnut husk application caused an increase in AS, although it was not statistically significant; however, this change resulted in an increase that was effective at low doses, whereas it resulted in a decrease due to the increase in microbial activity at high doses. This study has found that positive changes in the physical, chemical, and biological properties of the soils due to the application of hazelnut husk increased the hazelnut yield values.

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