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Effect of magnesium fertilization on some plant nutrient interactions and nut quality properties in Turkish hazelnut (*Corylus avellana* L.)

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Plant nutrient interactions and fertilization is one of the most important factors affecting the quality of hazelnuts. This study aimed to determine the relationships between some plant nutrients and some hazelnut quality criteria and yields. The trial was carried out at Tombul hazelnut orchards in Hazelnut Research Station between 2009 and 2011. The trial was designed as randomized complete blocks of magnesium nutrient at five different doses and three replications per treatment. Hazelnut orchards were fertilized with 0, 100, 150, 200 and 250 kg ha^{-1} magnesium in each year. Magnesium fertilization significantly affected hazelnut yield and quality. However, increasing amounts of magnesium fertilizer in the soil, where they cause significant nutrient interactions were identified. The magnesium content of the soils significantly increased to 260.30 mg kg^{-1}; however, because of the recent interactions, the available phosphorus and potassium of the soil decreased to 84.28 and 298.24 mg kg^{-1} significantly. The total yield was increased to 1747.05 kg ha^{-1} with 150 kg ha^{-1} magnesium fertilization. The protein quantity in the kernel was not changed but there was important increased in oil content, kernel ratio, shelled and kernel nut weight and healthy nut amounts, and also was decreased in the amount of empty and wrinkle nuts were identified. Although the total yield increased with increasing amount of magnesium fertilizer (200 and 250 kg ha^{-1}), especially the phosphorus and potassium interactions were increased in the soil, and also some nut quality properties such as kernel ratio, shelled and kernel weights, total oil, healthy nuts, empty and wrinkle nuts were be getting worse.

Key words: *Corylus avellana* L., fertilization, interactions, nutrients, quality.

INTRODUCTION

It is known that the 1.93% of the earth's crust is composed of magnesium. The magnesium appears in the earth's crust in the form of carbonate, silicate, sulfate, chloride and it is commonly found in the important

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minerals like biotite, dolomite, magnesite etc. (Kacar, 1984). In spite of the high amount of magnesium in the earth's crust, today there is often a lack of magnesium in several agriculture fields. Aktaş (1994) stated that the probability of magnesium deficiency is high in the especially the low percent of the base saturation and cation exchange capacity of the sandy and acidic soil. Kacar (1984) indicated that lack of magnesium is likely to be seen in the coarse-textured soil which is found in the areas that get heavy rain and the constant calcification of this kind of soil causes the lack of magnesium. Kacar and Katkat (2007) reported that the fact that chemical fertilizers which are produced with developing technology do not include magnesium, more products are harvested with recently developed varieties of plants and more nutritional elements are extracted from the soil increase the magnesium requirements. Excess nitrogen and potassium fertilizer is applied in soil solution comprising a high concentration with K^+ and NH_4^+ ions with Mg^{2+} ions by competing plants that inhibit the uptake of Mg^{2+}.

Hazelnut agriculture in Turkey, with production areas about 690.000 ha, is located in the West, Middle and East Black Sea regions. Especially Middle and East Black Sea region soils are immature soil over the non-calcareous, low depth and mostly receive average of 1000 mm rain. Özyazıcı et al. (2013) stated that 45.62% of soils in Middle and Eastern Black Sea Region are strong acid to low acid character, 61.15% of the soil is low calcareous and 2.97% extractable magnesium content is low, and 25.59% is medium. Liming is often applied to increase the pH level in hazelnut orchard soils with low pH level. Anonymous (2012) reported that, 90% of fertilizers used in hazelnut agriculture is nitrogen, and 10% covers other types. Hazelnut orchards located in Black Sea region receive too much rain and 45% of them have low pH. Because especially liming and nitrogen fertilizers are overused, often encounters with lack of magnesium.. Güneş et al. (2002) stated that magnesium deficiencies reason is lowest amount of found in soil, but the amount of other cautions such as H^+, K^+, NH_4^+, Ca^{++} and Mn^+ were also the reason of magnesium deficiencies.

Balanced nutrition is one of the most important factors for increasing yield and improving quality of hazelnut. Kernel ratio, total oil and protein contents, shelled and kernel nut weight, healthy nut, empty and wrinkle nuts ratio are some important quality parameters in hazelnut. These quality parameters are significantly affected by fertilization and nutrient interaction. Magnesium has substantial effects on increasing the yield and quality in hazelnut agriculture through interaction of magnesium with photosynthesis, formation of chlorophyll, synthesize of carbohydrate, and interactions of other plant nutrient elements. The features of hazelnut orchards and methods of plant nutrition in Turkey increase the importance of fertilization with magnesium. The objectives of this study were to indicate the effects on yield and quality in hazelnut agriculture with magnesium fertilization, to determine plant nutrient interactions with magnesium fertilization, and to determine appropriate level of magnesium fertilizers in hazelnut cultivation.

MATERIALS AND METHODS

The study was conducted Tombul hazelnut orchards in Hazelnut Research Station between the years 2009 and 2011. The trial was designed as randomized complete block designs with five apply magnesium doses and three replications per treatment. The experiment was established the average of 20 to 25 years old Tombul hazelnut ocak with 4 branches based on transplanting system. Magnesium doses were applied with 0, 100, 150, 200 and 250 kg ha^{-1}. For the 500 hazelnut ocaks to be located in one hectare orchard given fertilizer doses each ocak were calculated as 0, 2040, 3060, 4080 and 5100 g $ocak^{-1}$ $MgSO_4.7H_2O$ and these doses were applied during 3 years. Also, according the results of soil analysis of the hazelnut orchards, other fertilizers were applied to each hazelnut ocak in required amounts. Texture analysis of the experiment were performed according to Soil Survey Staff (1951), pH and EC analysis according to U.S. Salinity Lab Staff (1954), $CaCO_3$ analysis according to Çağlar (1958), organic matter content according to Nelson and Sommers (1982), available phosphorus according to Bray and Kurtz (1945), available potassium according to Knudsen et. al. (1982) and extractable magnesium Anonymous (1982) were done. Required fertilizers were applied in the hazelnut orchards during 3 years. Cultural maintenance were made throughout the year such as pruning, weed control, disease and insect control, etc. Each hazelnut ocak was harvested separately in the first week of August depending on climate (Ayfer et al., 1986; Köksal, 2002). Harvested hazelnuts were separated from husk and dried. The dry shelled nut yield of each hazelnut ocak was found in per a hectare. For each nut samples, the following quality criteria's were analyzed for kernel ratio, shelled and kernel weights, percent healthy nuts, empty nuts, wrinkled nuts and shell thickness according to Ayfer et al. (1986) and Koksal (2002). Chemical compositions of hazelnut samples were analyzed for protein content according to Hartwitz (1970), and oil contents by Weende analysis methods according to Ayfer et al. (1986).

Statistical analyses were performed using analysis of variance in JMP statistical software. Results were expressed as means ± standart deviation (SD). Differences at $p<0.05$ were considered to be significant. All data obtained were the mean from the three years (Düzgüneş et al., 1983).

RESULTS AND DISCUSSION

In the trial hazelnut orchards, after fertilizing with $MgSO_4.7H_2O$ in increasing amounts, each year soil samples were taken and analyzed and these findings are represented in Tables 1 and 2. It was stated that, soil samples were clay loam, soil reaction changed between 5.91 and 6.19, EC changed between 0.08 and 0.17 $dS.m^{-1}$ and was not salinity problem, amount of calcareous changed between 0.05 and 0.21% and soil organic matter contents changed between 4.72 and 6.05%. Extractable magnesium content of orchard soil was found around 55.48 mg kg^{-1} in 0 kg ha^{-1} Mg (control). It was stated that Tombul hazelnut orchard soils, which magnesium fertilizer used, extractable magnesium

Table 1. The effects of magnesium fertilizing on some soil properties.

Treatments Mg (Kg ha^{-1})	Texture	pH (1:3)	EC (dS.m^{-1})	$CaCO_3$ (%)	Organic matter (%)
0	CL	6.02±0.157	0.100±0.020^{c}*	0.05±0.017^{d}	4.72±0.479^{b}
100	CL	6.03±0.582	0.080±0.026^{c}	0.14±0.020^{b}	5.51±0.877^{ab}
150	CL	6.19±0.346	0.083±0.015^{c}	0.10±0.017^{bc}	6.05±0.220^{a}
200	CL	6.09±0.355	0.140±0.020^{b}	0.21±0.032^{a}	5.12±0.642^{ab}
250	CL	5.91±0.382	0.170±0.020^{a}	0.09±0.017^{cd}	5.21±0.264^{ab}
LSD (5%)		0.7069	0.0376	0.0393	1.006

*Means (± standart deviation) followed by different letters in the same column are significantly different from each other at p < 0.05 level

Table 2. The effects of magnesium fertilizing on some soil properties, leaf and nuts magnesium contents.

Treatments Mg (Kg ha^{-1})	Available phosphorus (mg kg^{-1})	Available potassium (mg kg^{-1})	Extractable magnesium (mg kg^{-1})	Magnesium content at the leaf (%)	Magnesium content at the nut (%)
0	125.87±16.68a*	329.52±119.10	55.48±23.2^{b}	0.14±0.0115^{b}	0.15±0.0802
100	100.95±21.00ab	343.98±60.10	172.17±75.1^{ab}	0.18±0.0153^{a}	0.16±0.0802
150	101.01±13.78ab	416.86±208	260.30±142.9^{a}	0.19±0.0200^{a}	0.15±0.0854
200	88.24±3.45b	318.69±221	245.11±95.3^{ab}	0.21±0.0153^{a}	0.17±0.0624
250	84.28±24.00b	298.24±184	248.84±156.2^{ab}	0.19±0.0208^{a}	0.16±0.0702
LSD (5%)	31.502	308.526	119.454	0.0307	0.1385

*Means (± standart deviation) followed by different letters in the same column are significantly different from each other at p < 0.05 level.

content was “too low” and “low”. FAO (1990), soils are classified according to extractable magnesium content as < 50 ppm “too low”, 50-160 ppm “low”, 160-480 ppm “sufficient”, 480-1500 ppm “much” and > 1500 ppm “too much”. As indicated in the Table 2, in soil where magnesium fertilizing was not applied, amount of average available phosphorus was 125.87 mg kg^{-1}, and with magnesium fertilizing in increasing doses, this amount decreased to 84.28 mg kg^{-1}. It was found out that increasing amount of magnesium in soil decreased the amount of available phosphorus because of existing interactions. On the other hand, MgxP interactions prevented the increase rate of hazelnut yield. This interaction decreased kernel ratio and healthy nuts ratio, also increased the rate of empty and wrinkle hazelnuts. Kacar (1984) reported that Ca and Mg in soil increased the phosphor fixation regarding soil pH and as the rate of Mg and Ca increased in the soil, plants hardly used the phosphorus. It was seen that available potassium content was around 329.52 mg kg^{-1} where magnesium fertilizer was not applied in trial soils, and increased to 416.86 mg kg^{-1} with 150 kg ha^{-1} magnesium fertilization. However, when magnesium fertilizer doses were increased to 200 and 250 kg ha^{-1}, available potassium contents of trial soil decreased to 318.70 and 298.24 mg kg^{-1} respectively. Some amending agent increases the retention of Mg due to the increase of effective caution exchange capacity (resulting from the pH increase) and to an altered Ca/Mg ratio. The K may displace Mg from the exchange sites thereby increasing the content of the latter in the soil solution (Viade et al., 2011). The equilibrium of exchangeable cations in the soil is proportional to the activity ratio of K for divalent cations in soil solution (Quaggio et al., 2011). It was also determined that MgxK interactions in the soil due to magnesium fertilizing had negative effects on yield and quality properties. Aktaş (1994) reported that the action among plant nutrition elements known as antagonism was seen more among cations. The most known example of antagonism among plant nutrition elements was between magnesium and potassium, and K competed with Mg to be absorbed in soil ion absorption. Genç (1987) defined that potassium fertilizers increased the amount of hazelnut yields and decreased the amount of empty nuts. For the balanced fertilization in hazelnut cultivation, magnesium and potassium fertilizers should be applied so as to not cause antagonism.

Every year, after the annual fertilizing of the hazelnut orchards, the necessary cultural maintenances were made, and each hazelnut ocak was harvested separately in August and the amounts of dry shelled hazelnut yield were determined. The increasing magnesium fertilization effects on the yield are observed in Figure 1.

Approximately 1502.32 kg ha^{-1} dry shelled hazelnut

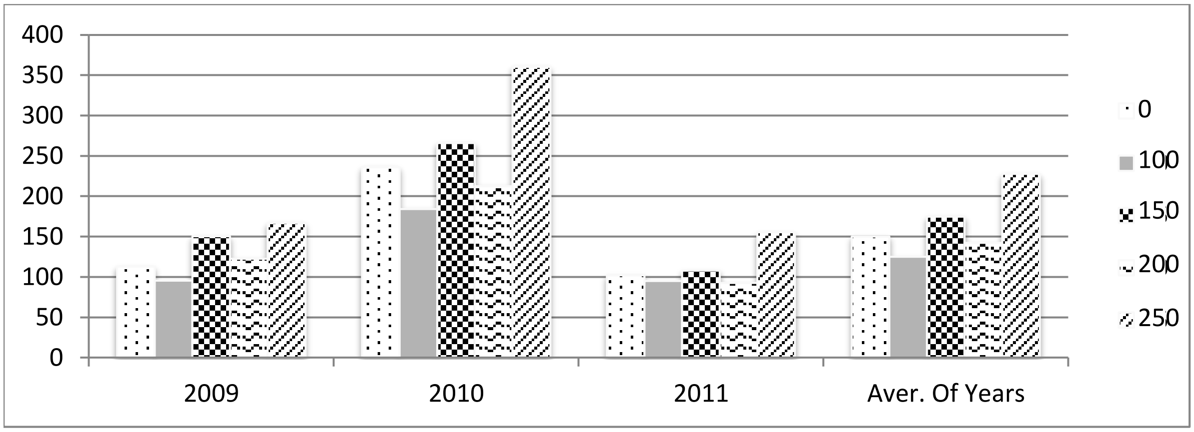

Figure 1. The effects of magnesium fertilizer on Tombul hazelnut yields ($Kg.da^{-1}$). LSD(5%): 145.499.

was obtained from 0 kg ha^{-1} application. The amounts of hazelnut yield increased with rising magnesium fertilizer doses and the highest amounts of yield to 2275.57 kg ha^{-1} was obtained from 250 kg ha^{-1} magnesium fertilization. Piroğlu and Genç (1970) stated that calcium ammonium nitrate and triple super phosphate fertilizers increases hazelnut yield as well as doing weed controls. Özenç and Çalışkan (2001) defined that the amounts of Tombul hazelnut yields were significantly increased with using mineral and organic fertilizers. Genç (1976) reported that the best fertilizing method to increase Tombul hazelnut productivity was as follows: 200 g $ocak^{-1}$ nitrogen, 300 g $ocak^{-1}$ phosphorus and 750 g $ocak^{-1}$ potassium. When Figure 1 is examined, both magnesium fertilizers and years significantly affected on the yield of Tombul hazelnut. While the amounts of hazelnuts were higher in 2010 in total, these amounts had been lower in 2009 and 2011. This has stemmed from the periodicities that occur depending on the vegetal characteristics of the hazelnut. Çetiner (1976) has stated that the yield fluctuation in Tombul hazelnut is in low or middle level; Ayfer et. al., (1986) has stated that the yield fluctuation is named as periodicity and it is seen in little amounts in Tombul hazelnut variety.

The contents of magnesium nutrition element in leaf and nut samples and the amount of protein and total oil in nut samples were determined (Tables 2 and 3). The magnesium nutrition elements in leaf were changed from 0.14 to 0.21%. Magnesium contents of leaf were more increased to 0.21% with 200 kg ha^{-1} magnesium fertilization. Jones Jr. et. al. (1991) classified according to the amounts of magnesium contents in hazelnut leaf samples 0.15 to 0.25% as “little”, 0.25 to 0.50% as “enough” and >0.50% as “much” and Snare (2007) has classified <18% as “little”, 0.19 to 0.24% as “middle”, 0.25 to 0.50% as “enough”, 0.51 to 1.00% as “much” and >1.00% as “excessive”. According to the present study results, magnesium contents of hazelnut leaves were found little and middle. Quaggio et al. (2011) reported that increased leaf K caused decreases on leaf Ca, Mg and B. The magnesium nutrition elements in kernels were changed from 0.15 to 0.17%. Magnesium contents of kernels were more increased to 0.17% with 200 kg ha^{-1} magnesium fertilization. Magnesium fertilization was not a significant effect on the contents of magnesium in nuts. It was also detected that magnesium fertilization was no effect for the protein contents of the kernels and the protein contents were between 17.11 and 17.62%. Ayfer et al. (1986) classified the hazelnuts as <14.4% little, 14.5 to 17.4% middle and >17.5% much according to their protein ingredients. In a similar way, Köksal (2002) reported that the protein contents in Tombul hazelnut was meanly 17.51%; Şahin et.al. (1990) reported that the protein contents as between 13.26 to 18.70 %. The total oil contents in the hazelnut samples were found as meanly 59.47% with 0 kg ha^{-1} applications. The increasing magnesium fertilization was significantly increased the total oil contents of the hazelnut; and 61.86% total oil was found in 100 kg ha^{-1} magnesium fertilization, 62.35% in 150 kg ha^{-1} fertilization, 62.14% in 200 kg ha^{-1} fertilization, and 62.08% in 250 kg ha^{-1} magnesium fertilization. Köksal (2002) stated that the oil amount of Tombul hazelnut was meanly 64.60 and 93.08% of it was unsaturated oil and 6.92% of it was saturated oil; Koyuncu et al. (1997) stated that the oil ratio of Tombul hazelnut in Terme and Çarşamba region was meanly 57.16%. This study results showed that magnesium fertilization was significantly increased the amounts of total oil in hazelnuts.

The effects of magnesium fertilization on some quality properties of trial hazelnuts were determined like percentage of kernel, weights of shell and kernel nuts, healthy nuts, empty nuts, wrinkle nuts and shell thickness (Tables 3 and 4). It has been detected that the percentage of kernels were found to 50.25% with 0 kg ha^{-1} applications and this ratio was decreased to 48.54% with

Table 3. Some chemical and quality properties of Tombul hazelnut.

Treatments Mg (Kg ha^{-1})	Protein (%)	Total oil (%)	Kernel ratio (%)	In-shell weight (g)	Kernel weight (g)
0	17.36 ± 0.494	59.47 ± 1.880[b*]	50.25 ± 0.664[ab]	182.81 ± 15.48	90.54 ± 7.81
100	17.11 ± 1.010	61.86 ± 1.601[a]	50.75 ± 1.293[ab]	187.03 ± 20.30	92.18 ± 9.98
150	17.46 ± 0.407	62.35 ± 1.214[a]	51.76 ± 2.100[a]	200.69 ± 18.10	103.11 ± 6.80
200	17.62 ± 0.735	62.14 ± 0.601[a]	48.85 ± 1.361[b]	197.46 ± 7.18	99.39 ± 1.53
250	17.25 ± 0.225	62.08 ± 0.440[a]	48.54 ± 1.580[b]	195.39 ± 21.90	95.15 ± 2.85
LSD (5%)	1.1565	2.316	2.6815	31.6581	15.741

*Means (± standart deviation) followed by different letters in the same column are significantly different from each other at $p < 0.05$ level.

Table 4. Some quality properties of Tombul hazelnut.

Treatments Mg (Kg ha^{-1})	Healthy nuts (%)	Empty nuts (%)	Wrinkle nuts (%)	Shell thickness (mm)
0	87.89±4.19	7.17±3.69	3.39±2.17	1.28±0.0954[ab]
100	89.06±5.02	7.39±5.26	2.00±1.30	1.32±0.0709[ab]
150	91.94±4.35	4.06±2.43	2.22±0.95	1.34±0.0379[a]
200	87.56±1.59	7.17±2.49	2.89±2.22	1.31±0.0265[ab]
250	84.39±7.77	6.83±3.24	5.22±3.47	1.22±0.0529[b]
LSD (5%)	9.080	6.502	4.009	0.1123

*Means (± standard deviation) followed by different letters in the same column are significantly different from each other at $p < 0.05$ level.

increasing amounts of magnesium fertilization. Ayfer et al. (1986), Çalışkan (1995), Çalışkan and Özenç (2001), Köksal (2002) stated that the kernel value of Tombul hazelnut changed between 49.9 to 51.7%. Decreasing kernel percentage has a significant loss of yield and quality properties. According to the present results, magnesium fertilization in hazelnut cultivation has to be made carefully in order to prevent loss of kernel quality. The weights of shell and kernel in 0 kg ha^{-1} application were between 182.81 and 90.54 g; these weights increased to 200.69 and 103.11 g with 150 kg ha^{-1} magnesium fertilization and the applications of more magnesium fertilizer were a negative effect on the weights of shell and kernel nuts. Ayfer et al. (1986) and Köksal (2002) stated that 100 kernel weights were meanly 96 and 90 g. The percentage of healthy nuts in 0 Kg ha^{-1}application was 87.89%, this amounts increased to 91.94% with the 150 kg ha^{-1} magnesium fertilization; however, the application of magnesium fertilizer in more amounts were decreased to the ratio of healthy nuts to 84.39%. Bostan (1997) informed that the healthy nuts ratio in Tombul hazelnut was 73.26%; Okay et al. (1986) informed that the healthy nuts ratio were increased in maintained hazelnut orchards and also wrinkle nuts ratio were decreased. The empty nuts ratio decreased meanly until 4.06% in 150 kg ha^{-1} magnesium fertilization and in the other applications, the empty nuts ratio increased to approximately 7% were identified. It was detected that the wrinkle nuts amount of the hazelnuts were meanly to 3.39% with 0 kg ha^{-1} applications. The wrinkle nuts amount decreased until 2.00 and 2.22% with 100 kg ha^{-1} and 150 kg ha^{-1} magnesium fertilization applications; with the increasing 200 and 250 kg ha^{-1} applications, the amounts of wrinkle nut could increase again meanly until 2.89 and 5.22%. Ayfer et al. (1986) and Köksal (2002) classified the hazelnuts as <3% as very little, 3 to 10% as little, 11 to 19% as middle, 20 to 29% as much and >30% as excessive according to their wrinkle amounts; and <3% as very little, 4 to 6% as little, 7 to 10% as middle, 11 to 14% as much and >15% as excessive according to their empty nut amounts. The shell thicknesses were found to 1.22 mm to 1.34 mm in the experiment hazelnuts. When the findings about the characteristics of quality and nutrient interactions in soils evaluated together, 150 kg ha^{-1} up to a dose of magnesium fertilizer was found to be effective. The more increasing magnesium fertilizer doses negatively affected the quality properties of hazelnut.

Conclusion

The results presented here evidence significant relations to plant nutrient interactions in soil and nut quality properties on Turkish hazelnut cultivars. In this study was detected that the use of magnesium fertilizer in hazelnut agriculture was a significant increasing the yield and quality properties. However, because of the interactions of magnesium nutrition element in the soil, the fertilizers used should be done carefully adjustment. Magnesium, phosphorus and potassium contents of soil were increased up to 150 kg ha^{-1} magnesium fertilization. When increasing the amount of magnesium fertilizer, significant interactions occur in soil systems. Although the highest yield was attained with 250 kg ha^{-1} magnesium fertilizer application, some quality properties of hazelnut were negatively affected due to the plant nutrition element interactions occuring in the soil. As the results of this study, the negative effects of nutrient element interactions in the soils were not observed up to 150 kg ha^{-1} Mg; hazelnut yield, the total oil, kernel percentage, in-shell and kernel weights, percentage of healthy nuts were increased and empty and wrinkle nut amounts were decreased through suitable magnesium fertilizer applications. When the soil, hazelnut yield and nut quality properties are considered together, it has been detected that the use of 150 kilogram magnesium fertilization per hectare in Turkish hazelnut cultivars is ideal.

Conflict of Interest

The authors have not declared any conflict of interest.

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