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Determination of the Effects of Different Planting Distances on Plant Development and Starting to Yield in 'Yomrali' Hazelnut Cultivar

Farklı Dikim Mesafelerinin 'Yomrali' Fındık Çeşidinde Bitki Gelişimi ve Verime Başlama Üzerine Etkileri

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DETERMINATION OF THE EFFECTS OF DIFFERENT PLANTING DISTANCES ON PLANT DEVELOPMENT AND STARTING TO YIELD IN 'YOMRALI' HAZELNUT CULTIVAR

ABSTRACT

Sustainability in hazelnut cultivation largely depends on reducing production costs. Priority should be given to high-yield cultivars, along with appropriate training and planting systems. Single-stem cultivation and determining optimal planting distances are crucial for effectively utilizing mechanization to reduce production costs. The research was conducted between 2022 and 2024 (the 3rd–5th leaf) years in a grower's orchard in the Çarşamba district of Samsun province. The effect of different planting distances between the plants (1.5, 3.0, and 4.5 m) on the vegetative and generative growth of the 'Yomrali' cultivar was investigated. Plant height, plant diameter and crown volume values at the end of the 5th leaf year of 'Yomrali' cultivar at different planting distances between the plants were determined as 309 cm, 83.9 mm and 25.8 m^3 at 1.5 m distance; 300 cm, 88.3 mm and 35.0 m^3 at 3.0 m distance and 306 cm, 91.9 mm and 26.0 m^3 at 4.5 m distance, respectively. No significant difference was found in terms of development among the plants at different planting distances. The cumulative number of nut clusters per decare was 54.353 at a distance of 1.5 m, 28.269 at a distance of 3.0 m, and 19.942 at a distance of 4.5 m in the 3rd to 5th leaf years of plants. The study concluded that, during the initial years of orchard establishment, dense planting (1.5 m) is more suitable for achieving high yields with the 'Yomrali' cultivar. In subsequent years, it is recommended to maintain the physiological balance between plant growth and yield through pruning and, if necessary, thinning of plants.

Keywords: Hazelnut, *Corylus avellana* L., Planting Distance, Pruning and Training, Yield, 'Yomrali'.

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FARKLI DİKİM MESAFELERİNİN 'YOMRALİ' FINDIK ÇEŞİDİNDE BİTKİ GELİŞİMİ VE VERİME BAŞLAMA ÜZERİNE ETKİLERİ

ÖZ

Fındık yetiştiriciliğinde sürdürülebilirlik büyük ölçüde üretim maliyetlerinin düşürülmesine bağlıdır. Yüksek verimli çeşitlere öncelik verilmeli, uygun terbiye ve dikim sistemleri uygulanmalıdır. Tek gövdeli yetiştiricilik ve optimum dikim mesafelerinin belirlenmesi, üretim maliyetlerini düşürmek için mekanizasyondan etkin bir şekilde yararlanmak açısından büyük önem taşımaktadır. Araştırma

2022-2024 yılları arasında Samsun'un Çarşamba ilçesinde bir üretici bahçesinde yürütülmüştür. Bitkiler arası farklı dikim mesafelerinin (1.5, 3.0 ve 4.5 m) 'Yomrali' çeşidinin vejetatif ve generatif gelişmeleri üzerine etkileri incelenmiştir. Farklı sıra üzeri dikim mesafelerine göre 5. yaprak yılı sonunda bitki boyu, bitki çapı ve taç hacmi değerleri sırasıyla 1.5 m mesafede 309 cm, 83.9 mm ve 25.8 m^3; 3.0 m mesafede 300 cm, 88.3 mm ve 35.0 m^3 ve 4.5 m mesafede 306 cm, 91.9 mm ve 26.0 m^3 olarak saptanmıştır. Dikim mesafeleri arasında bitki gelişimi bakımından önemli farklılık bulunmamıştır. Dekara kümülatif çotanak sayısı 1.5 m mesafede 54.353, 3.0 m mesafede 28.269 ve 4.5 m mesafede 19.942 adet olarak tespit edilmiştir. Araştırma sonucunda 'Yomrali' fındık çeşidinde bahçe tesisinin ilk yıllarında yüksek verim elde etmek için sık dikim uygulamasının (1.5 m) daha uygun olduğu belirlenmiştir. Sonraki yıllarda budamalarla bitki gelişimi ile verim arasındaki fizyolojik dengenin korunması ve gerektiğinde bitki seyreltmesi yapılması tavsiye edilmiştir.

Anahtar Kelimeler: Fındık, *Corylus avellana* L., Dikim Mesafesi, Budama ve Terbiye, Verim, 'Yomrali'.

1. INTRODUCTION

Hazelnuts are among the nut crops that are widely grown around the world. Türkiye is a leading country in the hazelnut production area, the amount and trade. According to FAO statistics for 2023, 650.000 tons (58%) of the world's 1.125.220 tons of hazelnut production were produced in Türkiye. Other important producer countries are Italy, the USA, Azerbaijan, Chile, Georgia, China, and France (FAOSTAT, 2025). Hazelnut production is concentrated in the coastal areas of the Black Sea Region in Türkiye. The provinces with the highest production are Ordu, Samsun, Düzce, Giresun, Sakarya, Zonguldak, Trabzon, Kocaeli and Bartın (TSI, 2024). One of the important problems of hazelnut farming in Türkiye is the low yield per decare. Some of the main reasons for the low yield are the lack of appropriate planting and training systems, the narrowing of the distances between the ocaks or plants in the orchards, and low light intensities that alter plant growth and productivity negatively due to lower photosynthetic rates (Beyhan, 1997; Beyhan et al., 1999; Beyhan et al., 2020; Balta et al., 2024).

As with the other fruit species, hazelnuts also require modern techniques in orchard establishment. Yield in hazelnuts is related to the number of plants per unit area, nut quantity per plant, and nut weight. Therefore, each improvement in these factors directly increases the total yield. Hazelnut cultivars (*C. avellana*) generally reach a height of 3-5 meters and start bearing fruit in the 3^{rd}-4^{th} years after planting. Due to these characteristics, hazelnut is considered suitable for dense planting (Erdoğan, 2023).

Traditionally, the ocak planting system is used in hazelnut cultivation in Türkiye, where plants are multi-stemmed or shrubby. However, in the last 20-30 years, interest in the row planting system has increased. In this system, in-row spacing was reduced to almost 1 meter and one or two plants were planted in each hole. Although this method increases the yield per hectare by approximately 50% compared to the ocak system, due to the hazelnut having a high suckering attitude, the plants took on a multi-trunk structure and the system turned into a hedge appearance rather than a row one. Thus, this system's productivity decreased due to decreased lighting, and nuts could only be taken from the upper canopy portions exposed to sunlight. For this reason, the opinion that the distance in rows should be increased to 2-3.5 meters has become widespread in recent years.

C. avellana has the ability to produce sucker offers the advantage of easy vegetative propagation. However it causes high labor costs. In hazelnuts, suckers removing accounts for 42% of total cultivation costs (Kılıç and Demir, 2004). The newly developed nitrogen-saline solution method (Serdar et al., 2017) facilitated sucker control and increased the applicability of the single-stem cultivation system. These advancements have led to testing single-trunk and/or high-density planting systems with cultivars (*C. avellana*) and determining the most appropriate distances between rows and within rows for these systems. This study was conducted to determine the effects of different row planting distances on plant development and yield initiation in the hazelnut cultivar 'Yomrali'.

2. MATERIAL AND METHOD

2.1. Material

The present study was conducted at the hazelnut orchard of Kaydan neighborhood in Çarşamba district of Samsun Province in 2022-2024 (between latitude 41^0 14' 27.6" N and longitude 36^0 43' 37.2" E). The orchard has an altitude of 4.0 m and is on flat land. The orchard was established in November 2019 within the scope of the 'Rehabilitation and Quality Improvement of Hazelnut Plantations That Have Completed Their Economic Life in the DOKAP Region' project, with the 'Yomrali' cultivar using potted seedlings. Row spacing was 6.0 m, and on-row plant spacing was 1.5 m. It has a clayey, slightly alkaline, unsalted and medium calcareous soil structure (Table 1). Monthly climatic data at Çarşamba district is given in Figure 1.

'Yomrali': This cultivar was registered by the Seed Registration and Certification Center on behalf of Ondokuz Mayıs University on 27 March 2023. The leafing and bud burst time is approximately 7-10 days after the 'Çakıldak' cultivar. It is suitable for single-trunk cultivation as a strong development characteristic and a low suckering tendency. It is a very productive cultivar, but yield decreases when not irrigated.

Table 1. Soil properties of the hazelnut orchard

Properties	Value	Level	Reference of Method
Saturation (%)	88	Clayey	TS 8333 (+%10) (Air-Dry) Yurdakul (2018)
pH	7.53	Slightly Alkaline	Yurdakul (2018)
Total Salinity (%)	0.04	Unsalted	TS 8334 (in the mud) Yurdakul (2018)
Lime (%)	6.11	Medium Calcareous	TS EN ISO 10693 (Modified) Yurdakul (2018)
Organic Matter (%)	1.93	Low Very Low	TS 8336 Walkley and Black (1934)
Available Phosphorus P_2O_5 (kg/da)	1.99	Low	Bray and Kurtz (1945)
Available Potassium K_2O (kg/da)	99.3	High	TS 8341 Hanway and Heidal (1952)

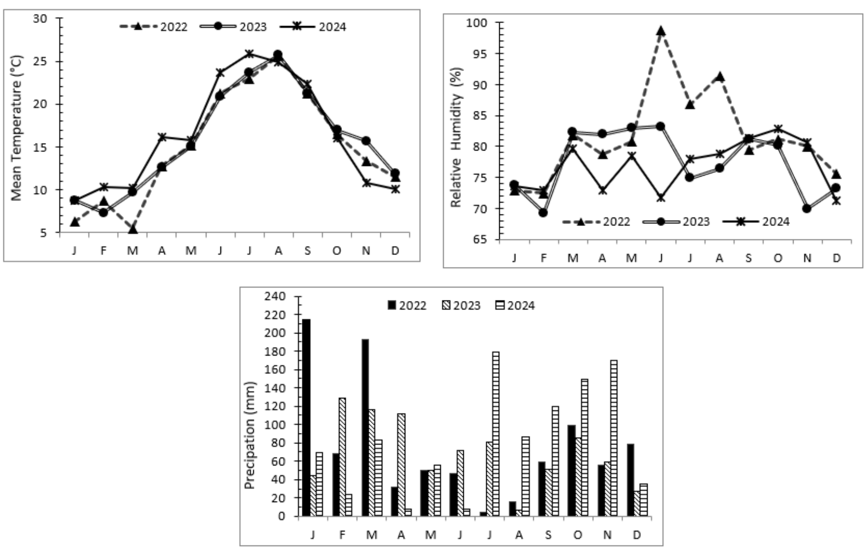

Figure 1. Monthly mean temperatures (°C), relative humidity (%) and total precipitation values (mm) of the experimental area (Anonymous, 2025).

2.2. Method

This research was carried out between 2022 and 2024 (in the 3rd and 5th leaf years) in the orchard of the 'Yomrali' hazelnut cultivar, which was established in 2019 with a planting distance of 6.0 x 1.5 m. Yield values for 2024 could not be obtained due to unexpected reasons. At the beginning of 2022, some plants on the row were removed, and the distances were rearranged as 1.5 m, 3.0 m, and 4.5 m (Figure 2). Although yield can be achieved through self-pollination in Turkish hazelnut cultivars, cultivars mixed were used in this study due to the yield and quality-enhancing effects of different pollinizers (Balık and Beyhan, 2019). 'Tombul', 'Foşa', 'Okay 28', 'Allahverdi' and 'Çakıldak' cultivars were used as pollinizers. The plants were trained according to the free vase system, and the crowning height was 15.5 ± 2.6 cm from the soil level. The number of scaffold branches in each plant varied between 2.61 and 3.30 (2.91 ± 0.4).

2.1.1. Orchard Management

- In the pruning every year in December, the shoots emerging below the crown level on the trunk were cut. One-year-old shoots longer than 40-50 cm, 1/4 or 1/5 of their length was cut off. Sucker removal was done by hand using a hazelnut knife twice a year (March and July) in 2022 and 2023, and once a year (November) in 2024.
- Weed control was done in May and July with a motorized scythe and using herbicide (480 g/L Glyphosate Isopropylamine Salt) before harvest.
- The trial orchard was irrigated using the drip irrigation method when needed.
- The fight against diseases (powdery mildew) and pests (Nut Weevil and Marmorated Stink Bug) was carried out by following the technical instructions.
- At the beginning of March 2022, 10 kg/da nitrogenous fertilizer (21% Ammonium sulphate) was applied by manually sprinkling the soil before the rain. In 2023 and 2024, 10 kg/da compound (15-15-15) and 10 kg/da nitrogenous (21% Ammonium sulphate) fertilizer applications were made at the beginning of March. In 2023 and 2024, foliar fertilization was also made in April.

2.1.2. Investigated Features

Harvesting was done in the last week of August, considering the optimum harvest properties. Harvest criteria were considered as; husks turned into yellow, reddish and brown color, reddish color of ¾ of nut hard shell. Nuts were dried in the sun to a moisture level of approximately 12% in the shell and 6% in the kernel after cluster husking. Pomological analyses on shell nuts and kernels were made according to Demir (2004), Balık (2018).

The Number of Clusters Per Plant: The number of fruit clusters per plant was determined before nut ripening.

The Number of Nuts Per Cluster: The number of nuts with good kernels was determined in 30 clusters harvested from each plant.

Nut Weight (g): The average nut weight was determined after the drying process from harvesting each plant.

The Number of Clusters Per Decar: It was determined by multiplying the number of clusters per plant by the number of plants in one decare.

Cumulative Number of Clusters Per Decar: It was determined by adding the number of clusters per decar on 2022, 2023 and 2024.

Yield Per Plant (g/plant): The yield for each plant was determined by multiplying the number of clusters per plant by the number of nuts in the clusters and the nut weight values.

Yield Per Trunk Cross-Sectional Area (g/cm^2): The yield per trunk cross-sectional area was determined by dividing the yield per plant by the stem cross-sectional area. Plant trunk diameter and circumference were measured at a height of approximately 15 cm above the soil surface from various directions using a caliper and a tape measure, respectively. Trunk cross-sectional area was calculated using the Area Formula given below.

$TCSA = \pi * (\text{Avg. Trunk Diameter}/2)^2$

Yield (kg/da): It was determined by multiplying the yield per plant by the number of plants per decare.

Plant Height (cm): At the end of the growing period, the distance from the soil level to the top of the plant was measured in all plants in each replication.

Plant Trunk Diameter (mm): At the end of the growing period, the diameter of all plants at 30 cm from the soil level was measured in each replication.

Lateral Shoot Length (cm): At the end of the growing period, the lateral one-year-old shoot length was measured in all plants in each replication and all directions.

Lateral Shoot Diameter (mm): At the end of the growing period, the lateral one-year-old shoot diameter was measured in the middle of the shoot in all plants in each replication and all directions.

Crown Width: At the end of the growing period, crown width measurements were made in the east-west and north-south directions, taking into account the height and crown projection of the plant in all plants in each repetition.

Crown Area (m^2) and Crown Volume (m^3): Crown area (m^2) was determined by multiplying the crown dimensions, and crown volume (m^3) was determined by multiplying the obtained data by the plant height.

2.1.3 Statistical Analysis

Three different applications on the row distances (1.5 m, 3.0 m and 4.5 m) were tried on the 'Yomrali' hazelnut cultivar. The experiment was conducted on three replicates and six plants in each replicate, totaling 54 plants. The results of each year were compared among themselves. The data obtained from the research were analyzed using the agricolae package in the R (2024.09.1+394) program. Differences among the various treatments were assessed using a randomized block design, one-way analysis of variance (ANOVA), and significant differences were analyzed using Duncan's test.

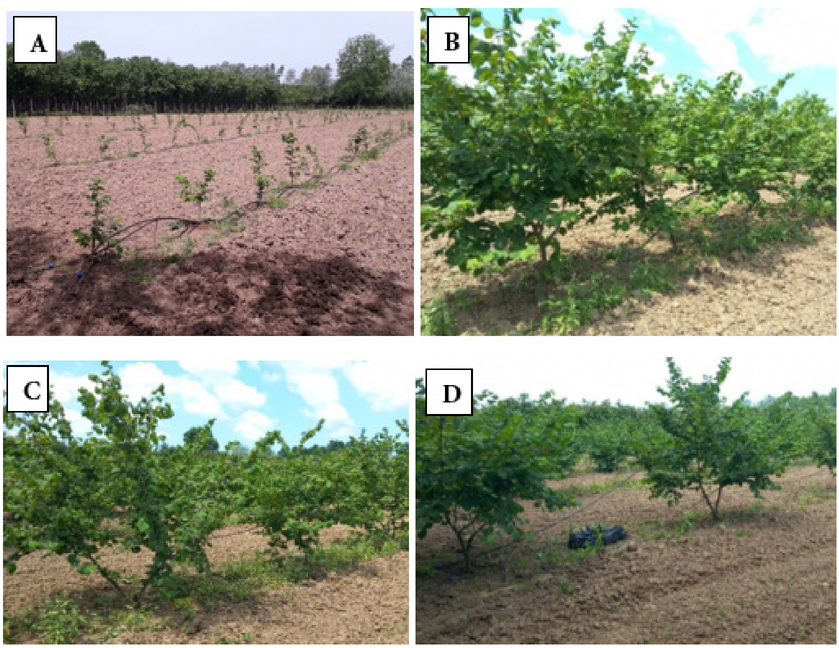

Figure 2. A: general view of the trial orchard in the 2019 planting year; view of plants in July 2023, B: 1.5 m, C: 3.0 m and D: 4.5 m.

3. RESULTS

3.1. Results for 2022

3.1.1. Plant Development

At the end of the first year of the study, plant height varied between 225 (3.0 m) and 238 (4.5 m) cm, lateral shoot length varied between 29.5 (1.5 m) and 34.4 cm (4.5 m), and lateral shoot diameter varied between 3.64 (1.5 m) and 4.24 mm (4.5 m). As a result of the statistics, the differences between planting distances for all three traits were insignificant. Significant differences were found among plant diameters ($p<0.05$). The highest plant diameter value was obtained with 64.2 mm at 4.5 m row spacing, while the lowest was obtained with 49.7 and 49.3 mm at 3.0 and 1.5 m row spacing, respectively (Table 2).

According to the plant crown width results, no difference was found between row distances in the North-South direction, while significant differences were found in the East-West direction ($p<0.05$). The highest value in this direction was 210 cm for 4.5 m spacing, while the lowest was 179 cm for 1.5 m.

Significant differences were found for both traits when the crown area and volume values were examined ($p<0.05$). The highest crown area was 4.40 and 3.96 m^2 for 4.5 and 3.0 m spacing, respectively, and the lowest was 3.35 m^2 for 1.5 m. The highest crown volume was 9.26 m^3 from 4.5 m spacing, followed by 7.94 m^3 from 3.0 m spacing. The lowest value was 6.27 m^3 from 1.5 m spacing.

3.1.2. Productivity

In the first year of the study, the number of clusters per plant varied between 32.6 (3 m) and 61.3 (1.5 m), the number of clusters per decare varied between 1356 (4.5 m) and 6808 (1.5 m), the number of nuts per cluster varied between 4.82 (1.5 m) and 5.30 (4.5 m), and the nut weight varied between 2.23 (4.5 m) and 2.51 g (1.5 m). The differences between the number of nuts per cluster and the nut weight values were insignificant. On the other hand, very significant differences were found between the number of clusters per plant and the number of clusters per decare. The highest number of clusters with 61.3 per plant and 6808 per decare was obtained from 1.5 m on row spacing (Table 3).

As a result of statistical analysis, very significant differences were found between row distances for yield per decare, yield per plant, and yield per stem cross sectional area ($p<0.05$). The highest yield per decare was obtained with 81.6 kg/da at 1.5 m in row spacing, while the lowest yield was obtained with 19.9 and 15.9 kg/

da at 3.0 and 4.5 m row spacing, respectively. The highest yield per plant was obtained with 1.5 m in row spacing (735 g), while the lowest yield was obtained with 4.5 and 3.0 m in row spacing (431 and 362 g), respectively. Similarly, the highest yield per stem cross-sectional area was obtained from 1.5 m row spacing (38.8 g), the lowest from 3.0 and 4.5 m (18.8 and 14.2 g).

Table 2. Effect of different in-row distances on the plant development in 2022

Distance	Plant Hight (cm)	Plant Diameter (mm)	Lateral Shoot		Crown Width		Crown Area (m²)	Crown Volume (m³)
			Lenght (cm)	Diameter (mm)	East-West (cm)	North-Sout (cm)		
1.5 m	225 ±6.01	49.3 b* ±2.28	29.5 ±1.31	3.64 ±0.09	179 b ±7.87	187 ±10.25	3.35± b ±0.08	6.27 b ±0.34
3.0 m	225 ±5.34	49.7 b ±1.55	33.1 ±1.40	4.01 ±0.12	197 ab ±6.05	200 ±7.02	3.96± a ±0.13	7.94 ab ±0.41
4.5 m	238 ±4.42	64.2 a ±3.13	34.4 ±1.44	4.24 ±0.11	210 a ±8.14	209 ±7.80	4.40± a ±0.24	9.26 a ±0.84
P	N.S	≤0.01	N.S.	N.S.	≤0.05	N.S.	≤0.05	≤0.05

* The difference between means marked with different letters is significant.
N.S.: Non significant.

Table 3. Effect of different in-row distances on the productivity in 2022

Distance	Number of ClustersPer Plant	Number of ClustersPer Decare	Number of NutsPer Clusters	Nut Weight (g)	Yield		
					Plant (g/plant)	**TCSA (g/cm²)	Decare (kg/da)
1.5 m	61.3 a* ±11.09	6808 a ±472	4.82 ±0.18	2.51 ±0.17	735 a ±49.5	38.8 a ±3.02	81.6 a ±5.49
3.0 m	32.6 b ±6.42	1796 b ±156	4.96 ±0.14	2.27 ±0.28	362 b ±30.4	18.8 b ±2.02	19.9 b ±1.67
4.5 m	36.6 b ±6.30	1356 b ±216	5.30 ±0.26	2.23 ±0.24	431 b ±73.3	14.2 b ±3.84	15.9 b ±2.71
P	≤0.01	≤0.001	N.S.	N.S.	≤0.01	≤0.01	≤0.001

* The difference between means marked with different letters is significant.
**TCSA, Trunk cross sectional area
N.S.: Non significant.

3.2. Results For 2023

3.2.1. Plant Development

At the end of the second year of the study, plant height varied between 258 cm (4.5 m) and 272 cm (1.5 m), plant diameter varied between 67.2 mm (3.0 m) and 74.5 mm (4.5 m), lateral shoot length varied between 23.4 cm (1.5 m) and 26.0 cm (3.0 m) and lateral shoot diameter varied between 3.04 mm (1.5 m) and 3.44 mm (3.0 m). As a result of statistical analysis, differences between in-row spacings for all four traits were insignificant (Table 4).

As for crown development, the crown width in the East-West direction varied between 261 cm (4.5 m) and 268 cm (3.0 m), the crown area varied between 6.41 m^2 (1.5 m) and 7.08 m^2 (3.0 m) and the crown volume varied between 15.6 m^3 (1.5 m) and 18.7 m^3 (3.0 m). As a result of statistical analysis, the differences between the in-row distances for all three traits were insignificant. The crown width in the North-South direction varied between 242 cm (1.5 m) and 266 cm (4.5 m), and significant differences were found between different in-row distances effects. The highest crown width was obtained from 266-263 cm with 4.5 and 3.0 m, respectively, while the lowest was obtained from 242 cm with 1.5 m in row spacing.

3.2.2. Productivity

In the second year, no difference was found among the values of the number of clusters per plant and the number of nuts per cluster, but significant differences were found in the values of nut weight and the number of clusters per decare (Table 5). The highest nut weight was obtained from 4.5 and 3.0 m spacing with 2.08 and 2.04 g, respectively, while the lowest was obtained from 1.5 m with 1.83 g. The highest number of clusters per decare was obtained from 1.5 m row spacing with 16428 pieces, while the lowest values were obtained from 3.0 and 4.5 m spacing with 9808 and 7400, respectively.

Different row spacings did not significantly affect yield per plant and yield per decare, but they significantly affected yield per decare. The highest yield per decare was obtained at 1.5 m row spacing (124 kg), while the lowest was at 3.0 and 4.5 m, respectively (82.7 and 64.4 kg).

Table 4. Effect of different in-row distances on the plant development in 2023

Distance	Plant Hight (cm)	Plant Diameter (mm)	Lateral Shoot		Crown Width		Crown Area (m^2)	Crown Volume (m^3)
			Lenght (cm)	Diameter (mm)	East-West (cm)	North-South (cm)		
1.5 m	272 ±6.84	68.0 ±3.81	23.4 ±1.80	3.04 ±0.14	264 ±6.72	242 b* ±10.03	6.41 ±0.24	15.6 ±0.90
3.0 m	264 ±6.81	67.2 ±3.22	26.0 ±1.74	3.44 ±0.12	268 ±5.23	263 a ±7.52	7.08 ±0.12	18.7 ±0.62
4.5 m	258 ±2.61	74.5 ±3.60	25.4 ±1.82	3.21 ±0.13	261 ±6.75	266 a ±8.21	6.95 ±0.19	18.5 ±1.02
P	N.S.	N.S.	N.S.	N.S.	N.S.	≤0.05	N.S.	N.S.

* The difference between means marked with different letters is significant.

N.S.: Non significant.

Table 5. Effect of different in-row distances on the productivity in 2023

Distance	Number of Clusters Per Plant	Number of Clusters Per Decare	Number of Nuts Per Clusters	Nut Weight (g)	Yield		
					Plant (g plant)	**TCSA (g/cm^2)	Decare (kg/da)
1.5 m	148 ±11.07	16428 a* ±1681	4.15 ±0.23	1.81 b ±0.03	1117 ±126	31.3 ±4.75	124.0 a ±14.00
3.0 m	178 ±12.68	9808 b ±132	4.08 ±0.33	2.06 a ±0.07	1503 ±138	43.9 ±8.18	82.7 b ±7.62
4.5 m	200 ±36.54	7400 b ±1169	4.16 ±0.24	2.08 a ±0.04	1742 ±320	42.6 ±11.17	64.4 b ±11.84
P	N.S.	≤0.01	N.S.	≤0.05	N.S.	N.S.	≤0.05

* The difference between means marked with different letters is significant.

**TCSA, Trunk cross sectional area

N.S.: Non significant.

3.3. Results For 2024

3.3.1. Plant Development

At the end of the third year, plant height varied between 300 cm (3.0 m) and 309 cm (1.5 m), plant diameter 83.9 mm (1.5 m) and 91.9 mm (4.5 m), lateral shoot length 23.3 cm (1.5 m) and 25.8 cm (3.0 m), and lateral shoot diameter 3.08 mm (1.5 m) and 3.39 mm (3.0 m). As a result of the analysis, the differences between the in-row distances for all three traits were insignificant (Table 6).

The crown width in the east-west direction varied between 316 cm (4.5 m) and 341 cm (3.0 m), and the north-south direction between 279 cm (1.5 m) and 319 cm (3.0 m). As a result of the analysis, the differences between the in-row distances for both traits were insignificant.

The crown area varied between 9.07 m^2 (4.5 m) and 10.92 m^2 (3.0 m) and the crown volume varied between 25.8 m^3 (1.5 m) and 35.0 m^3 (3.0 m). As a result of the analysis, the differences between the in-row distances for both traits were insignificant. Different in-row distances did not have a significant effect on plant development traits in 2024.

At the end of the third year of study, the number of clusters per plant varied between 280 and 303, and the number of clusters per decare varied between 11186 and 31117. As a result of the analysis, no significant difference was found betwe-en the number of clusters per plant (1.5 m: 280, 3.0 m: 303, 4.5 m: 302), while very significant differences were found between the number of clusters per decare (Figure 3). According to the in-row spacing, the highest number of clusters per decare was obtained from the 1.5 m application with 31117 units, while the lowest was obtained from the 3.0 and 4.5 m methods with 16665 and 11186 units.

Table 6. Effect of different in-row distances on the plant development in 2024

Distance	Plant Hight (cm)	Plant Diameter (mm)	Lateral Shoot		Crown Width		Crown Area (m^2)	Crown Volume (m^3)
			Lenght (cm)	Diameter (mm)	East-West (cm)	North-South (cm)		
1.5 m	309 ±6.40	83.9 ±4.76	23.3 ±1.10	3.08 ±0.10	327 ±10.22	279 ±15.50	9.15 ±0.67	25.8 ±3.71
3.0 m	300 ±4.68	88.3 ±3.65	25.8 ±1.02	3.39 ±0.11	341 ±6.92	319 ±7.45	10.92 ±0.66	35.0 ±3.71
4.5 m	306 ±9.04	91.9 ±4.20	24.9 ±0.95	3.14 ±0.09	316 ±12.90	286 ±14.47	9.07 ±0.40	26.0 ±1.81
P	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

N.S.: Non significant.

4. DISCUSSION

The traditional training system, a multi-stem bush form with 6 to 8 stems, is the most commonly used growing system in hazelnut orchards in Türkiye. In the orchards trained in multi-stem bush form, the distance between bushes varies from 4.5 m to 6 m (2500-4000 plants/ha) (Beyhan et al., 1999). New training systems have been developed to increase planting density and yield per hectare, and to apply cultural and technical practices more effectively for hazelnuts. The training system used more recently in intensive orchards, mainly in the United States and France, is the vase with a single trunk. This system makes it much easier to use, as well as to carry out sucker control, cultural practices, and mechanical harvesting more effectively (Lagerstedt and Painter, 1973).

Tree spacing is highly variable in different hazelnut growing countries, as they depend on the fertility of the soil, rainfall, cultivar vigor and mechanization requirements. In some previous studies, planting distances between hazelnut plants or trees within rows were reported to range from 2.0 m to 6.0 m in free-vase and similar systems (Baron and Stebbins, 1978; Tous et al., 1994; Me et al., 2001). These distances were even reduced to 0.7 m in a double vertical spindle training system (Sokol, 2018) and to 0.33 m in hedgerows (Beyhan, 2007). The planting distances used in this study for the 'Yomrali' hazelnut cultivar are similar to those reported in previous studies.

Although the plants with a planting distance of 4.5 m at the end of the 3rd leaf year (2022) had higher height, better height development was observed in the increasing planting density in the following years (Figure 3). Bozkurt and Erdin

(1989) stated that plants planted at a higher density had a faster height increase in order to reach the light. Plant diameter increased as planting distance increased in all leaf years. Bignami et al. (2005) stated that diameter development was stronger as planting distance increased in hazelnut.

Throughout three years of trials, it was observed that differences in planting distances were insignificant in terms of lateral shoot development (Table 2, 4, 6). But in the 3rd leaf year, lateral shoot development was higher due to the plants having more vegetative development, slowed down slightly due to the increase in generative development of the plants in the following years (Figure 3C). Romisondo et al. (1983) stated that the ideal shoot length for high yield in hazelnuts should be between 15 and 20 cm. Since the plants in our study have just started to bear fruit, their lateral shoot lengths are slightly longer. İşbakan and Bostan (2020) reported a positive relationship between yield values and lateral shoot length.

The plants had very strong crown development throughout the trial period. The average crown volume was 7.82 m^3 in 2022, 17.6 m^3 in 2023 and 28.9 m^3 in 2024. This shows that the 'Yomrali' hazelnut cultivar has strong vegetative development.

In terms of the number of cluster per plant (number/plant), the highest values were obtained from 1.5 m distance in the 3rd leaf year while the differences between planting distances in the 4th and 5th leaf years were found to be statistically insignificant. Consequently, we can say that because the plants in the 1.5 m group tend to bear nuts as soon as possible in the 3rd leaf year due to their narrower area, the generative development tendencies of the plants in other row distances increase in the following years. Riggert and McDonald (1987), who reported a relationship between tree density and early yield, also support this result. Emphasizing that the number of clusters in the 'Kalınkara' hazelnut cultivar is an important factor determining plant yield potential, Bostan (2023) stated that the total number of clusters is affected by seasonal conditions and applied cultivation techniques, but stated that the increase in the number of clusters is limited by factors such as dropping. İşbakan and Bostan (2020) reported a positive relationship between yield and lateral shoot length, yield and plant stem diameter.

The number of nuts per cluster was 5.02 in the 3rd leaf year, while it decreased to 4.13 in the 4th leaf year. Therefore, the number of nuts in the cluster decreased slightly with the number of clusters in the plants over the years. When this feature was examined according to the planting distances, the differences between the planting distances in both trial years (3rd and 4th leaf years) were insignificant. The number of pistillate flowers per cluster and the number of fruits per cluster are cultivar characteristics (Beyhan and Marangoz, 2007). In hazelnut, the number of nuts per cluster is a highly heritable trait (Thompson et al., 1996). However, it is affected by different orchard management practices. Bostan (2019) stated that pruning and other orchard practices can affect yield and quality and the number of nuts in the cluster varies depending on the number of plants in the ocaks.

There was no difference between planting distances regarding nut weight in the 3rd leaf year, but in the 4th leaf year (Tables 4.2 and 4.4). The highest nut weight in the 4th leaf year was obtained from 4.5 and 3.0 m distances as 2.08 and 2.06 g, respectively. The lowest nut weight was obtained from a distance of 1.5 m as 1.81 g. The nut weight decreased as the growing area of the plants became limited. Bak and Karadeniz's (2021) reports support our findings. On the other hand, while the average nut weight was 2.33 g in the 3rd leaf year of the experiment, it decreased to 1.98 g in the 4th leaf year. It can be said that the nut weight decreases as the generative development of plants increases. Karagöl and İslam (2023) stated that rehabilitation applications in hazelnut orchards increased yield and quality, and the yield increase values in rehabilitation plots reached 67% per plant in the first year and 60% in the second year compared to the control.

In terms of the sustainability of hazelnut cultivation, getting as much product as possible from newly established orchards in the first years is desirable. The number of nut clusters per decar is the leading indicator affecting yield in hazelnuts. It varied between 1356-6808 in the first leaf year, 7400-16428 in the second leaf year and 11186-31117 in the third leaf year (Figure 3D). The cumulative number of nut clusters per decare was 54353 at a distance of 1.5 m, 28269 at a distance of 3.0 m, and 19942 at a distance of 4.5 m in the 3-5th leaf years of plants. In other words, in these years, the 1.5 m distance had 1.92 times more nut clusters than the 3.0 m distance and 2.73 times more than the 4.5 m distance. This situation offers a great advantage in earning more income in the facility's early years (Riggert and McDonald, 1987). However, dense planting may require more thorough pruning and thinning of plants in subsequent years. Beyhan (2007) and Ellena et al. (2018) reported that yield per hectare increases logarithmically depending on planting density. High-density planting (2500 trees/ha) yielded the highest yield per hectare; however, the results show that medium-density planting (1250 trees/ha) provided the best balance between light availability, canopy development, kernel quality, and nutritional value (Portarena et al., 2024).

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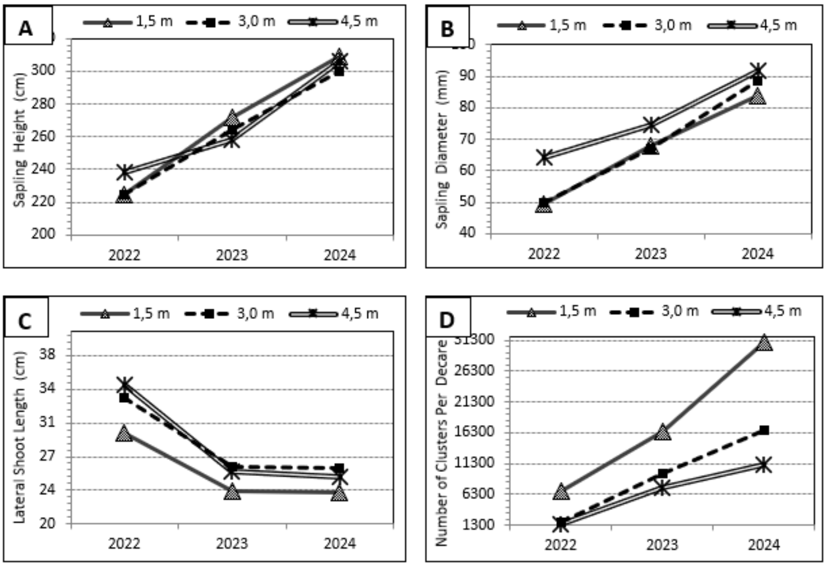

Figure 3. A: plant height development of hazelnut saplings according to years, B: plant diameter development of hazelnut saplings according to years, C: lateral shoot lengths of hazelnut saplings according to years, D: nut clusters per decare in all three trial years.

5. CONCLUSIONS

Vegetative and generative developments of 'Yomrali' hazelnut cultivar according to different planting distances (1.5, 3.0, and 4.5 m) were investigated in the 3rd-5th leaf years in this study. In the study, no difference was found in terms of plant development between different row planting distances. However, the highest yield per decare (kg/da) or/and number of clusters per decare were obtained from the 1.5 m row distance. As a result of the research, it was determined that high-density planting (1.5 m) was more suitable for obtaining high yields in the first years of orchard establishment in the 'Yomrali' hazelnut cultivar. However, in subsequent years, it is recommended to maintain the physiological balance between plant development and yield by pruning and thinning when necessary. As it is known for many fruit crops, plant densities higher than needed can be acceptable in orchard establishment initially and then some of the trees are removed to have lower plant densities. Further investigation on the interaction of light interception and tree density on yield development and fruit quality would be desirable. It is recommended that the research be continued in the coming years to reach more precise results on this subject and to provide more accurate recommendations to producers.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethics

This study does not require ethics committee approval.

Author Contribution Rates

Design of Study: AE (%10), ÜS (%70), NB(%20)

Data Acquisition: AE (%35), ÜS (%60), NB(%5)

Data Analysis: AE (%50), ÜS (%40), NB(%10)

Writing up: AE (%60), ÜS (%5), NB(%35)

Submission and Revision: AE (%65), ÜS (%10), NB(%25)

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