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EFFECT OF DIFFERENT PLANT DENSITY ON THE FORAGE YIELD AND SOME FORAGE QUALITY CHARACTERISTICS OF MORINGA (*Moringa oleifera* Lam.)

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ABSTRACT

In recent years, sustainable animal husbandry has increasingly emphasized the use of highly adaptable shrub and tree species as alternative forage crops. Among these, *Moringa oleifera* Lam., commonly known as Moringa, has emerged as a promising feed source due to its exceptional nutritional value. This study aimed to evaluate the potential of Moringa as a forage crop suitable for the Mediterranean climate. The research was conducted during the 2020 and 2021 growing seasons in the experimental fields of the Department of Field Crops, Faculty of Agriculture, Ege University, Türkiye. The study investigated the effects of four different plant densities (20x60 cm, 30x60 cm, 40x60 cm, and 60x60 cm) on various forage quality traits. The Moringa cultivar "PKM-1" served as the plant material, and parameters such as plant height, stem diameter, biomass yield, dry matter, crude ash, crude protein, crude fat, neutral detergent fiber (NDF), acid detergent fiber (ADF) and hemicellulose were determined across two consecutive vegetation periods. Results indicated that, under Mediterranean ecological conditions, Moringa exhibited average plant heights ranging from 159.2 to 170.3 cm, with total biomass yields between 33.10 and 69.70 t ha^{-1}. The crude protein content varied from 17.12% to 18.15%, while ADF and NDF ratios ranged from 35.31% to 37.85% and 45.66% to 49.71%, respectively. Higher planting densities led to increased biomass yield, with the highest values observed at a 20x60 cm planting density. This density also demonstrated favorable results for crude protein, NDF, and ADF, suggesting its suitability for optimizing forage quality in Moringa cultivation.

Keywords: *Moringa oleifera*, plant density, forage quality, Mediterranean climate, sustainability

INTRODUCTION

The use of roughage is crucial in both physiological and economic aspects of ruminant animal nutrition. A wide variety of plant species can be utilized as roughage (Amad and Zentek, 2023). In Türkiye, meadows, pastures, forage crops, and straw are the primary roughage sources (Hanoglu Oral and Gokkus, 2021). However, other developed countries employ alternative sources. In the pursuit of sustainable animal nutrition, the evaluation of drought-resistant shrubs and tree species as alternative forage sources has gained prominence in recent years (Alavilli et al., 2022). Many of these alternative plant species possess the potential to thrive under Türkiye's climatic conditions. Unlike conventional forage crops, there is an increasing demand for alternative plants that can provide high-quality roughage and adapt to diverse climatic conditions (Ambadi and Basmacioglu-Malayoglu, 2022; Budakli Carpici et al., 2023).

One such plant is the Drumstick tree (*Moringa oleifera* Lam.), renowned for its highly nutritious and beneficial leaves, making it one of the most promising food sources globally (Patil et al., 2022). *Moringa oleifera* belongs to the Moringaceae family, which includes 13 known species worldwide, with *Moringa oleifera* being the most valuable. Native to South Asia, *Moringa oleifera* is cultivated in numerous countries. The plant is widely used for human nutrition, fodder, medicinal purposes, and water purification (Amaglo et al., 2006). Given its adaptability, nutritional content, and agricultural value, *Moringa oleifera* is considered a suitable species to help mitigate the effects of climate change in vulnerable regions (Trigo et al., 2021). Its resilience to arid conditions enables sustained productivity even during periods of food scarcity, underscoring its significance as a vital resource (Fahey, 2005). Moreover, *Moringa oleifera* has been shown to enhance the health status, feed efficiency, and growth performance of various animal species (Amad and Zentek, 2023). These attributes contribute to its recognition as a high-quality and valuable feed plant. Often referred to as the “miracle tree” *Moringa oleifera* is celebrated for its rich nutrient profile (Patil et al., 2022). Research consistently highlights that the nutritional content and value of *Moringa oleifera* far exceed those of other plants (Koul and Chase, 2015; Gopalakrishnan et al., 2016). For instance, Yameogo et al. (2011) found that Moringa contains 31.65% crude protein, 34.80% crude fat, and 6.53% crude ash. Notably, nearly every part of the plant, from seeds to leaves and roots to essential oil, is valuable. Moringa contains significantly higher levels of vitamins and minerals than most other plants. For example, Moringa has four times more calcium than milk, seven times more potassium than oranges, and three times more vitamin C than bananas (Islam et al., 2021).

In Moringa, various cultural practices, such as cutting and planting density under different agroecological conditions, have been identified as critical management practices affecting biomass yield and leaf quality (Sánchez et al., 2006). Mabapa et al. (2017) emphasized that plant density is crucial, with higher densities leading to increased yields in Moringa plants. Basra et al. (2015) reported optimal row spacings for Moringa at 15x30 cm (narrow) and 15x60 cm (wide) with mowing frequencies of 15, 20, and 30 days. They concluded that narrow spacing (15x30 cm) and an optimum mowing frequency of 30 days maximize nutrient composition and biomass production. Similarly, other studies suggest that dry matter yield increases with higher planting densities, recommending high-density planting for enhanced leaf production (Adu-Dapaah et al., 2017).

Effective plant management is particularly vital for the sustainability of perennial forage crops. The yield and quality of forage crops are directly influenced by factors such as cutting time, frequency, and height (Atis et al., 2019; Ileri et al., 2020). In this study, the effects of different planting densities of *Moringa oleifera* Lam., a novel and unique plant in Türkiye's agriculture and animal husbandry sectors, on yield and specific feed quality characteristics were investigated under Mediterranean climate conditions.

MATERIAL AND METHODS

The research was conducted in 2020 and 2021 in the experimental fields of Department of Field Crops, Faculty of Agriculture, Ege University, Türkiye (27º13'E, 38º27'N and altitude 26 m) which has a Mediterranean climate zone.

Table 1. Soil characteristics of the experimental area

Physical and Chemical Traits	Value	Unit	Physical and Chemical Traits	Value	Unit
pH	7.3		Phosphorus (P)	1.6	mg kg^{-1}
EC	0.5	mS cm^{-1}	Potassium (K)	398	mg kg^{-1}
Clay	19.6	%	Calcium (Ca)	377	mg kg^{-1}
Sand	61.5	%	Magnesium (Mg)	450	mg kg^{-1}
Loam	18.9	%	Sodium (Na)	19	mg kg^{-1}
$CaCO_3$	2.86	%	Iron (Fe)	14	mg kg^{-1}
Soil texture	Silty-clay loam		Copper (Cu)	9	mg kg^{-1}
Organic matter	1.06	%	Zinc (Zn)	5	mg kg^{-1}
Nitrogen (N)	0.081	%	Manganese (Mn)	59	mg kg^{-1}

The soil of the test area has the characteristics of sandy-loamy texture (Table 1). The pH value of 7.3 in the test area shows that the soil of the test area reacts close to neutral (Kacar and Inal, 2008). Organic matter content is quite low and lime content is at medium level. Nitrogen, phosphorus and calcium contents are low and iron, copper, zinc and manganese contents, which are microelements, are high (Gunes et al., 2000). Table 2 shows the average temperatures and total amounts of precipitation for the trial years and over the long term. When the data of the trial location and years were evaluated, it was observed that Moringa plant could be grown and there were no problems due to the lack of extreme differences.

Table 2. Climate data 2020-2021 and long-term (30 years)

Years	Months												
	1	2	3	4	5	6	7	8	9	10	11	12	X - Σ
	Average Temperature (°C)												
2020	8.3	10.8	13.5	16.4	21.6	25.1	29.7	29.3	26.9	20.9	14.3	12.4	19.1
2021	10.6	11.1	11.1	16.7	22.9	25.4	30.6	29.9	24.9	18.7	-	-	20.2
Long term	8.8	9.5	11.7	15.8	20.8	25.6	28.0	27.6	23.6	18.8	14.1	10.5	17.9
	Total Precipitation (mm)												
2020	37.5	76.6	83.0	56.1	55.2	24.9	1.4	0.4	0.5	53.6	2.2	126.0	517.4
2021	213.5	138.0	98.0	25.4	0.6	31.4	1.3	0.0	0.3	27.9	-	-	536.4
Long term	121.0	101.9	74.3	47.0	29.3	8.3	2.0	2.2	15.7	44.3	95.0	144.1	685.1

X: Mean, **Σ**: Total

The experiment was established with 3 replications according to the randomized complete block design experimental design (Acikgoz et al., 2004). In the experiment, plot sizes were arranged as 3.6 m x 2.4 m = 8.64 m^2 and 2 m path was left between the plots. The factor was different plant densities (20x60 cm, 30x60 cm, 40x60 cm and 60x60 cm). PKM-1 variety of Moringa (*Moringa oleifera* Lam.) plant originating from India was used as plant material. Seeds were germination tested before sowing. Sowing was done on 16.05.2020 by hand. Each plot consisted of 6 rows. After planting, the seeds were covered with 1-2 cm soil and irrigation was carried out after planting. Irrigation was done regularly to maintain the soil moisture at field capacity in the summer. The first hoeing was done when the plants were about 15-20 cm tall and hoeing was repeated when needed according to weed status.

Before sowing, compound fertilizer (15-15-15) was applied to all plots with 50 kg ha^{-1} N, 50 kg ha^{-1} P_2O_5 and 50 kg ha^{-1} K_2O as basic fertilizer and 50 kg ha^{-1} N fertilizer was applied when the plant height reached 50-60 cm. After harvest, fertilization treatments were repeated in both years. There was no need for pest and disease spraying etc. in the experiment. The first harvest (H-I) in the *Moringa oleifera* plots was carried out on August 17, 2020, after the plants were given a growth period of approximately 90 days (Gadzirayi et al., 2019). After this date, the plants in the plots were given a growth period of 60 days and the second harvest (H-II) was carried out on October 17, 2020. In the second year, the first harvest (H-I) was made on August 16, 2021, similar to the first year. The second harvest (H-II) was made on November 9, 2021, depending on the climate conditions and the growing status of the plants.

In this study, the distance from the soil surface to the tip of the plant was measured with a ruler and the plant height (cm) was calculated. For this purpose, 10 randomly selected plants were used. Stem diameter of 10 plants was measured by a digital caliper in each plots. During the harvesting process, in plots with 6 rows of plants, the rows on the edges were separated as a border effect and the middle 4 rows of plants were harvested with the help of a hand sickle, leaving a stubble height of 30 cm above the soil level (Basra et al., 2015). Samples were dried at 65°C for 48 h, weighed and dry matter % was estimated. The dry weight samples were then ground in a grinding mill and prepared for chemical analysis. Nitrogen was determined using Kjeldahl method, and nitrogen content was multiplied by a coefficient of 6.25 to calculate crude protein content. Crude ash and crude fat content were determined as described by AOAC (1997). Neutral detergent fiber (NDF), acid detergent fiber (ADF) and hemicellulose were carried out (Van Soest et al., 1991).

ANOVA analysis was performed on the data obtained from the study (Table 3). Biomass yield trait was arranged as the sum of harvests and other traits were arranged as the averages of harvests. In addition, the study years were also considered as a factor to determine the year effect. Differences were determined using the LSD test and 5% probability levels were both used to determine the separate groups (Acikgoz et al., 2004).

RESULTS AND DISCUSSION

The statistical analysis of plant height indicated that only plant density had a statistically significant effect ($p < 0.05$), whereas the effects of year and the interaction between plant density and year were non-significant (Table 4). Among the different plant densities, the highest mean plant height was observed at the 60x60 cm density, with a value of 170.3 cm, while the lowest mean plant height was recorded at the 20x60 cm density, with a value of 159.2 cm. The overall two-year average plant height under Mediterranean climate conditions was determined to be 165.1 cm. Plant height is predominantly influenced by genetic factors. Mih et al. (2008) reported that plant height increased with rising plant density. These differences are due to climatic conditions and other agronomic treatment differences.

Table 3. Results of variance analysis of the examined characteristics

Sources of Variance	df	PH	SD	BY	DM	CA	CP	CF	NDF	ADF	HEM
D	3	134.92^{**}	0.08^{**}	1474.68^{**}	0.69^{**}	0.28^{**}	1.19^{**}	0.02^{**}	18.60^{**}	7.15^{**}	2.81^{**}
Y	1	25.42^{ns}	0.05^{**}	1343.26^{**}	39.89^{**}	0.20^{**}	4.91^{**}	0.01^{ns}	6.25^{**}	4.57^{**}	0.13^{ns}
DxY	3	6.39^{ns}	0.01^{**}	51.28^{**}	0.02^{ns}	0.02^{ns}	0.02^{ns}	0.01^{ns}	0.05^{ns}	0.27^{**}	0.24^{**}

*ns: not significant, D: plant density, Y: year, *: significant at 0.05 level, **: significant at 0.01 level*
PH: plant height, SD: stem diameter, BY: biomass yield, DM: dry matter, CA: crude ash, CP: crude protein, CF: crude fat, NDF: neutral detergent fiber, ADF: acid detergent fiber, HEM: hemicellulose

Table 4. Effects of different plant densities on plant height and stem diameter of *Moringa oleifera*

Plant Height (cm)									
Plant	2020			2021			Means of 2 Years		
Density (cm)	H-I	H-II	Mean	H-I	H-II	Mean	H-I	H-II	Mean
20 x 60	149.3	168.8	159.1	170.2	148.7	159.4	159.8	158.7	159.2
30 x 60	159.0	172.9	166.0	171.9	151.0	161.4	165.4	162.0	163.7
40 x 60	159.2	176.8	168.0	176.4	156.7	166.5	167.8	166.7	167.3
60 x 60	159.2	183.9	171.6	178.2	159.7	168.9	168.7	171.8	170.3
Mean	156.7	175.6	166.1	174.2	154.0	164.1	165.4	164.8	165.1
LSD (0.05)				D: 4.0 Y: ns DxY: ns					

Stem Diameter (cm)									
Plant	2020			2021			Means of 2 Years		
Density (cm)	H-I	H-II	Mean	H-I	H-II	Mean	H-I	H-II	Mean
20 x 60	1.90	2.06	1.98	2.07	2.20	2.13	1.98	2.13	2.06
30 x 60	2.08	2.26	2.17	2.14	2.33	2.24	2.11	2.29	2.20
40 x 60	2.13	2.31	2.22	2.17	2.42	2.30	2.15	2.37	2.26
60 x 60	2.17	2.40	2.29	2.24	2.46	2.35	2.21	2.43	2.32
Mean	2.07	2.26	2.16	2.16	2.35	2.25	2.11	2.31	2.21
LSD (0.05)				D: 0.02 Y: 0.02 DxY: 0.03					

ns: not significant D: plant density Y: year

The analysis results for stem diameter were statistically significant ($p < 0.05$) for plant density, year, and the interaction between plant density and year (Table 4). The highest two-year mean stem diameter, recorded at the 60x60 cm plant density, was 2.32 cm. Comparing the yearly averages, the stem diameter in the second year (2.25 cm) was higher than in the first year (2.16 cm), which aligns with expected growth patterns. The interaction between plant density and year revealed that the highest average stem diameter was 2.35 cm at the 60x60 cm density in the second year, whereas the lowest average stem diameter was 1.98 cm at the 20x60 cm density in the first year. Stem diameter is recognized as a trait significantly influenced by a plant´s genetic composition. In plants, particularly woody species, the stem functions as the trunk, playing a critical role in maintaining an upright posture and supporting other organs (Roddick and Hanson, 2007). It is generally anticipated that the stem diameter of *Moringa oleifera* and similar species will increase with each growing year a finding supported by our study. As a perennial and rapidly growing plant, *Moringa oleifera* exhibited an increase in stem diameter over the years, with the highest values observed in plots with lower planting densities. The stem diameter measurements obtained in this study are consistent with those reported by other researchers (Goss, 2012; Pradhan et al., 2023).

Table 5. Effects of different plant densities on biomass yield of *Moringa oleifera*

Biomass Yield (t ha^{-1})									
Plant	2020			2021			Means of 2 Years		
Density (cm)	H-I	H-II	Total	H-I	H-II	Total	H-I	H-II	Total
20 x 60	36.90	22.10	59.00	52.00	28.40	80.40	44.45	25.25	69.70
30 x 60	31.05	19.85	50.90	46.15	23.15	69.30	38.60	21.50	60.10
40 x 60	26.20	18.05	44.25	34.85	19.95	54.80	30.53	19.00	49.53
60 x 60	14.60	13.75	28.35	21.75	16.10	37.85	18.18	14.93	33.10
Mean	21.79	18.44	45.63	38.69	21.90	60.59	32.94	20.17	53.11
LSD (0.05)				D: 1.54 Y: 1.09 DxY: 2.18					

ns: not significant D: plant density Y: year

The statistical analysis of biomass yield data revealed significant effects ($p < 0.05$) of plant density, year, and the interaction between plant density and year (Table 5). When evaluating the results by plant density, the highest biomass yield was observed at a plant density of 20x60 cm (69.70 kg ha^{-1}). Conversely, the lowest biomass yield was recorded at a plant density of 60x60 cm (33.10 kg ha^{-1}). There were also notable variations between the years, with biomass yield increasing from 45.63 kg ha^{-1} in the first year to 60.59 kg ha^{-1} in the second year. Furthermore, the interaction between plant density and year showed that the highest biomass production occurred at a density of 20x60 cm, yielding 80.40 kg ha^{-1} in the second year. In contrast, the lowest biomass production was recorded at 28.35 kg ha^{-1} at a plant density of 60x60 cm in the first year.

These findings align with the report by Nouman et al. (2013), who noted that plant growth significantly impacts the biomass yield of *Moringa oleifera*. Additionally, higher planting densities are positively correlated with increased forage production (Kumalasari et al., 2017). Our study supports these conclusions, demonstrating that higher plant densities result in increased biomass yield. These results are consistent with the findings of Amaglo et al. (2006) and Mabapa et al. (2017).

Table 6. Effects of different plant densities on dry matter, crude ash, crude protein and crude fat ratios of *Moringa oleifera*

Plant Density (cm)	2020			2021			Means of 2 Years		
Dry Matter Ratio (%)									
	H-I	H-II	Mean	H-I	H-II	Mean	H-I	H-II	Mean
20 x 60	15.91	17.93	16.92	18.58	20.58	19.58	17.25	19.26	18.25
30 x 60	16.34	18.03	17.19	18.81	20.67	19.74	17.58	19.35	18.46
40 x 60	16.57	18.40	17.49	19.04	20.85	19.95	17.81	19.63	18.72
60 x 60	16.58	18.86	17.72	19.38	21.33	20.36	17.98	20.10	19.04
Mean	16.35	18.31	17.33	18.95	20.86	19.91	17.65	19.58	18.62
LSD (0.05)				D: 0.15	Y: 0.11	DxY: ns			
Crude Ash Ratio (%)									
	H-I	H-II	Mean	H-I	H-II	Mean	H-I	H-II	Mean
20 x 60	9.82	9.77	9.80	10.05	9.87	9.96	9.93	9.82	9.88
30 x 60	9.71	9.55	9.63	9.90	9.68	9.79	9.81	9.61	9.71
40 x 60	9.66	9.48	9.57	9.73	9.56	9.64	9.69	9.52	9.61
60 x 60	9.25	9.15	9.20	9.59	9.47	9.53	9.42	9.31	9.36
Mean	9.61	9.49	9.55	9.82	9.64	9.73	9.71	9.56	9.64
LSD (0.05)				D: 0.10	Y: 0.07	DxY: ns			
Crude Protein Ratio (%)									
	H-I	H-II	Mean	H-I	H-II	Mean	H-I	H-II	Mean
20 x 60	18.92	18.18	18.55	18.06	17.45	17.76	18.49	17.82	18.15
30 x 60	18.87	17.96	18.41	17.86	17.02	17.44	18.36	17.49	17.93
40 x 60	18.50	17.64	18.07	17.61	16.84	17.22	18.06	17.24	17.65
60 x 60	18.09	17.15	17.62	17.11	16.12	16.62	17.60	16.64	17.12
Mean	18.59	17.73	18.16	17.66	16.86	17.26	18.13	17.29	17.71
LSD (0.05)				D: 0.11	Y: 0.08	DxY: ns			
Crude Fat Ratio (%)									
	H-I	H-II	Mean	H-I	H-II	Mean	H-I	H-II	Mean
20 x 60	2.14	1.81	1.97	2.03	1.92	1.98	2.08	1.87	1.97
30 x 60	2.16	1.85	2.01	2.10	1.92	2.01	2.13	1.88	2.01
40 x 60	2.08	1.82	1.95	2.06	1.90	1.98	2.07	1.86	1.97
60 x 60	2.03	1.75	1.89	1.98	1.78	1.88	2.01	1.77	1.89
Mean	2.11	1.81	1.96	2.04	1.88	1.96	2.07	1.84	1.96
LSD (0.05)				D: 0.03	Y: ns	DxY: ns			

ns: not significant D: plant density Y: year

The statistical analysis of dry matter ratio revealed significant effects ($p < 0.05$) of plant density and year factors. However, the interaction between plant density and year was not significant (Table 6). The highest average dry matter ratio was recorded at a plant density of 60x60 cm, at 19.04%, while the lowest was observed at a 20x60 cm plant density, at 18.25%. Notably, the dry matter ratio significantly increased in the second year, rising from 17.33% in the first year to 19.91% in the second year. This increase suggests that the potential for dry matter production may continue to improve in subsequent years. Our findings are consistent with the results reported by Sánchez et al. (2006) and Arif et al. (2020).

The study also found significant effects ($p < 0.05$) on the crude ash ratio due to plant density and year. However, the interaction between plant density and year was not significant (Table 6). The highest average crude ash ratio was recorded at a 20x60 cm plant density, at 9.88%, while the lowest value was observed at a 60x60 cm plant density, at 9.36%. Significant differences were also noted between the years, with the lowest average crude ash value recorded in the first year (9.55%) and a slight increase to 9.73% in the second year.

Crude ash, which is crucial for the formation of nucleoproteins and the facilitation of oxygen transport, is defined as the residual value remaining after the dry matter in plants is incinerated at high temperatures. Determining crude ash content is vital in roughage, as maintaining a certain ash ratio in feed is preferred for optimal animal nutrition. Researchers such as Al-Masri (2003), Sánchez et al. (2006), and have reported that Moringa possesses a high ash concentration, despite wide chemical variability. The crude ash values obtained in our study ranged from 9.15% to 10.05%, aligning with the values reported by Sánchez-Machado et al. (2010) and Valdivié-Navarro et al. (2020), which ranged from 7.62% to 14.60%. However, our results are lower than the 12.41% reported by Alarape et al. (2023). These differences may be attributed to variations in climatic conditions and cultural practices.

The study observed that plant density and year significantly ($p < 0.05$) affected crude protein ratios. However, no interaction was detected between year and plant density (Table 6). The highest crude protein ratio was recorded at a 20x60 cm plant density, averaging 18.15%, while the lowest was found at a 60x60 cm plant density, at 17.12%. Significant differences were also noted between the years, with the highest crude protein ratio recorded in the first year (18.16%) and a decrease to 17.26% in the second year. Crude protein content is a crucial indicator of a plant's nutritional quality and is essential for their use as feed or food resources (Khanal et al., 2020). In our findings, *Moringa oleifera* exhibited an average crude protein ratio of 18.16% in the planting year, which decreased to 17.26% in the second year. The two-year average was determined to be 17.71%. Researchers have noted that crude protein ratios in Moringa vary depending on the plant parts and can range from 11.4% to 40% (Nouman et al., 2013; Mendieta-Araica et al., 2013). Our findings are highly consistent with the crude protein ratios reported by Chodur et al. (2018), Hassanein (2018). Various researchers have attributed such differences to genetic and climatic factors, as well as cultural practices like irrigation and fertilization (Sarwar et al., 2020). The variations observed in our study are likely due to differences in ecological and agricultural conditions, as well as variations in plant varieties and harvest times.

The analysis of crude fat ratios from this study, conducted in a Mediterranean ecology, showed that plant density had significant effects. However, the effects of year and the interaction between plant density and year were not significant (Table 6). The highest value over the two-year average was recorded at 2.01% at a 30x60 cm plant density, while the lowest value was observed at 1.89% at a 60x60 cm plant density. The fat content in various plant parts (root, stem, leaf, flower, seed), which protects these organs, varies in proportions (Eris, 2007; Yurtvermez and Gidik, 2021). These proportions can also vary depending on species and varieties (Mahajan et al., 2020). As with other characteristics, the fat ratio changes according to the developmental stages of plants (Pallardy, 2008). Studies on different plants have indicated that crude fat ratios are lower in the early stages of growth and increase in the later stages (Singh and Todaria, 2012). Our results are consistent with the crude fat ratios reported by Sánchez-Machado et al. (2010), which ranged from 1.28% to 4.96%.

Table 7. Effects of different plant densities on NDF, ADF and hemicellulose of *Moringa oleifera*

NDF (%)									
Plant	**2020**			**2021**			**Means of 2 Years**		
Density (cm)	**H-I**	**H-II**	**Mean**	**H-I**	**H-II**	**Mean**	**H-I**	**H-II**	**Mean**
20 x 60	44.61	45.68	45.15	45.77	46.59	46.18	45.19	46.14	45.66
30 x 60	46.14	47.72	46.93	47.73	48.21	47.97	46.93	47.97	47.45
40 x 60	47.43	48.93	48.18	48.90	49.92	49.41	48.17	49.43	48.80
60 x 60	48.68	49.96	49.32	49.27	50.94	50.10	48.97	50.45	49.71
Mean	46.72	48.08	47.40	47.92	48.92	48.42	47.32	48.50	47.91
LSD (0.05)	D: 0.18 Y: 0.13 DxY: ns								
ADF (%)									
Plant	**2020**			**2021**			**Means of 2 Years**		
Density (cm)	**H-I**	**H-II**	**Mean**	**H-I**	**H-II**	**Mean**	**H-I**	**H-II**	**Mean**
20 x 60	34.49	34.80	34.65	35.47	36.47	35.97	34.98	35.64	35.31
30 x 60	35.57	36.62	36.10	36.68	37.76	37.22	36.13	37.19	36.66
40 x 60	36.62	37.28	36.95	36.97	38.23	37.60	36.79	37.76	37.27
60 x 60	37.25	38.06	37.65	37.26	38.84	38.05	37.25	38.45	37.85
Mean	35.98	36.69	36.34	36.59	37.82	37.21	36.29	37.26	36.77
LSD (0.05)	D: 0.15 Y: 0.11 DxY: 0.21								
Hemicellulose (%)									
Plant	**2020**			**2021**			**Means of 2 Years**		
Density (cm)	**H-I**	**H-II**	**Mean**	**H-I**	**H-II**	**Mean**	**H-I**	**H-II**	**Mean**
20 x 60	10.12	10.88	10.50	10.30	10.12	10.21	10.21	10.50	10.36
30 x 60	10.57	11.10	10.84	11.05	10.46	10.75	10.81	10.78	10.79
40 x 60	10.82	11.65	11.23	11.93	11.70	11.81	11.37	11.67	11.52
60 x 60	11.43	11.90	11.67	12.01	12.10	12.05	11.72	12.00	11.86
Mean	10.74	11.38	11.06	11.32	11.09	11.21	11.03	11.24	11.13
LSD (0.05)	D: 0.24 Y: ns DxY: 0.34								

ns: not significant D: plant density Y: year

The analysis of neutral detergent fiber (NDF) data revealed significant ($p < 0.05$) effects of plant density and year. However, the interaction between plant density and year was not significant (Table 7). The NDF values from our study indicated that the highest average value, 49.71%, was observed at a plant density of 60x60 cm, whereas the lowest value, 45.66%, was recorded at a plant density of

20x60 cm. Additionally, the NDF value increased from 47.40% in the first year to 48.42% in the second year.

NDF is a crucial criterion for evaluating the quality and digestibility of roughage, making it important in animal feding (Sarikaya et al., 2023). It is well-established that NDF values increase with the plant's developmental stage (Acar et al., 2021). As the crude cellulose content—the structural component of plant cell walls—increases with development, the NDF value also rises. Our results align with studies investigating different genotypes and ecological conditions of Moringa plants (Bashar et al., 2020; Valdivié-Navarro et al., 2020).

The analysis of acid detergent fiber (ADF) data revealed significant ($p < 0.05$) effects of plant density, year, and the interactions between plant density and year (Table 7). When analyzing ADF values by plant density, the highest average ADF value of 37.85% was recorded at a plant density of 60x60 cm over two years, while the lowest average ADF value of 35.31% was observed at a plant density of 20x60 cm. The lowest average ADF value, 36.34%, was recorded in the first year, while an ADF value of 37.21% was recorded in the second year. Considering the plant density × year interaction, the highest ADF value of 38.05% was recorded in the second year at a plant density of 60x60 cm, while the lowest ADF value of 34.65% was observed in the first year at a plant density of 20x60 cm.

ADF represents the portion remaining after subtracting the hemicellulose from the NDF value. This criterion is particularly informative regarding digestibility and the animal's energy intake (Van Soest, 1991). Our findings are consistent with studies conducted on *Moringa oleifera* under various genotypes, ecological conditions, and agronomic treatments (Bashar et al., 2020; Valdivié-Navarro et al., 2020).

The analysis of hemicellulose data revealed significant ($p < 0.05$) effects of plant density and plant density × year interaction (Table 7). The highest two-year average hemicellulose was recorded at 11.86% at a plant density of 60x60 cm, while the lowest value was 10.36% at a 20x60 cm plant density. Additionally, the interaction between plant density and year revealed that the highest hemicellulose was achieved at 12.05% at a plant density of 60x60 cm in the second year, whereas the lowest hemicellulose was 10.21% at a plant density of 20x60 cm in the second year.

The proportions of cellulose and hemicellulose are higher in young and fresh plants at the beginning of growth, gradually increasing as the vegetation matures. Since these components are difficult to digest, lower proportions in feed are preferred (Oktem et al., 2021). Quintanilla-Medina et al. (2018) reported that the hemicellulose in Moringa ranges from 4.01% to 6.98%. The current findings are higher than these reported values. These differences may be attributed to variations in climatic conditions and cultural practices.

CONCLUSION

The research conducted under Mediterranean ecological conditions yielded promising results regarding biomass yield and forage quality characteristics of *Moringa oleifera*. The data analysis indicated that a plant density of 20x60 cm (69.70 t ha^{-1}) provided optimal conditions, resulting in the highest biomass yield and superior forage quality characteristics. This plant density is therefore recommended for optimizing *Moringa oleifera* cultivation in similar ecological settings.

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