Journal of King Saud University – Science 35 (2023) 102419

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Journal of King Saud University – Science

journal homepage: www.sciencedirect.com

Original article

Optimizing plant density for fiber and seed production in industrial hemp (*Cannabis sativa* L.)

Levent Yazici

Yozgat Bozok University, Faculty of Agriculture, Department of Field Crops, Yozgat, Turkey

ARTICLE INFO

Article history:
Received 15 July 2022
Revised 5 October 2022
Accepted 27 October 2022
Available online 2 November 2022

Keywords:
Industrial hemp
Cannabis sativa L.
Plant density
Fiber yield
Seed yield

ABSTRACT

Background: Industrial hemp (*Cannabis sativa* L.) is rated among the important green fibers and planting density significantly alters its fiber and seed production. However, optimum planting density is unknown for different cultivars available in Turkey.
Methods: This study determined the effects of four planting densities (i.e., 100, 150, 200, and 250 plants m^{-2}) on yield and quality traits of local 'Narlısaray' population and 'Futura 75′ industrial hemp cultivar.
Results: Planting density significantly altered the yield and fiber production. The 'Narlısaray' population recorded higher values for plant height, technical stem length, stem diameter, biomass yield, dry stem weight, and fiber yield. In contrast, seed yield, fiber rate, and oil rate were higher in 'Futura 75′ cultivar. According to the average data of two years, plant height varied from 183.1 to 202.4 cm, technical stem length ranged from 130.8 to 151.3 cm, stem diameter 7.2–10.2 mm, fresh biomass 16400.3–22790.3 kg ha^{-1}, stem dry weight 6730.8–9290.8 kg ha^{-1}, fiber yield 1820.9–2610.9 kg ha^{-1}, seed yield was 820.8–940.8 kh da^{-1}, fiber ratio 27.7–30.3 %, and oil ratio was 28.5–31.1 %.
Conclusion: The two-season average evaluation showed that the most appropriate planting density was 150 plant m^{-2} of hemp under ecological conditions of Yozgat province, Turkey.

1. Introduction

Hemp (*Cannabis sativa* L.) is an annual plant of the genus *Cannabis* in *Cannabinaceae* family. It is exclusively wind-pollinated and has dioecious (male and female flowers on separate plants) or monoecious (male and female flowers on the same plant) plants. Monoecious varieties are more uniform than dioecious varieties. Monoecious varieties are used for both fiber and seed purposes, whereas dioecious varieties are used for fiber production (Dhont and Muthu, 2021).

Globally, hemp is one of the oldest cultivated plants, originated from Central Asia, and discovered in the BC archaeological excavations. Hemp fibers have been found dating to 10,000 BCE, and seed remains dating back to 8260 BCE (Kung, 1959; Chang, 1968; Abel, 1980; Okazaki et al., 2011). In the ancient Chinese times, wild species of this plant were used 8500 years ago, and the evidence for the cultivation and use of the plant as a textile material date back to 6000 years ago (Schultes and Hofmann 1980; Fleming and Clarke 1998). In Turkey, hemp was also reported, where hemp textile remains from the 7th century have been identified in the excavations carried out in the ancient city of Gordion in the Yassıhöyük village of Polatlı district (Bellinger, 1962; Dhont and Muthu, 2021).

Historically, humans have used hemp as fiber source. Secondly, it has been used in the medicines and less frequently for seeds and oil. In recent years, industrial hemp sector has witnessed remarkable growth, especially in countries situated in the European Union, the United States, and Canada, with significant increase economic volume. Moreover, it has become one of the most exciting plants in the world as the use of its every part is rapidly increasing for industrial and medicinal purposes. Roots, stems, fibers, flowers, seeds, leaves, and overall total biomass of hemp are used for various purposes in different sectors. For example, fiber obtained from the stems of hemp can be used in various fields such as textile plastic and construction materials. Leaves, and flowers are used in the pharmaceutical and cosmetic industries. Seeds and oil are used in the food and feed industry (Yazici and Yilmaz, 2021).

The use of plant parts as food, fiber, and medicine is responsible for widespread distribution of industrial hemp. Inherently, hemp is a plant with broad adaptability, as its several genotypes can be

Peer review under responsibility of King Saud University.

ELSEVIER Production and hosting by Elsevier

E-mail address: levent.yazici@yobu.edu.tr

https://doi.org/10.1016/j.jksus.2022.102419

found in temperate and tropical regions. As hemp efficiently utilizes light, water, and nutrients at proper plant density, its stem, fiber, seed yield, and cannabinoids may significantly change with varying density. Plant height, stem diameter, and branching also decrease with the increase in plant density (Amaducci et al., 2002a; Van der Werf et al., 1995; Yazici et al., 2020; Westerhuis, 2016).

Planting density is an important agronomic management affecting the productivity and economic returns of field crops (Farooq et al., 2015, 2017; Hussain et al., 2016a, 2016b). The planting density of hemp varies according to the purpose of production. Generally, lower planting density is used for the hemp plants cultivated for seed production compared to those sown to produce fiber. Bocsa and Karus (1998) used 100–150 plants per m^{-2}, whereas Ranalli (1999) used a lower planting density (90 plants per m^{-2}) for seed production.

Different researchers have used various planting densities to produce industrial hemp. For instance, Amaducci et al. (2002b) used 180 plants m^{-2}, Townshend and Boleyn (2008) used 150–225 plants m^{-2}, Amaducci et al. (2012) used even lower density, i.e., 90–100 plants m^{-2}, whereas Hall et al. (2014) used high density (300 plants m^{-2}) for hemp production. Additionally, planting density of 120 plants m^{-2} was used by Campiglia et al. (2017). Deng et al. (2019) recommended a high density (329–371 plants m^{-2}) for better yield of high-quality fiber. For fiber and seed production 90–150 plants m^{-2} has been suggested by Tang et al. (2017). Unfortunately, limited studies have optimized planting density for industrial hemp in Turkey. Therefore, this study determined the effects of different planting densities on some yield and quality traits of different industrial hemp cultivars. It was hypothesized that different cultivars will respond differently to the planting densities. The planting density at which different cultivars perform better would be recommended for higher production and economic returns.

2. Materials and Methods

2.1. Experimental site

This study was carried out in the experimental field of Yozgat Bozok University, Boğazlıyan Vocational School during 2020 and 2021. The precipitation and temperature values of the experimental site during 2020 and 2021 are illustrated in Figs. 1 and 2. Differences in temperature and rain average data were seen in the first and second years of the experiment. In the first year, precipitation and temperature values were higher than in the second year. The soil of the experiment site has clayey texture, with 0.8 % organic matter, 20.25 kg ha^{-1} phosphorus (P_2O_5), and 680.78 kg ha^{-1} potassium (K_2O) in 2020, whereas 1.3 % organic matter, 14.50 kg ha^{-1} phosphorus (P_2O_5), and 630.24 kg ha^{-1} potassium (K_2O) during 2021.

2.2. Experimental setup and treatments

The experiment was conducted according to randomized complete block design with split-plot design and three replications (Fig. 3). Four different planting densities (i.e., 100, 150, 200, and 250 plants m^{-2}) were used in the study. Dioecious 'Narlısaray' population and monoecious 'Futura 75′ variety were used as experimental materials. The trial area was ploughed with a 3-row cultivator, double-row rotary harrow combination, and milling cutter before planting, then leveled with a Tapan leveler. The cultivars were grown in 5 m long rows with 20 cm row spacing. Sowing was done by hand on April 25, 2020, and April 30, 2021. Before planting, the number of seeds to be planted per unit area were calculated using the formula given below:

Seed quantity (g/m^2) = desired number of plants in m^2 × 1000 grain weight × 10 / purity (%) × germination rate (%).

Seeds were subjected to a germination test before sowing which indicated germination rate of 85–90 % in 'Futura 75′ variety and 80–85 % in 'Narlısaray population'. The plant population was counted in each experimental unit upon emergence. After emergence, average plant density was close to target in both years. Instead of the target (100, 150, 200, 250 plant m^{-2}) plant density, actual planting density was 95, 154, 190, 240 plant m^{-2} in 2020 and 105, 140, 190 and 237 plant m^{-2} in 2021. Thinning was done in the experimental units with a high number of emergences. Wheat was the last crop grown in the field trial area of this experiment. Two rows on the sides were left to reduce the border effect in both years, and the evaluations were made only for the four middle rows.

2.3. Data collection

Harvesting of 'Futura 75′ variety was done by hand during 2020 and 2021 on September 10 and 16, respectively, whereas it was done on October 17 and 24 for 'Narlısaray' population (Fig. 4). Harvesting was started when the seeds were 75–80 % matured, for fiber and seed purposes (Globorodko, 1994). According to soil analysis, the fertilizer 60 kg/ha N and 60 kg/ha P_2O_5 was applied during planting, and 60 kg/ha N was the top dressed during the weeding period. Weed control was done by hand with a hoe. No diseases or pests were observed in the field trails. Supplemental irrigation was given if needed using drip irrigation method. Oil ratios were determined as a percentage value from the seeds of each parcel after grinding a certain amount and weighing 2 g, boiling in 80 ml ether for 60 min in a Soxtec 2055 oil analyzer with the highest temperature of 135 °C.

2.4. Data analysis

The collected data on different traits were subjected to normality tested, which indicated that data had normal distribution. The differences among years were tested with paired *t* test, which indi-

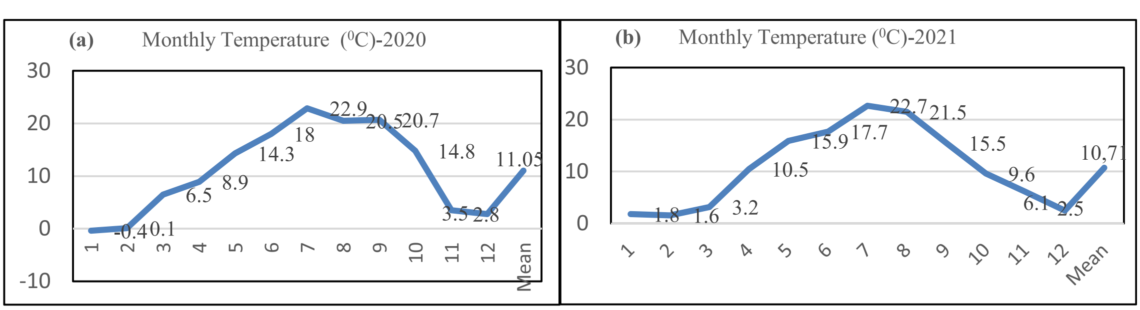

Fig. 1. Monthly average temperature data for the years (a) 2020 and (b) 2021.

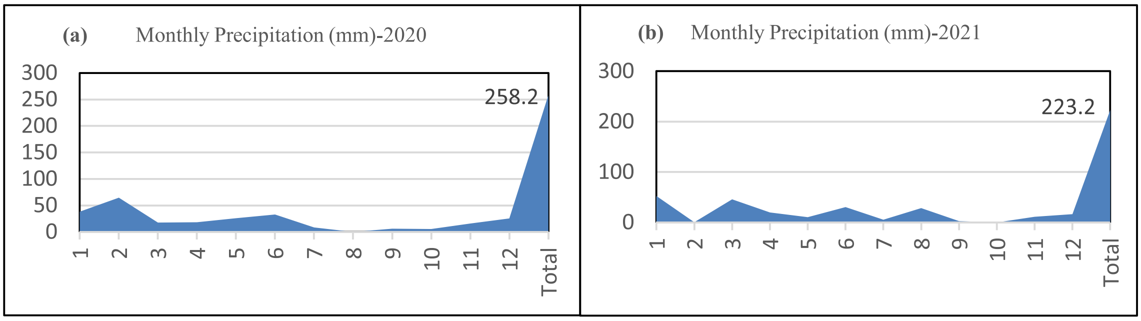

Fig. 2. Monthly average precipitation data for the years (a) 2020 and (b) 2021.

Fig. 3. Images from the experimental field.

(a) *(b)* *(c)*

Fig. 4. Hemp post-harvest processes (a; dry stem, b; fiber, c; seed).

cated that year effect was significant. Therefore, data of both years were analyzed and interpreted separately. Two-way analysis of variance (ANOVA) was used to infer the differences among treatments. Tukey's post-hoc test was used to infer the differences among means where ANOVA denoted significant differences.

3. Results and discussion

The average values of plant height, technical stem length, stem diameter, and output of ANOVA for different planting densities and cultivars are given in Table 1.

3.1. Plant height

Plant height was significantly altered by year, variety, and planting densities ($P < 0.01$). Plant height varied between 208.9 and 223.9 cm, with an average of 215.1 cm in first year. Plant height of hemp is known to decreases increase in planting density (Amaducci et al. 2008). It was noted in the current study that plant height decreased in 200 and 250 plant m^{-2} planting densities during both years. Plant height was higher (235.9 cm) in 'Narlısaray' population and lower (194.2 cm) in the 'Futura 75′ variety in 2020 (Table 1).

The highest average plant height was recorded under 150 plants m^{-2}, while the lowest was noted for 100 and 250 plants m^{-2} planting densities. Tang et al. (2017) studied 'Futura 75′ and 'Bialobrzeskie' hemp cultivars with different plant densities (30, 60, 120, and 240 plants m^{-2}) and reported that plant height was 217.2 cm, 200.1 cm, 194.2 cm, and 183.7 cm in 30, 60, 120, and 240 plants m^{-2} planting densities, respectively. Amaducci et al. (2008) evaluated monoecious and dioecious hemp cultivars under 120, 240, and 360 plants m^{-2} planting densities and reported that 'Futura 75′ cultivar had 162.0 cm and 185.0 cm plant height during 1st and 2nd year, respectively. Likewise, 'Tiborszallasi' cultivar had 168.0 cm and 215.0 cm plant height during 1st and 2nd year, respectively.

Plant height varied between 157.2 and 180.9 cm, with an average of 166.7 cm during 2nd year of the current study. The 'Narlısaray' and 'Futura 75′ had 191.8 cm and 131.2 cm plant heights, respectively. The highest plant height (180.9 cm) was noted for 150 plants m^{-2} planting density, whereas the lowest (157.2 cm) was recorded for 100 plants m^{-2}. Hall et al. (2014) eval-

Table 1
Average values of plant height, technical stem length, and stem diameter and variance analysis results of different plant density applications in cannabis cultivars.

	Plant height (cm)		Technical stem length (cm)		Stem diameter (mm)	
Plant Density	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
100	208.91c	157.26c	154.08c	107.51c	10.41 a	9.98 a
150	223.89 a	180.94 a	171.64 a	130.89 a	8.75b	7.66b
200	215.59b	165.35b	166.89 ab	119.63b	8.32b	7.01b
250	212.00b	163.27b	163.76b	118.85b	8.01c	6.43c
Mean	215.10	166.71	164.09	119.22	8.87	7.77
LSD Value	5.49	6.66	5.29	8.85	0.85	0.75
Variety / Population						
Narlısaray	235.99 a	191.80 a	196.91 a	141.02 a	9.06 a	8.58 a
Futura 75	194.20b	141.60b	131.27b	97.41b	8.68 a	6.96b
LSD Value	5.19	8.90	2.73	6.78	0.57	0.62
Variation Sources-Combined Years						
	MS	F Ratio	MS	F Ratio	MS	F Ratio
Year (A)	28104.2	545.72**	24164.1	928.98**	14.57	36.89**
Variety (B)	25382.1	583.24**	35810.8	619.34**	12.00	79.23*
Recurrence	146.56	3.36	10.19	0.17	0.51	3.39
Density (C)	817.79	15.88**	851.70	32.74**	20.73	52.50**
A × B	212.24	4.12	1456.13	55.98**	4.70	11.92**
A × C	43.79	0.85	25.57	0.98	0.73	1.85
B × C	83.92	1.62	71.26	2.73	0.62	1.57
A × B × C	27.47	0.53	149.55	5.74**	3.60	9.13**
CV (%)	3.75		3.60		7.54	

*, **, Significant at 5% and 1% level, respectively.

uated hemp under different planting densities (100, 200, 300, and 400 plants m^{-2}) and reported the highest plant height (120.1 cm and 114.0 cm) at 100 and 200 plants m^{-2}. Similarly, Amaducci et al. (2002a) determined the average plant height as 180–240 cm in a study to assess hemp's plant density and nitrogen effect. Westerhuis et al. (2009) noted an average plant height of 146–211 cm under 99–283 plants m^{-2} planting density.

3.2. Technical stem length

Technical stem length was significantly ($P < 0.01$) affected by year, cultivar, planting density, and year × cultivar and year × cultivar × planting density. Mean technical stem length varied from 154.1 to 171.6 cm during 1st year, with an average of 164.1 cm. Likewise, the technical stem lengths of 'Narlısaray' population and 'Futura 75′ cultivar were 196.9 and 131.2 cm, respectively (Table 1).

The highest technical stem length (171.6 cm) during first year was recorded for 150 plants m^{-2} and (166.9 cm) at 200 plants m^{-2} planting densities, while the lowest was recorded for 100 and 250 plants m^{-2} planting densities. During 2nd year, technical stem length varied from 107.5 to 130.9 cm, with an average of 119.2 cm. The 'Narlısaray' population and 'Futura 75′ variety had technical stem length of 141.0 cm and 97.41 cm, respectively.

Plant densities of 150 and 200 plants m^{-2} recorded the highest values for technical stem length during 2nd year, while planting at 100 plants m^{-2} resulted in the lowest technical stem length. Grabowska and Koziara (2006) reported the technical stem length between 115 and 185 with seeding densities of 40, 80, 120, and 160 kg ha^{-1}.

3.3. Stem diameter

Stem diameter was significantly altered by cultivars. The mean stem diameter data ranged between 8.01 and 10.41 mm, with an average value of 8.87 mm during 1st year (Table 1). The mean stem diameter as 9.1 and 8.7 mm in 'Narlısaray' and 'Futura 75′ cultivars, respectively. The highest stem diameter (10.41 mm) and the lowest (8.01 mm) stem diameter was noted for 100 and 250 plants m^{-2} planting densities, respectively. The average stem diameter varied between 6.43 and 9.98 mm, with an average of 7.77 mm during the 2nd year (Table 1). The highest stem diameter was noted under 100 and 150 plants m^{-2} planting densities, whereas planting at 250 plants m^{-2} resulted in the lowest values. The mean stem diameter was 8.58 mm in 'Narlısaray' population and 6.96 mm in 'Futura 75′ variety. Westerhuis et al. (2009) reported 6.9 mm, 5.9 mm, and 5.3 mm, stem diameters for 'Futura 75′ plants sown under 120, 240, and 360 plants m^{-2} planting densities, respectively. Similarly, Campiglia et al. (2017) noted 6.0 mm, 5.4 mm, and 4.6 mm, stem diameters for hemp plants sown under 40, 80, and 120 plants m^{-2} planting densities. Meanwhile, Amaducci et al. (2012) reported a stem diameter of 10.4 mm, 8.1 mm, and 6.1 mm, for planting densities of 45, 90, 180 plants m^{-2}, respectively. The results of the current study are in parallel with Westerhuis et al. (2009) and Campiglia et al. (2017).

3.4. Fresh biomass

Year, and planting density had significant effect ($P < 0.01$) 1on fresh biomass production. The fresh biomass ranged between 20280.1 and 25640.8 kg ha^{-1} with an average of 22680.1 kg ha^{-1} during 1st year (Table 2). Similarly, fresh biomass ranged between 12520.3 and 19930.7 kg ha^{-1} during 2nd year with an average value of 15890.5 kg ha^{-1}. The 'Narlısaray' population produced higher fresh biomass than 'Futura 75′ variety during both years. The highest fresh biomass was noted under 150 and 200 plants m^{-2} planting densities, while 100 and 250 plants m^{-2} planting density resulted in the lowest production of fresh biomass during both years of the study (Table 2).

3.5. Stem dry weight

Stem dry weight was significantly ($P < 0.01$) altered by year and planting density, and variety and year × variety ($P < 0.05$) (Table 2). Stem dry weight ranged between 8170.1 and 10220.8 kg ha^{-1} with an average of 9010.5 kg ha^{-1}. In contrast, stem dry weight differed between 5170.8 and 8360.8 kg ha^{-1}, with an average of 6890.46 kg ha^{-1}. The highest and the lowest stem dry weight was noted for 150 and 250 plants m^{-2} planting densities, respectively during both years. The 'Narlısaray' population recorded

Table 2
Average values of fresh biomass, dry stem weight, fiber yield and variance analysis results of different plant density applications in hemp cultivars.

	Fresh biomass (kg ha^{-1})		**Dry stem weight (kg ha^{-1})**		**Fiber yield (kg ha^{-1})**	
Plant Density	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
100	20280.17b	12520.33c	8290.83	5170.83c	2140.25 a	1510.69c
150	25640.83 a	19930.73 a	10220.83	8360.83 a	2770.55 a	2460.33 a
200	23810.25 a	15670.50b	9320.17	6740.83b	2590.77 a	1930.27b
250	20980.17b	15440.50b	8170.17	6600.16b	2400.02 a	1990.55b
Mean	22680.11	15890.52	9000.50	6720.41	2470.90	1970.71
LSD Value	2210.50	1910.85	830.69	840.57	900.58	420.06
Variety / Population						
Narlısaray	23410.87 a	17430.11 a	10490.91 a	8310.66 a	2840.29 a	2360.83 a
Futura 75	21940.33b	14350.91b	7510.08b	5130.16b	2110.51b	1580.59b
LSD Value	800.68	2830.47	480.64	1130.45	100.14	300.31
Variation Sources-Combined Years						
	MS	F Ratio	MS	F Ratio	MS	F Ratio
Year (A)	552,579	131.72**	624,264	68.157**	30226.1	47.929**
Variety (B)	620,363	4.6084	114,330	106.98**	68414.6	53.208**
Recurrence	248,705	1.8475	54283.6	5.0798	3285.84	2.5555
Density (C)	878,896	20.950**	143,261	15.641**	12,566	19.925**
A × B	76,470	1.8229	1160.33	0.1267	89.3438	0.1417
A × C	54883.4	1.3083	14721.4	1.6073	873.092	1.3845
B × C	49942.7	1.1905	25620.2	2.7972	1051.56	1.6674
A × B × C	3439.27	0.0820	1186.78	0.1296	205.065	0.3252
CV (%)	10.61		12.16		11.27	

*, **, Significant at 5% and 1% level, respectively.

higher stem dry weight than 'Futura 75′ variety during each year of the study (Table 2). Van der Werf et al. (1995) indicated that the highest dry stem yield was noted at 90 plants m^{-2} planting density in industrial hemp.

3.6. Fiber yield

Fiber yield was significantly ($P < 0.01$) altered by year and density and the variety ($P < 0.05$). The stems become thinner with increasing planting density which resulted in lower fiber yield (Table 2). The fiber yield varied between 2140.2 and 2770.5 kg ha^{-1}, with an average of 2490.9 kg ha^{-1} during 1st year. Similarly, during 2nd year, fiber yield changed between 1630.5 and 2460.3 kg ha^{-1}, with an average value of 2010.9 kg ha^{-1}. The highest fiber yield was recorded for 150 and 200 plants m^{-2} densities, while the lowest was recorded for 100 plants m^{-2} planting density. The 'Narlısaray' population produced higher fiber yield than 'Futura 75′ variety during both years of the study (Table 2). Deng et al. (2019) reported highest-fiber yield for hemp under planting density of 32–37 plants m^{-2}.

3.7. Seed yield

Seed yield was significantly ($P < 0.01$) affected by year, variety, density, and year × variety interaction. Seed yield varied between 960.1 and 1100.4 kg ha^{-1}, with an average of 1040.0 kg ha^{-1} during 1st year. Similarly, seed yield differed between 690.3 and 800.2 kg ha^{-1} with an average value of 740.5 kg ha^{-1} during 2nd year of the study. The highest seed yield was recorded for 100 and 150 plants m^{-2} planting densities, while 250 plants m^{-2} planting density resulted in the lowest seed yield during both years of the study. Regarding varieties, 'Narlısaray' population produced higher seed yield than 'Futura 75′ variety during both years of the study (Table 3). Townhend and Boleyn (2008) reported the

Table 3
Average values of seed yield, fiber ratio, oil ratio and variance analysis results of different plant density applications in hemp cultivars.

	Seed yield (kg ha^{-1})		Fiber ratio (%)		Oil ratio (%)	
Plant Density	2020	2021	2020	2021	2020	2021
100	1100.03 a	790.20 a	25.76	29.73	30.33	31.92
150	1090.33 a	800.16 a	27.25	29.84	29.59	29.84
200	1000.33 a	690.33 a	28.09	29.44	29.29	29.44
250	960.17 a	690.33 a	29.68	30.38	28.16	28.89
Mean	1040.05	740.50	27.69	29.84	29.34	30.02
LSD Value	170.34	180.32	2.29	5.12	1.78	4.44
Variety / Population						
Narlısaray	510.36b	450.58b	27.13b	28.58b	30.84 a	28.20 a
Futura 75	1560.75 a	1030.43 a	28.26 a	31.11 a	27.85b	31.84b
LSD Value	70.95	80.85	1.08	2.43	1.44	1.56
Variation Sources-Combined Years						
	MS	F Ratio	MS	F Ratio	MS	F Ratio
Year (A)	10478.4	93.341**	55.5239	9.41**	5.51345	1.19
Variety (B)	79935.4	983.54**	40.1939	7.78	1.25489	3.60
Recurrence	42.9778	0.5288	6.19184	1.19	5.30516	15.23
Density (C)	490.907	4.3730**	10.7002	1.81	14.0994	3.06*
A × B	6776.99	60.368**	5.79223	0.98	131.374	28.55**
A × C	12.2603	0.1092	6.23035	1.05	1.30722	0.28
B × C	72.061	0.6419	4.23177	0.71	0.54833	0.11
A × B × C	73.6134	0.6557	1.83292	0.31	0.65079	0.14
CV (%)	11.86		8.43		7.22	

*, **, Significant at 5% and 1% level, respectively.

seed yield of 800.4–930.1 kg ha^{-1} in the first year and 1640–1840 kg ha^{-1} in the second year for hemp planted six different plant densities (125, 150, 175, 200, 250 plants m^{-2}).

3.8. Fiber ratio

The fiber ratio was significantly ($P < 0.01$) altered by different years, varieties, and their interaction. The fiber ratio varied between 25.7 and 30.2 %, with an average of 27.9 %. The highest fiber ratio value was recorded for 250 plants m^{-2} planting density, while the lowest was noted for 100 plants m^{-2}. The 'Narlısaray' population recorded lower fiber ratio than 'Futura 75" variety (Table 3).

3.9. Oil ratio

The effect of variety on oil ratio traits was significant ($P < 0.01$). Oil ratio varied between 28.16 and 30.33 %, with an average of 29.35 %. The oil content was 30.84 % in 'Narlısaray' population, while 27.85 % in 'Futura 75′ cultivar. The highest oil ratio was noted for 100 plants m^{-2} planting density, while the lowest was noted for 250 plants m^{-2}. Townhend and Boleyn (2008) reported the average oil rate as 30.9–32.5 % at different plant densities (125, 150, 175, 200, 250 plants m^{-2}).

4. Conclusion

The results indicated that high planting density (200 and 250 plants m^{-2}) negatively affected several traits, i.e., plant height, technical stem length, stem diameter, fresh biomass yield, stem dry weight, fiber yield, seed yield, and oil rate. The increase in plant density at a specific rate increased the plant height and technical stem length. Nevertheless, plant height decreased with increase in plant density. For plant height and technical stem length, 150 plants m^{-2} was the most suitable planting density. Stem diameter linearly decreased with increasing planting density. The thickest stems were produced under 100 plants m^{-2} planting density. Plant height and stem diameters traits of 'Narlısaray' were higher than 'Futura 75′. Seed yield of 'Futura 75′ was higher than 'Narlısaray'. Higher seed yield was noted under 100 and 150 plants m^{-2} planting densities than 200 and 250 plants per m^{-2}. The results revealed that lower planting density, i.e., 100 and 150 plants m^{-2} is optimum for industrial hemp production in agroclimatic conditions of Yozgat province, Turkey.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abel, E.L., 1980. Cannabis in the Ancient World. In: Marihuana. Springer, Boston, MA. https://doi.org/10.1007/978-1-4899-2189-5_1
Amaducci, S., Errani, M., Venturi, G., 2002a. Plant Population Effects on Fibre Hemp Morphology and Production. Journal of Industrial Hemp 7 (2), 33–60. https://doi.org/10.1300/J237v07n02_04.
Amaducci, S., Errani, M., Venturi, G., 2002b. Response of Hemp to Plant Population and Nitrogen Fertilisation. Ital. J. Agron. 6 (2), 103–111.
Amaducci, S., Colauzzi, M., Bellocchi, G., Cosentino, S.L., Pahkala, K., Stomph, T.J., Westerhuis, W., Zatta, A., Venturi, G., 2012. Evaluation of a phenological model for strategic decisions for hemp (Cannabis Sativa L.) biomass production across European sites. Ind. Crops Prod. 37 (1), 100–110.
Amaducci, S., Zata, A., Pelai, F., Venturi, G., 2008. Influence of agronomic factors on yield and quality of hemp (Cannabis sativa L.) fiber and implication for an innovative production system. Field Crops Research. 107, 161–169.
Bellinger, L., 1962. Textiles from Gordion. Bull Needle Bobbin Club 46, 4–33.
Bocsa, I., Karus, M., 1998. The cultivation of hemp: botany, varieties, cultivation and harvesting. Sebastopol, Hemptech, California, p. 186.
Campiglia, E., Radicetti, E., Mancinelli, R., 2017. Plant density and nitrogen fertilization affect the agronomic performance of industrial hemp (Cannabis sativa L.) in a Mediterranean environment. Ind. Crops Prod. 100, 246–254.
Chang K, 1968. The Archeology of Ancient China (New Haven: Yale University Press, 1968), pp. 111–12;
Deng, G., Du, G., Yang, Y., Bao, Y., Liu, F., 2019. Planting Density and Fertilization Evidently Influence the Fiber Yield of Hemp (Cannabis sativa L.). Agronomy 9, 368. https://doi.org/10.3390/agronomy9070368.
Dhondt, F., Muthu, S.S., 2021. Hemp and Sustainability, Springer, Sustainable Textiles: Production, Processing, Manufacturing & Chemistry, ISBN 978-981-16-3334-8 (eBook), https://doi.org/10.1007/978-981-16-3334-8.
Farooq, S., Shahid, M., Khan, M.B., Hussain, M., Farooq, M., 2015. Improving the productivity of bread wheat by good management practices under terminal drought. J. Agron. Crop Sci. 201 (3), 173–188.
Farooq, S., Hussain, M., Jabran, K., Hassan, W., Rizwan, M.S., Yasir, T.A., 2017. Osmopriming with $CaCl_2$ improves wheat (Triticum aestivum L.) production under water-limited environments. Environ. Sci. Pollut. Res. 24 (15), 13638–13649.
Fleming, M.P., Clarke, R.C., 1998. Physical evidence for the antiquity of Cannabis sativa L. Journal of the International Hemp Association 5 (2), 80–95.
Goloborodko, P.A., 1994. Spravocnik konoplewoda. Kiew "Uroshai", 79 S. (1994).
Grabowska, L., Koziara, W., 2006. The Effect of Nitrogen Dose, Sowing Density and Time of Harvest on Development and Yields of Hemp Cultivar Bialobrzeskie. Journal of Natural Fibers 2 (4), 1–17. https://doi.org/10.1300/J395v02n04_01.
Hall, J., Bhattarai, S.P., Midmore, D.J., 2014. Effect of industrial hemp (Cannabis sativa L) planting density on weed suppression, crop growth, physiological responses, and fiber yield in the subtropics. Renewable Bioresources 2014. https://doi.org/10.7243/2052-6237-2-1. http://www.hoajonline.com/journals/pdf/2052-6237-2-1.pdf.
Hussain, M., Waqas-ul-Haq, M., Farooq, S., Jabran, K., Farroq, M., 2016a. The impact of seed priming and row spacing on the productivity of different cultivars of irrigated wheat under early season drought. Exp. Agric. 52 (3), 477–490.
Hussain, M., Farooq, S., Jabran, K., Ijaz, M., Sattar, A., Hassan, W., 2016b. Wheat sown with narrow spacing results in higher yield and water use efficiency under deficit supplemental irrigation at the vegetative and reproductive stage. Agronomy 6 (2), 22.
Kung, C.T., 1959. Archeology in China (Toronto: University of Toronto Press, 1959), 1: 131.
Okazaki, H., Kobayashi, M., Momohara, A., Eguchi, S., Okamoto, T., Yanagisawa, S., Okubo, S,, Kiyonaga, J., 2011. Early Holocene coastal environment change inferred from deposits at Okinoshima archeological site, Boso Peninsula, central Japan. Quatern Int 230:87–94. https://doi.org/10.1016/j.quaint.2009.11.002.
Ranalli, P., 1999. Agronomical and physiological advances in hemp crops. pp. 61-84. In: Ranalli, P. (Ed.), Advances in hemp research. Food Products Press, New York, United States of America.
Schultes, R.E., Hofmann, A., 1980. The botany and chemistry of hallucinogens, No. 1025. Charles C Thomas Pub Limited.
Tang, K., Struik, P.C., Yin, X., Calzolari, D., Musio, S., Thouminot, C., Bjelkova, M., Stramkale, V., Magagnini, G., Amaducci, S., 2017. A comprehensive study of planting density and nitrogen fertilization effect on dual-purpose hemp (Cannabis sativa L.) cultivation. Ind. Crops Prod. 107, 427–438.
Townshend, J.M., Boleyn, J.M. 2008. Plant density effect on oil seed yield and quality of industrial hemp cv. Fasamo in Canterbury. Agronomy Society of New Zealand Special Publication No. l3 / Grassland Research and Practice Series No. 14
Van der Werf, H.M.G., Wijlhuizen, M., De Schutter, J.A.A., 1995. Plant density and self–thinning affect yield and quality of fibre hemp (Cannabis sativa L.). Field Crop Research 40, 153–164.
Westerhuis, W., Amaducci, S., Struik, P.C., Zatta, A., Van Dam, J.E.G., Stomph, T.J. 2009. Sowing density and harvest time affect fibre content in hemp (Cannabis sativa) through their effects on stem weight. Annals of Applied Biology, 225-244.ISSN 0003-4746.
Westerhuis, W. 2016. Hemp for textiles: plant size matters. Wageningen University, Wageningen. Available at: https://edepot.wur.nl/378698. Accessed 8 Dec 2020.
Yazici, L., Yılmaz, G. 2021. Endüstrıyel Kenevır ve Geleceği, the 12th International Scientific Research Congress (UBAK), 17 / 18 ARALIK 2021, Online, Ankara.
Yazici, L., Yılmaz, G., Koçer, T., Sakar, H., 2020. Investigation of some Yield Characteristics of Hemp (Cannabis sativa L.) in Tokat Ecology. J. Int. Environmental Application & Science 15 (2), 104–108.