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The Effects of Irrigation, Topping, and Interrow Spacing on the Yield and Quality of Hemp (*Cannabis sativa* L.) Fibers in Temperate Climatic Conditions

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Abstract: The study was aimed at determining the most suitable irrigation schedule program for hemp grown for fibers by using evaporation from the free water surface (E_o), measured by a Class A pan and related crop plant coefficient (K_c). The experiment, carried out in Vojvodina, a northern part of the Republic of Serbia, included three irrigation regimes: I_1, I_2, and I_3 corresponding, respectively, to daily evaporation from an open water surface (E_o), two interrow spacings: RS_1 (12.5 cm) and RS_2 (25 cm), and topped (T) and not topped (NT) variants. The K_c values used for the calculation of daily evapotranspiration (ET_d) were 0.42 for April and May and 1.00 (I_1), 0.80 (I_2), and 0.60 (I_3) from June to the harvest. In addition, the nonirrigated (I_o) control variant was also included in the trial. The dioecious fiber hemp variety Marina was used for the trials. Irrigation was carried out by a drip irrigation system and was scheduled based on the water budget method. It started when readily available water (RAW) in the soil layer of 0.4 m was completely depleted by the plants. In the first year of the study, irrigation did not influence the yield of hemp fiber, but in the second one, the best result was achieved for the irrigation variant I_1. Interrow spacing did not have a statistically significant effect on both the hemp fiber yield and the quality. The topping of plants significantly decreased the yield of hemp, and it is not recommended when the hemp is cultivated for fibers. The quality of the hemp fibers was not influenced by irrigation, inter-row spacing, and topping. The rate of hemp evapotranspiration was in an interval of 312 mm (ET_a) to 520 mm (ET_m). The highest values of IWUE and ETWUE in both years and the bark yield in the first year were detected for the I_3 irrigation variant, which suggested that the crop plant coefficient (K_c) of 0.6 could be recommended for the correction of E_o values in the calculation of the daily evapotranspiration of hemp (ET_d) from June to August. The yield response factor (K_y) with values of 0.22 and 0.60 for the total growing season reveals that, in rainy years, hemp for fiber production could be grown without irrigation in the temperate climate of the Vojvodina region. However, such years are rare. Without doubt, irrigation of fiber hemp is recommended in the mentioned region in order to obtain high yields of good quality product.

Keywords: irrigation; fiber quality; hemp; row spacing; topping; yield

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1. Introduction

Hemp (*Cannabis sativa* L.), originating from Asia, is considered one of the oldest cultivated plants used for fiber production [1,2]. According to the FAOSTAT data [3], France, China, the Democratic People's Republic of Korea, Poland, and the Netherlands are the leading hemp producers sharing 88% of the total hemp world production; their grown areas in 2020 extended over more than 54,000 hectares. Hemp is traditionally cultivated in Vojvodina, the northern part of the Republic of Serbia, and the largest cultivated area of 20,000 ha was recorded in 1968. However, in the next twenty-year period (1968–1988), hemp cultivation decreased down to 2–4000 ha per year. Currently, hemp cultivated for fiber production covers an area of about 350 ha [4]. Regardless of the modest areas on which hemp is grown in Vojvodina, there is a growing interest in increasing acreages in the near future because of very favorable agroecological conditions and the interest of local farmers in the production of this plant.

Research carried out in different climatic and soil conditions indicates that irrigation could seriously influence the yield of hemp fiber [5,6]. Namely, Hackett [7] defined water stress as the most limiting factor affecting fiber yield and quality. In conditions of gradual reductions in water resources for irrigation, care should be taken about its rational use, i.e., the highest yield per unit of water consumed should be achieved. Therefore, it is of most importance to know and supply the right amount of water needed for the plants [8,9]. The development of irrigation schedules for any crop implies a study of the crop's requirements for water, that is, evapotranspiration (ET). The most reliable method for the estimation of crop ET is a direct measurement in field conditions. As direct methods require more time, special equipment, and can be performed only in specialized research institutions, several indirect methods for determining ET values have been proposed [10]. Among them, the pan evaporation method for the estimation of crop evapotranspiration is highly preferred due to the simplicity of measurements, low cost and maintenance [8], but also the identical effects of temperature, solar radiation, humidity, and wind speed on both crop ET and pan evaporation [11,12]. Besides climatic factors, the rate of evaporation from an evaporation pan (E_o) depends upon the type of pan used, the amount of water in the pan, and the location of the pan. In addition, the rate of evaporation from the pan is affected by the physical properties of the surrounding area (pavement, bare soil, well-watered crop), whereby Class A is the most common pan type. Studies have shown that evaporation pans can be used to accurately schedule irrigations [8,13]. However, Smajstrla et al. [14] highlighted that the E_o is not equal to the plant water requirements, which are lower; therefore, corrective coefficients should be determined for each plant species for the particular region. Taking into account that competition for water resources is increasing dramatically, the ultimate goal of irrigation is to utilize added water efficiently (IWUE), which is defined as the amount of yield produced per unit of irrigation water applied (kg m^{-3}). In addition, it is important to estimate water use efficiency taking into consideration plants' evapotranspiration (ETWUE). ETWUE depends on environmental and management conditions, but mostly on the precipitation amount and distribution and establishes whether the growing season is favorable for plant production or not. Wang et al. [15] pointed out that all factors that increase yield and decrease water used for ET positively affect water use efficiency.

The actual evaluation of stress affecting the yield due to soil water deficit during the growing season of different plants can be performed by estimating the yield response factor (K_y), which represents the amount of yield (Y) lost per unit of ET loss [16]. A larger K_y value indicates larger yield losses due to water deficits. Plant cultivation density is also an important factor affecting fiber yield and quality [17,18]. Hall et al. [19] reported that hemp planted at a high density encourages taller heights and restricts side branching, both positively affecting the fiber quality. Opposite to the aforementioned report, Campiglia et al. [20] reported that a higher plant density results in shorter plant heights as the hemp plants tended to reach the reproductive stage earlier. However, Deleuran and Flennmark [21] pointed out that lower densities in fiber hemp production are not acceptable since they do not affect weed control, while fiber yield and quality can be reduced.

Among different agronomical practices for industrial hemp cultivation, Leonte et al. [22] reported that the topping of plants reduces their height, which facilitates mechanized harvesting, reducing the sowing rate, while the yield and quality of fibers remain unchanged compared to production without topping. Since there are no data on hemp production under irrigation in the Vojvodina region, the objective of this research was to determine the most suitable irrigation schedule program for hemp grown for fiber by using evaporation from the free water surface and related plant–pan coefficients. The effects of topping and row spacing on the fiber yield and quality parameters, with a focus on cellulose and lignin contents, were analyzed too. Bearing in mind that fiber performance depends on its chemical composition, it is important to emphasize that, to our best knowledge, there is no literature data about the effects of irrigation, topping, and interrow spacing on the chemical composition of hemp fiber. The obtained results could enhance the optimization of fiber hemp production in the mentioned geographical region.

2. Materials and Methods

2.1. Site Description

Experimental research on the influence of irrigation on the yield and evapotranspiration of hemp (*Cannabis sativa* L.) grown for fibers was conducted in the experimental field of the Institute of Field and Vegetable Crops Novi Sad at the Department of Alternative Plant Species in Bački Petrovac (45°19′ N latitude, 19°50′ E longitude, and 84 m altitudes) in 2018 and was repeated in 2019. Over the 2000–2017 period, the annual mean values of the air temperature and precipitation were 12.1 °C (19.3 °C in the growing season, April–August) and 626 mm (328 mm or about 50% in the growing season), respectively. According to the Hargreaves climate classification system, the study area is classified as semiarid in the summer period, from June to August [23].

2.2. Soil Properties

The soil from the experimental field was classified as calcareous, gleyic chernozem according to the IUSS Working Group WRB [24]. It belongs to a Clay loam textural class according to Tommerup's classification [25]. Water, physical, and chemical properties of the soil are given in Tables 1 and 2.

Table 1. Water and physical properties of the soil.

Depth (m)	Textural Status (%)			Field Capacity (33 kPa) (mas.%)	Lento Capillary Moisture (625 kPa) (mas.%)	Wilting Point (1500 kPa) (mas.%)	Soil Bulk Density (g cm^{-3})	Specific Density (g cm^{-3})	Total Porosity (vol.%)	Readily Available Water (mm)
	Sand	Clay	Silt							
0.4	41	34	25	27.93	15.61	12.65	1.35	2.66	49.13	54.5

Table 2. Chemical properties of the soil.

Depth (m)	pH		$CaCO_3$ (%)	Humus (%)	N (%)	P_2O_5	K_2O
	KCl	H_2O				(mg 100 g^{-1})	
0.4	7.28	8.17	6.01	2.9	0.19	29.77	30.43

Concerning the water, physical, and chemical properties, this soil is quite suitable for any crop and irrigation system [26].

2.3. Crop Management, Experimental Design, and Irrigation Treatments

The field operations consisted of the following: plowing at a depth of 0.3 m, seedbed preparation with a seedbed cultivator, and sowing with a pneumatic drill Majevica 4RK (Majevica, Bačka Palanka, Serbia). In both years of the experiment, 450 kg ha^{-1} of 15:15:15 NPK fertilizer (67.5 kg ha^{-1} of N, K_2O, and P_2O_5) was applied to the experimental plots before plowing in the autumn, while 50 kg ha^{-1} of Sulfamo 25 MPPA N 25 + 4 MgO + 27 SO_3 (12.5 kg ha^{-1} of N, 2 kg ha^{-1} of MgO, and 13.5 kg ha^{-1} of SO_3) was applied in the spring. In the first year, the preceding crop was watermelon and in the second, grain sorghum. Hemp was sown on April 17 and 24 (seeds were sown 0.03–0.04 m deep and spaced 0.03–0.04 m in rows) and harvested on August 14 and 12 (at the stage of full male flowering of the plants) in 2018 and 2019, respectively. The dioecious fiber hemp variety

Marina, created at the Institute of Field and Vegetable Crops from Novi Sad, was used for the trials.

The trial was established as a randomized complete block design with three replicates. The experiment included three variables: two interrow spacings: RS_1 (12.5 cm, ≈240 plants m^{-2}) and RS_2 (25 cm, ≈120 plants m^{-2}), topped (T) and not topped (NT) variants, and three irrigation regimes: I_1, I_2, and I_3 corresponding, respectively, to daily evaporation from an open water surface (E_o). The trial included, as well, a nonirrigated (I_o) control variant (Figure 1). Irrigation was managed using an Excel-based irrigation tool that employs meteorological, soil, and crop data for a day-by-day estimation of the soil water budget in the effective root zone. Daily water use on evapotranspiration (ET_d) was computed from the evaporation from an open water surface (E_o), the pan coefficient (K_p), and the crop plant coefficient (K_c), Equation (1).

$$ET_d = E_o \times K_p \times K_c \quad (1)$$

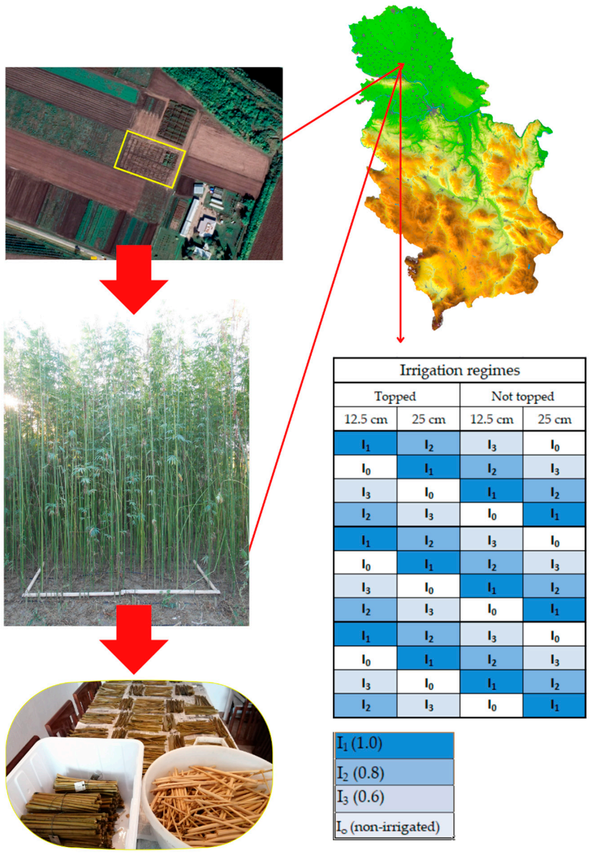

Figure 1. Location of the trial and experimental design showing the main analyzed factors: irrigation 1.00 (I_1), 0.80 (I_2), and 0.60 (I_3) corresponding, respectively, to daily evaporation from an open water surface (E_o), I_o (non-irrigated control variant), two interrow spacings: RS_1 (12.5 cm) and RS_2 (25 cm), and topped (T) and not topped (NT) variants.

E_o was measured using a Class A pan located at a meteorological station near the experimental plot. The pan was placed on a wooden support at a height of 0.15 m above the soil surface, and readings were recorded daily. A K_p equal to 0.80 in a semiarid environment (average relative humidity 40–70%, low wind speed, fetch 1 m) was used to determine the reference evapotranspiration (ET_o) needed in the irrigation program. The Kc values used for ET_d calculation were 0.42 for April and May and 1.00 (I_1), 0.80 (I_2), and 0.60 (I_3) from June to August (when the harvest was performed) [27]. The irrigation depth was restricted to the soil depth of 0.4 m, where most of the roots are expected to grow [6]. In other words, irrigation started when RAW in the soil layer of 0.4 m (54.5 mm) was completely depleted by the plants. The daily rainfall, measured by a rain gauge on the experimental plot in the balance sheet, was registered as water inflow. After heavy rain greater than the soil capacity for RAW, a calculation of deep percolation below the active root zone was made. The irrigation rate was 30 mm at the beginning of the season, and 40 mm in the middle of the season. The plants were irrigated by a drip irrigation system (drippers spaced every 0.33 m with an average flow of 2.0 L h^{-1} under a pressure of 100 kPa) with laterals placed at 0.5 m in distance. The volume of the irrigation water and the pressure in the system were controlled by the flow meter and the pressure gauge installed in the hose nozzle used for irrigation.

2.4. Sampling and Laboratory Analysis

The area of each individual basic plot was 7 m^2 (2 m × 3.5 m). At harvest, the aboveground fresh biomass and the number of plants were determined from the center of the basic plot from an area of 2.5 m^2, while each side was 0.5 m away in order to avoid the effect of irrigation from neighboring plots.

Plants were cut at the base of the stems. Thirty plants per plot were brought to the laboratory to be separated into two fractions: stems and the remaining parts (leaves and inflorescences). Plant materials were weighed and subsequently dried in the air to calculate the dry matter content. Plant height was determined from the dried plants. For the analysis of the content and quality of the fibers, 20 cm long parts of 20 stems were taken 30 cm above the base of the stem. Fiber extraction was carried out with NaOH according to the Bredemann method [28].

2.5. Determination of the Chemical Composition of Hemp Fibers

The chemical composition of hemp fibers was determined according to the procedure described by Ivanovska et al. [29]. In brief, the hemp fiber noncellulosic components were removed in the following order: water soluble components (extraction with boiling water for 30 min and drying at room temperature for 72 h), fats and waxes (Soxhlet extraction with dichloromethane for 4 h and drying at room temperature for 72 h), pectin (extraction with 1% ammonium oxalate at boiling temperature for 1 h, washing with distilled water, and drying at room temperature for 72 h), lignin (extraction with 0.7% sodium chlorite (pH 4.0–4.5) at boiling temperature for 2 h, rinsing with 2% $NaHSO_3$, washing, and drying at room temperature for 72 h), and hemicelluloses (treatment with 17.5% sodium hydroxide at room temperature for 45 min followed by neutralization with 10% acetic acid, washing with distilled water, rinsing with 0.5% $NaHCO_3$, washing with distilled water, and drying at room temperature for 72 h). After the removal of the noncellulosic components, α-cellulose remained as a solid residue.

2.6. Data Analysis

To evaluate the effects of different watering regimes on bark yield, irrigation water use efficiency (IWUE) and evapotranspiration water use efficiency (ETWUE) were calculated. IWUE (kg m^{-3}) and ETWUE (kg m^{-3}) were estimated according to Bos [30], Equations (2) and (4), and Viets [31], Equations (3) and (5).

$$\text{IWUE} = Y_m - Y_a/I, \tag{2}$$

$$\text{IWUE} = Y_m/I, \tag{3}$$

$$\text{ETWUE} = Y_m - Y_a/ET_m - ET_a, \tag{4}$$

$$\text{ETWUE} = Y_m, Y_a/ET_m, ET_a, \tag{5}$$

where Y_m is the maximum harvested bark yield (under irrigation, nonlimiting conditions, kg ha^{-1}), ET_m is the maximum evapotranspiration (mm) corresponding to Y_m, Y_a is the actual harvested bark yield (nonirrigated, kg ha^{-1}), ET_a is the actual evapotranspiration (mm) corresponding to Y_a, and I is the total seasonal irrigation water applied (m^{-3} ha).

To express the yield lost per unit of evapotranspiration loss, the yield response factor (K_y) was computed according to Doorenbos and Kassam [16], Equation (6).

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y\left(1 - \frac{ET_a}{ET_m}\right) \quad (6)$$

2.7. Statistical Analysis

The statistical processing of data was conducted by the analysis of variance (ANOVA) using the IBM SPSS Statistics software (version 26.0, modified 2021), and means were separated using Fisher's protected least significant difference (LSD) test at the 95% level of probability to identify significant differences between the treatments for biomass yield, green stem yield, dry stem yield, plant height, bark yield, and fiber chemical composition (i.e., cellulose and lignin contents).

3. Results

3.1. Weather Conditions and Applied Irrigation Water Amount

Rainfall and air temperature data were obtained from an on-site meteorological station located about 200 m from the experimental plot and are presented in Figures 2 and 3. In 2018, the growing season for hemp lasted 120 days (from 17 April to 14 August) (Table 3), and during that period, there was 274 mm of rainfall (Table 3). In the period from the third decade of May to mid-June, only 15.3 mm of rainfall fell, and irrigation events on all treatments were carried out in that period (Figure 2). In the third decades of June and in July, when the hemp water requirements were the greatest, 55.3 mm and 89.2 mm of rain fell, respectively (Figure 2), and hence, there was no irrigation during that part of the growing season. During the growing season, the mean air temperature was 20.9 °C (Table 3), which is 1.6 °C higher than the long-term average (19.3 °C). The amounts of water added by irrigation were 60 mm (4 and 11 Jun), 30 mm (6 Jun), and 30 mm (8 Jun) during the entire season on the I_1, I_2, and I_3 variants, respectively (Figure 2). In 2019, the hemp growing season lasted 111 days (from April 24 to August 12) (Table 4) with 295 mm of rainfall and a 20.9 °C mean growing season air temperature (Table 4). All irrigation events were conducted in July as there was only 35 mm of rain. In total, 100 mm (30 mm, 30 mm, and 40 mm on 3, 18, and 26 July), 70 mm (30 mm and 40 mm on 12 and 23 July), and 70 mm (30 and 40 on 16 and 29 July) of water was added by irrigation on the I_1, I_2, and I_3 variants, respectively (Figure 3).

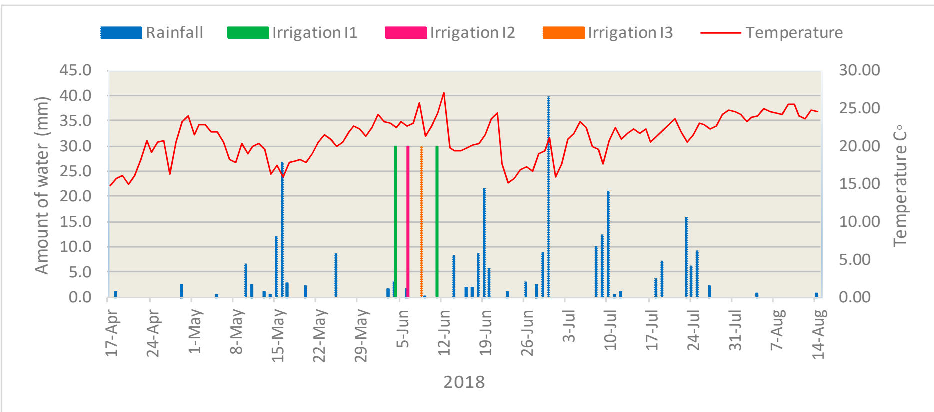

Figure 2. Irrigation water applied, mean daily air temperature (°C), and daily precipitation (mm) in 2018.

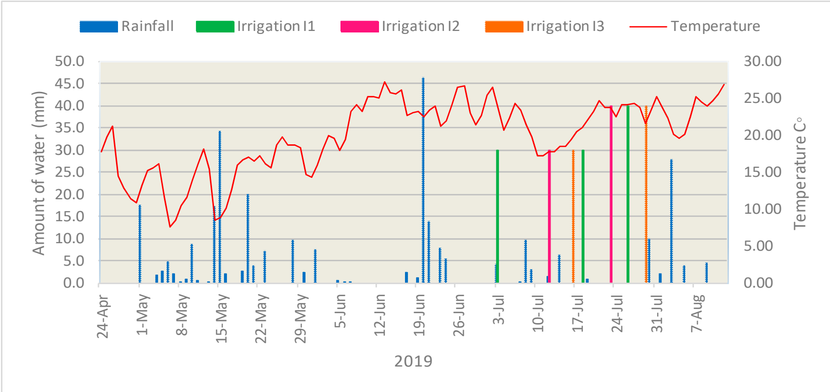

Figure 3. Irrigation water applied, mean daily air temperature (°C), and daily precipitation (mm) in 2019.

Table 3. Water budget of fiber hemp in 2018.

Elements	From Sowing to 4–5 Pairs of Leaves 17.IV–22.V			From 4–5 Pairs of Leaves to the Appearance of Male Flowers 23.V–26.VI			From the Appearance of Male Flowers to the Harvest 27.VI–14.VIII			The Entire Season/Average 17.IV–14.VIII		
	I_1	I_2	I_3	I_1	I_2	I_3	I_1	I_2	I_3	I_1	I_2	I_3
E_o (mm)		177			170			240			588	
ET_m (mm)	74	74	74	142	118	94	240	192	144	456	384	312
ET_m (%)	16.3	19.3	23.8	31.1	30.7	30	52.6	50.0	46.2	100	100	100
Duration (days)		36			35			49			120	
ET_d (mm)	2.1	2.1	2.1	4.1	3.4	2.7	4.9	3.9	2.9	3.7	3.1	2.6
Rainfall (mm)		58			67			149			274	
Temp. (°C)		19.1			21.3			22.2			20.9	
$\Delta\pm$	−16	−16	−16	−37	−37	−27	−91	0	+5			
r (mm)	53	53	53	37	37	37	0	0	10			
ET_a (mm)	74	74	74	104	104	94	149	149	144	327	327	312
d (mm)	0	0	0	38	14	0	91	43	0	129	57	0
s (mm)	0	0	0	0	0	0	0	0	0	0	0	0
Irrigation (mm)	0	0	0	60	30	30	0	0	0			

E_o—evaporation from an open water surface (mm), ET_m—evapotranspiration in irrigated treatments (mm), ET_d—daily evapotranspiration (mm), $\Delta\pm$—a difference in rainfall, ET_m—deficit (d, mm) or suficit (s, mm) after consuming or filling the reserve (r, mm) of soil RAW, ET_a—actual evapotranspiration, rainfed (mm).

Table 4. Water budget of fiber hemp in 2019.

Elements	From Sowing to 4–5 Pairs of Leaves 24.IV–12.VI			From 4–5 Pairs of Leaves to the Appearance of Male Flowers 13.VI–4.VII			From the Appearance of Male Flowers to the Harvest 5.VII–12.VIII			The Entire Season/Average 24.IV–12.VIII		
	I_1	I_2	I_3	I_1	I_2	I_3	I_1	I_2	I_3	I_1	I_2	I_3
E_o (mm)		186			112			240			538	
ET_m (mm)	168	157	147	112	89	67	240	192	118	520	438	332
ET_m (%)	32.3	35.8	44.3	21.5	20.3	20.2	46.2	43.8	35.5	100	100	100
Duration (days)		50			22			39			111	
ET_d (mm)	3.4	3.1	2.9	5.1	4.0	3.0	6.2	4.9	3.0	4.7	3.9	3.0
Rainfall (mm)		146			80			69			295	
Temp. (°C)		16.3			24.0			22.4			20.9	
$\Delta\pm$	−22	−11	−1	−19	−9	13	0	−21	−49			
r (mm)	41	41	41	19	30	40	0	21	53			
ET_a (mm)	168	157	147	99	89	67	69	90	118	336	336	332
d (mm)	0	0	0	13	0	0	171	102	0	184	102	0
s (mm)	0	0	0	0	0	13	0	0	4	0	0	17
Irrigation (mm)	0	0	0	0	0	0	100	70	70			

E_o—evaporation from an open water surface (mm), ET_m—evapotranspiration in irrigated treatments (mm), ET_d—daily evapotranspiration (mm), $\Delta\pm$—a difference in rainfall, ET_m—deficit (d, mm) or suficit (s, mm) after consuming or filling the reserve (r, mm) of soil RAW, ET_a—actual evapotranspiration, rainfed (mm).

3.2. Yield Data, Plant Height, and Fiber Chemical Composition

In 2018, the highest bark yield (6.6 t ha^{-1}), biomass (56.7 t ha^{-1}), green stem (45.2 t ha^{-1}), and dry stem (18.0 t ha^{-1}) yields were detected for the I_3 variant. The plant height was not affected by irrigation. All studied elements had statistically significantly higher values for the non-topped variant compared to the topped one. Statistically significant differences in the fiber yields between RS_1 and RS_2 were not found (Table 5). The highest yield of hemp bark (9.3 t ha^{-1}, Table 5) and the highest cellulose content (80.6%, Table 6), as the most desirable, were achieved on the irrigation variant I_3 at a distance between plant rows of 12.5 cm without topping (Table 5). In the case of the first variant of irrigation (I_1), the lignin content in the hemp fibers (Table 6) was significantly lower not only compared to other variants of irrigation (I_2, I_3), but also in relation to the nonirrigated variant (I_o).

Table 5. Irrigation, topping, and interrow spacing effects on plant height and yield of hemp fiber.

			Biomass Yield (t ha^{-1})		**Green Stem Yield (t ha^{-1})**		**Dry Stem Yield (t ha^{-1})**		**Plant Height (m)**		**Bark Yield (t ha^{-1})**	
			2018	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
							Irrigation regimes					
		I_1	49.4	40.7	37.5	30.8	14.5	11.6	3.1	2.4	5.4	4.7
		I_2	54.2	28.6	42.9	21.9	17.0	8.6	3.1	1.9	6.2	3.5
		I_3	56.7	30.9	45.2	23.4	18.0	9.6	3.0	2.2	6.6	3.7
		I_0	53.6	28.1	42.2	22.1	16.7	8.6	3.0	1.9	6.0	3.4
		LSD	4.71	2.63	3.41	2.3	1.52	1.1	0.31	0.17	0.74	0.51
							Topping treatment					
		T	44.9	29.3	34.8	22.1	12.7	8.5	2.8	2.0	4.5	3.4
		NT	62.0	34.8	49.1	27.0	20.4	10.8	3.3	2.3	7.5	4.3
		LSD	3.33	1.9	2.41	1.3	1.07	0.7	0.22	0.12	0.53	0.36
							Interrow spacing					
		RS_1	55.1	32.5	43.9	25.0	16.9	9.7	3.0	2.0	6.0	3.8
		RS_2	51.9	31.6	40.0	24.1	16.2	9.5	3.1	2.2	6.0	3.8
		LSD	3.33	1.9	2.41	1.6	1.07	0.7	0.22	0.12	0.53	0.36
						Irrigation regime x Topping treatment x Interrow spacing						
I_1	T	12.5	45.5	43.2	35.1	32.1	12.4	11.8	2.8	2.3	4.3	5.1
		25.0	33.2	36.8	22.9	27.4	7.5	9.7	3.4	2.4	2.9	3.9
	NT	12.5	55.2	46.4	43.5	36.3	17.0	14.1	3.1	2.5	6.6	5.7
		25.0	63.7	36.3	48.4	27.6	21.3	10.8	3.3	2.4	7.7	4.3
I_2	T	12.5	52.3	22.4	40.8	16.8	14.4	6.8	2.5	1.6	5.0	2.7
		25.0	42.1	21.2	33.1	16.0	12.3	6.3	2.8	1.8	4.6	2.4
	NT	12.5	62.0	36.4	51.0	29.1	21.1	11.1	3.5	2.0	7.7	4.5
		25.0	60.4	34.4	46.6	25.6	20.2	10.4	3.5	2.3	7.4	4.3
I_3	T	12.5	42.7	30.8	33.3	23.1	12.5	9.0	2.6	2.1	4.3	3.5
		25.0	42.0	30.7	32.7	22.9	12.1	9.5	2.8	2.0	4.6	3.8
	NT	12.5	78.4	34.3	63.8	26.5	26.2	10.3	3.3	2.4	9.3	3.9
		25.0	63.6	28.0	50.9	21.1	21.0	9.4	3.5	2.4	8.1	3.9
I_0	T	12.5	47.9	21.6	38.6	16.2	13.9	6.3	2.8	1.5	4.7	2.3
		25.0	53.7	28.0	41.9	22.3	16.6	8.3	2.8	2.1	5.8	3.3
	NT	12.5	56.5	25.1	44.9	20.2	17.6	8.2	3.5	1.9	6.4	3.2
		25.0	56.1	37.9	43.6	29.8	18.6	11.7	3.0	2.4	6.9	4.8
		LSD	9.41	5.27	6.81	4.57	3.03	2.14	0.61	0.35	1.48	1.02

Note: Irrigation regimes: 1.00 (I_1), 0.80 (I_2), and 0.60 (I_3), T: topped treatment, NT: not topped treatment; RS_1: interrow spacing 12.5 cm, RS_2: interrow spacing 25 cm.

Table 6. Irrigation, topping, and row spacing effects on the quality of hemp fibers.

			α-Cellulose (%)		Lignin (%)	
			2018	2019	2018	2019
			Irrigation regimes			
		I_1	77.5	70.1	2.4	7.1
		I_2	76.8	69.9	3.5	7.3
		I_3	77.4	69.8	3.4	7.2
		I_o	77.7	70.2	3.4	6.5
		LSD	2.65	2.25	0.76	0.89
			Topping treatment			
		T	76.5	70.0	3.3	7.0
		NT	78.2	70.5	3.1	7.1
		LSD	1.88	1.59	0.54	0.63
			Interrow spacing			
		RS_1	77.6	70.0	3.1	7.1
		RS_2	77.1	70.5	3.2	7.0
		LSD	1.88	1.59	0.54	0.63
			Irrigation regimen x Topping treatment x Interrow spacing			
I_1	T	12.5	76.7	70.4	2.5	6.5
		25.0	78.5	70.4	2.2	6.2
	NT	12.5	76.6	71.3	2.2	7.4
		25.0	78.2	71.7	2.7	8.5
I_2	T	12.5	75.1	69.8	3.2	7.6
		25.0	76.1	70.1	4.1	7.4
	NT	12.5	78.2	70.1	3.5	6.9
		25.0	77.6	69.7	3.1	7.1
I_3	T	12.5	75.7	68.8	3.5	7.7
		25.0	75.5	69.4	3.9	7.3
	NT	12.5	80.6	69.4	3.4	7.6
		25.0	77.7	71.7	3.0	6.3
I_0	T	12.5	79.6	69.8	3.7	6.4
		25.0	74.8	71.2	3.3	6.6
	NT	12.5	78.2	70.4	3.0	6.6
		25.0	78.3	69.8	3.5	6.3
		LSD	5.31	4.49	1.52	1.78

Note: Irrigation regimes: 1.00 (I_1), 0.80 (I_2), and 0.60 (I_3), T: topped treatment, NT: not topped treatment; RS_1: interrow spacing 12.5 cm, RS_2: interrow spacing 25 cm.

In 2019, the highest bark yield (5.4 t ha^{-1}), biomass (40.7 t ha^{-1}), green stem (30.8 t ha^{-1}), dry stem (11.6 t ha^{-1}), and plant heights were detected for the I_1 variant. All studied elements had statistically significantly higher values for the non-topped variant compared to the topped one. Statistically significant differences in the fiber yields between RS_1 and RS_2 were not found except for plants' height values, which were significantly higher in the variant RS_2 (2.2 m) compared to the variant RS_1 (2.0 m) (Table 5). The highest yield of hemp bark (5.7 t ha^{-1}, Table 5) and the highest cellulose content (80.6%, Table 6) were achieved for irrigation variant I_1 at a distance between plant rows of 12.5 cm without topping (Tables 5 and 6). In regard to the lignin content in the hemp fibers, the highest value (8.5%) was determined for irrigation variant I_1 at a distance between plant rows of 25 cm without topping (Tables 5 and 6).

3.3. Crop Water Use

In 2018, the seasonal evapotranspiration of fiber hemp in irrigation conditions (ET_m) was 456 mm (I_1), 384 mm (I_2), 312 mm (I_3), and 312 mm for the nonirrigated control variant (ET_a). The highest ET_m was obtained for the period from the appearance of male flowers to the end of the season, being 144–240 mm or 46.2–52.6% of the total water used during the entire growing season (Table 5), depending on the applied irrigation regime. The highest average value of 2.9–4.9 mm of daily water used for evapotranspiration (ET_d) was detected in the period from the appearance of male flowers to the end of the season, while the average value for the entire growing season was 2.6–4.3 mm (Table 5). A maximum ET_d value of 6.8–8.5 mm was detected on 11 August, at the end of the growing season, i.e., 117 days after planting (Figure 4). In 2019, the seasonal evapotranspiration values of fiber hemp in irrigation conditions (ET_m) were 520 mm (I_1), 438 mm (I_2), 332 mm (I_3), and 332 mm for the nonirrigated control variant (ET_a). The highest ET_m was obtained for the period from the appearance of male flowers to the end of the season and amounted to 118–240 mm or 35.5–46.2% of the total water used during the entire growing season (Table 6), depending on the applied irrigation regime. The highest average value of 3.0–6.2 mm of daily water used for evapotranspiration (ET_d) was detected in the period from the appearance of male flowers to the end of the season, while the average value for the entire growing season was 3.0–4.7 mm (Table 6). A maximum ET_d value of 5.1–8.5 mm was detected on 22 July, i.e., 90 days after planting (Figure 5).

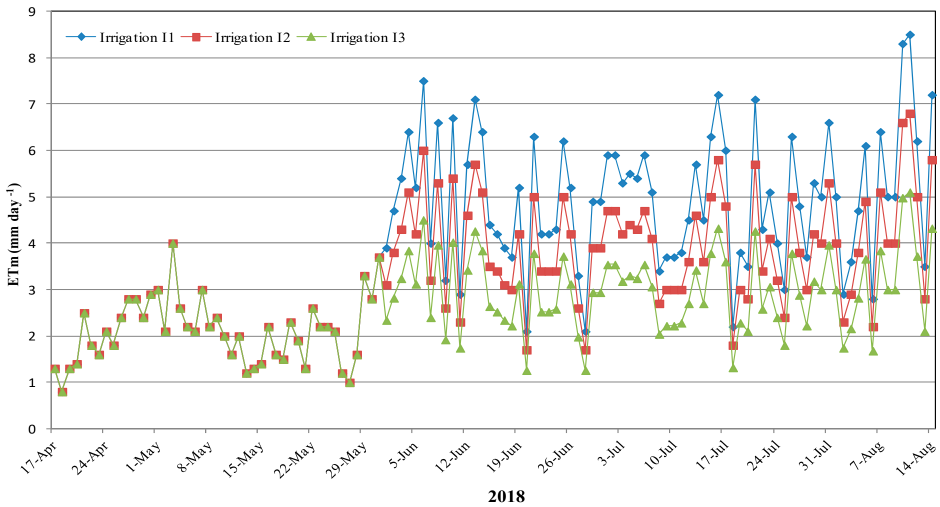

Figure 4. Daily fiber hemp evapotranspiration under the three irrigation regimes in 2018.

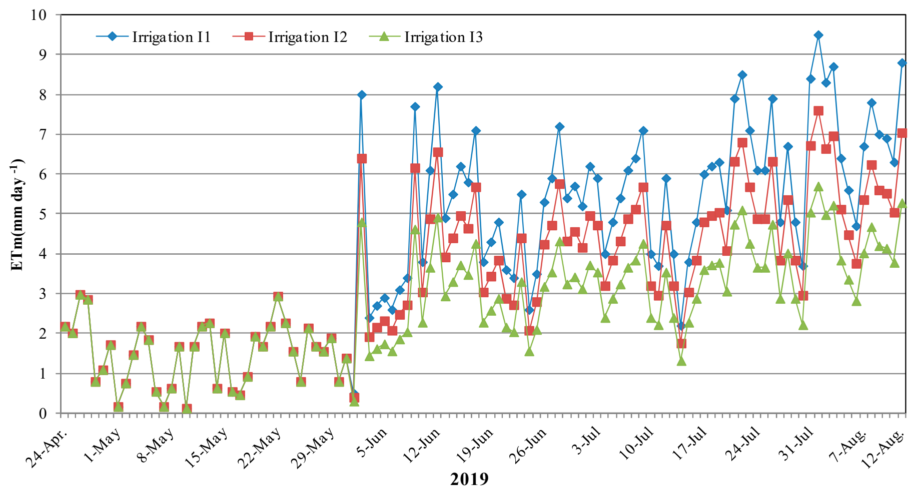

Figure 5. Daily fiber hemp evapotranspiration under the three irrigation regimes in 2019.

In 2018, the IWUE values (Equation (2)) were 0.67 kg m^{-3} and 2.0 kg m^{-3} for variants I_2 and I_3, respectively, but the values of 9.0 kg m^{-3}, 20.7 kg m^{-3}, and 22.0 kg m^{-3} were calculated for the variants I_1, I_2, and I_3 (Equation (3)), respectively (Table 7). The IWUE value for the I_1 variant could not be calculated (Equation (2)) as the bark yield was lower than that obtained for I_0 (Table 3). The ETWUE values (Equation (4)) were 0.28 kg m^{-3} for the I_2 variant, and 1.18 kg m^{-3}, 1.61 kg m^{-3}, 2.12 kg m^{-3}, and 1.92 kg m^{-3} (Equation (5)) for I_1, I_2, I_3, and I_0, respectively (Table 7). The K_y value was 0.22 for the entire growing season (Table 7).

Table 7. Irrigation water use efficiency (IWUE), evapotranspiration water use efficiency (ETWUE), and yield response factor (K_y) of fiber hemp.

Year	War.	IWUE (Equation (2))	IWUE (Equation (3))	ETWUE (Equation (4))	ETWUE (Equation (5))	ET_m	ET_a	$1 - ET_a/ET_m$	Y_m	Y_a	$1 - Y_a/Y_m$	K_y
2018	I_1	-	9.0	-	1.18	456		-	5.4	-	-	-
	I_2	0.67	20.7	0.28	1.61	384		0.148	6.2	-	0.032	0.22
	I_3	2.0	22.0	-	2.12	312		-	6.6	-	-	-
	I_0	-	-	-	1.92	-	312	-	-	6.0	-	-
2019	I_1	1.18	4.27	0.69	0.90	520	-	0.35	4.7	-	0.210	0.60
	I_2	0.14	5.0	0.09	0.80	438	-	0.21	3.5	-	-	-
	I_3	0.43	5.29	-	1.11	332	-	-	3.7	-	-	-
	I_0	-	-	-	1.02	-	332	-	-	3.4	-	-

$1 - ET_a/ET_m$ is the relative evapotranspiration deficit; $1 - Y_a/Y_m$ is the relative yield decrease; ET_m is the maximum evapotranspiration (mm) corresponding to Y_m; ET_a is the actual evapotranspiration (mm) corresponding to Y_a; Y_m is the maximum harvested bark yield (under irrigation, nonlimiting conditions, kg ha^{-1}); and Ya is the actual harvested bark yield (under nonirrigated conditions, kg ha^{-1}).

In 2019, the IWUE values (Equation (2)) were 1.18 kg m^{-3}, 0.14 kg m^{-3}, and 0.43 kg m^{-3} for variants I_1, I_2, and I_3, respectively, but the values of 4.27 kg m^{-3}, 5.0 kg m^{-3}, and 5.29 kg m^{-3} were calculated for the variants I_1, I_2, and I_3 (Equation (3)), respectively (Table 7). The ETWUE values (Equation (4)) were 0.69 kg m^{-3} and 0.09 for the I_1 and I_2 variants, respectively, and 0.90 kg m^{-3}, 0.80 kg m^{-3}, 1.11 kg m^{-3}, and 1.02 kg m^{-3} (Equation (5)) for I_1, I_2, I_3, and I_0, respectively (Table 7). The K_y value was 0.60 for the entire growing season (Table 7).

4. Discussion

For the meaningful interpretation of plant responses to the environment, exact knowledge of the weather conditions during the growing season is indispensable. Based on the amount and distribution of precipitation, both years of study were considered favorable for the production of hemp in the Vojvodina region. However, in 2018, from the third decade of May to mid-June, the rainfall was only 15.3 mm, and irrigation events were carried out on all treatments during that period. The amounts of water added by irrigation were 60 mm, 30 mm, and 30 mm during the entire season on the I_1, I_2, and I_3 variants, respectively. In July 2019, there was only 35 mm of rain, and irrigation on all treatments was conducted in that month. The amounts of water added were 100 mm, 70 mm, and 70 mm on the I_1, I_2, and I_3 variants, respectively. The abovementioned information confirms the statement of Pejić et al. [32]: that irrigation in Vojvodina has a supplementary characteristic; irrigation can be defined as supplementing rainfall for successful crop production. Pejić et al. [9] pointed out that in the growing season of fiber hemp in 2017, there was only 99 mm of rain, and therefore, 320 mm of water was added by irrigation. This shows that individual years can differ in the amount of precipitation and water added by irrigation in Vojvodina. The differences in air temperature during the study period significantly affected not only the duration of the individual subperiods, but also the duration of the entire growing season. In 2019, the first subperiod (from sowing to 4–5 pairs of leaves) lasted longer by 14 days than in 2018 (50/36 days) as the air temperature was lower by 2.8 °C (16.3/19.1 °C), but the second subperiod (from 4–5 pairs of leaves to the appearance of male flowers) lasted shorter by 13 days (22/35 days) because the temperature was higher by 2.7 °C (24.0/21.3 °C) (Tables 5 and 6). Low temperatures in the first vegetation subperiod in 2019 affected the growth and height of the plants, and high temperatures in the second subperiod influenced the values of plant evapotranspiration (Table 5). Shorter hemp plants, influenced by unfavorable temperature conditions in the first subperiod of vegetation in 2019, were the reason for the lower values of all examined parameters compared to 2018.

Cosentino et al. [27] also pointed out that the air temperature could be a limiting factor in hemp production, even in the case of an optimal water supply to the plants.

The research conducted in different soil and climate conditions indicated that irrigation has a significant effect on the yield of fiber hemp [5,6,33]. The results of the yield parameters under different irrigation regimes presented in the current study are similar to or higher than those obtained in other studies carried out in similar environments, but with different cultivars. Both years of the study were favorable for plant production in the region. Rainfall during the vegetation period, both in terms of the amount and distribution, provided a favorable water regime for the soil without irrigation, which resulted in a high yield in the conditions of the natural water supply. In 2018, irrigation did not significantly affect the yield of fiber hemp, but significantly higher values of the studied parameters were recorded in 2019 for the I_1 irrigation variant compared to the I_2, I_3, and the control nonirrigated variant (I_o); however, the differences between the I_2, I_3, and the I_o variant were not statistically significant (Table 3). The abovementioned information confirms the supplementary characteristic of irrigation in Vojvodina [34], i.e., that rainfall following irrigation can affect the soil water regime and irrigation schedule of growing plants. Trochoulias and Johns [35] also confirmed the same, i.e., that in Southern Australia, in wet years, supplementary irrigation decreased the nut size of macadamia in the well-watered treatments relative to the rainfed controls. Excessive water caused by unexpected rainfall in 2018 (Figure 2) reduced the yield of cultivated plants (Table 3) and altered the chemical composition of the hemp fibers, primarily by reducing the woody component, i.e., lignin (Table 4). This fact is proven by the results obtained for the first variant of irrigation (I_1), whereby both the yield (Table 3) and lignin content in the hemp fibers (Table 4) were significantly lower not only in relation to the other variants of irrigation (I_2, I_3), but also in relation to the nonirrigated variant (I_o). However, in 2019, irrigation did not have a statistically significant effect on the chemical composition of the hemp fibers (Table 4). In general, the growing conditions in 2018 were more favorable compared to 2019 concerning the chemical composition of the fibers, i.e., fibers with a higher cellulose and lower lignin content were obtained. The results obtained for biomass (49.4–56.7/28.1–40.7 t ha^{-1}), green stem (37.5–45.2/22.1–30.8 t ha^{-1}), dry stem (14.5–18.0/8.6–11.6 t ha^{-1}), and bark yield (5.4–6.6/3.4–4.7 t ha^{-1}) in studied the years are in agreement with results published by Di Bari et al. [6] in the environment of the Mediterranean climate. Namely, the authors reported biomass, green stem, dry stem, and bark yields of 28–38 t ha^{-1}, 22.13–27.78 t ha^{-1}, 8.77–12.56 t ha^{-1}, and 5.55–5.68 t ha^{-1}, respectively. In our experiment, plant height values of 3.0–3.1 m and 1.9–2.4 m in 2018 and 2019, respectively, were higher or similar than those recorded in an experiment carried out in the Mediterranean climate (1.9–2.2 m), which is the main reason for the differences and similarities in the studied parameters. The results obtained for bark yield in 2019 are similar to the results of Tsaliki et al. [33], who reported averaged three-year results for bark yield of 4.27 and 4.57 t ha^{-1} for var. Bialobrzeskie and var. Futura, respectively, in the Mediterranean environment in northern Greece. Zadrozniak et al. [36] pointed out that the height of hemp plants depends on the length of vegetation, planting density, and variety. They also reported that, depending on weather conditions in the growing season, the plants may grow 1.0–5.0 m. Very similar results for hemp bark yield were reported by Bennett et al. [37] in the wet climate of Wales. It was highlighted that the highest bark yields of 6.1 t ha^{-1} and 5.8 t ha^{-1} were determined in Beniko, a monoecious fiber-rich Polish variety, and Fedora 19, a French monoecious–dioecious early-maturing hybrid, respectively. Lisson and Mendham [5], Di Bari et al. [6], and Cosentino et al. [27] showed that deficit irrigation practices can be recommended in hemp production regardless of the purpose of use. Sometimes, full irrigation treatment is not the best option. Concerning fiber quality in terms of its chemical composition, growing conditions resulting in lower lignin and higher cellulose contents, properties desired for hemp fiber intended for textile processing, should be chosen.

In both years, all studied yield elements as well as plants height, had statistically significant higher values for the non-topped variant as compared to the topped one

(Table 3), but differences in fiber quality in terms of their chemical compositions were not found (Table 4). Leonte et al. [22] reported that topping hemp plants reduces their height, which facilitates mechanized harvesting, but fiber yield and quality remain unchanged as compared to production without topping. The results obtained in our research clearly indicate that the topping of plants is not recommended when the hemp is produced for fibers because it significantly decreases the yield with no effect on the quality of fibers.

The possibility of growing hemp in conditions of different densities speaks of its plasticity and the possibility of adapting to the needs of production, i.e., the method of use. Hemp plants cultivated for fibers are planted closely together to promote stalk elongation while reducing branching, which provides higher and better fiber yields [18]. However, different varieties in different regions vary in their optimal planting densities [17]. In the study years, statistically significant differences in the fiber yield and quality between RS_1 and RS_2 were not found (Tables 3 and 4). The obtained results are in agreement with the report of Amaducci et al. [38] in that the pure fiber content of the whole stem was not significantly influenced by plant density as fiber yield slightly increased with plant population. By summarizing the results of long-term field trials carried out in France, Legros et al. [39] reported that the highest fiber yield is obtained from late cultivars that have long vegetative growth with a seeding density of 150–200 plants m^{-2} at emergence. Westerhuis et al. [40] concluded that fiber yield was higher at a higher sowing density only at the early harvesting time. Lisson and Mendham [5] and Amaducci et al. [41] found the best results for fiber hemp yield with a plant density of 120 per m^{-2} in Northwest Tasmania, Australia and in Bologna, Italy. Cosentino et al. [27] suggested the row distance of 0.20 m and 240 plants m^{-2} for fiber hemp production in the Mediterranean climate. According to the findings of Amaducci et al. [42], growing hemp for long bast fibers of 180 plants m^{-2} should be chosen instead of 270 plants m^{-2} to decrease seed cost, which seems to be most acceptable for the climate and soil conditions in the Vojvodina region. The results of Struik et al. [43] suggested that only extremely high plant densities or densities below the lowest target could affect aboveground yields, but in general, the effects of plant density on aboveground and stem dry matter yields are small and statistically insignificant, which contributes to resolving this issue.

Literature recommendations for the water requirements of hemp are often ambiguous. Therefore, any estimation of hemp water requirements should be accompanied by a description of the associated growing conditions. This includes the growing variety, soil type, applied agronomic practices, environmental factors, and the applied irrigation system as well as the way of determination (field plots, lysimeters, calculation using ET_o or E_o, and K_c). The water amounts used for fiber hemp evapotranspiration in irrigation conditions (ET_m) were 456 mm/520 mm (I_1), 384 mm/438 mm (I_2), 312 mm/332 (I_3), and 312/332 mm for the nonirrigated control variant (ET_a) in 2018 and 2019, respectively (Table 5, Table 6). In the first year of the study, statistically significant differences in all the examined yield parameters were determined in variants I_2, I_3, and I_o in relation to variant I_1, whereas there were no differences between I_2, I_3, and I_o (Table 3). In the second year, all the studied parameters were significantly higher for I_1 as compared to variants I_2, I_3, and I_o, which suggests that the values of water used for evapotranspiration in the interval 312–520 mm (Tables 5 and 6) should be accepted as the real water consumption of hemp in the examined years. The results obtained for hemp evapotranspiration in our experiment are in accordance with those published by Kišgeci [44], who reported that during the growing period in the Vojvodina region, fiber hemp needs 250–350 mm of rainfall. Pejić et al. [9] recorded the ETm of fiber hemp for 470 mm at the same location just a year earlier and pointed out that the growing season of fiber hemp in 2017 was warmer by 1.7 °C; there was only 99 mm of rain, and 320 mm of water was added by irrigation. The above discussion confirms that water used for plants' evapotranspiration is affected by many factors, first of all, by environmental conditions. Very similar results for fiber hemp evapotranspiration were reported by Di Bari et al. [6] for the environment of the Mediterranean climate in Italy for the same length of the growing season. The authors determined an ET_m in the range of 410–460 mm. They specifically stressed that the maximum ET_m can be obtained in the optimal water regime in the years characterized by high temperatures and low rainfalls. Furthermore, they noted that with a reduction in the irrigation water applied, the levels of seasonal ET_m tended to be proportionally lower. In the same environment, Cosentino et al. [27] reported that dioecious late genotypes of fiber hemp need 450 mm of water.

The highest water consumption for evapotranspiration recorded in the period from the appearance of male flowers to the end of the season (Tables 5 and 6) indicates that this is the most sensitive part of hemp vegetation regarding water deficits. Merfield [45] also reported that hemp water demand is concentrated during the rapid growth phase. Maximum ET_d values of 6.8–8.5 mm and 5.7–9.5 mm were detected on 11 August and 1 August in the first and second years of the study, respectively (Figures 4 and 5), and are in accordance with the results obtained by Di Bari et al. [6], who reported maximum ET_d values of 6 mm in the environment of the Mediterranean climate, and Pejić et al. [9], who recorded an ET_d of 7.5 mm for hemp grown at the same location as studied in the current investigation.

The best methods to evaluate the effectiveness of irrigation are the coefficients of irrigation (IWUE) and evapotranspiration (ETWUE) water use efficiency. The IWUE provides a more realistic assessment of the irrigation effectiveness, while the ETWUE establishes whether the growing period is favorable for plant production or not. Pejic et al. [46] pointed out that special attention should be paid when comparing results since WUE's calculations may be different [30,31,47,48]. Pejic et al. [10] highlighted that in climatic conditions where irrigation is of a supplementary nature, the WUE calculation differs (the calculation also takes into account the yields and the evapotranspiration of the nonirrigated variant, Bos [30]) in relation to arid regions where crop production cannot be realized in conditions of the natural water supply to plants (values are calculated as the ratio of the yield and water added by irrigation or water used in plant evapotranspiration, Viets [31]). They also indicated that it should be known in which units the results are expressed (kg m^{-3}, t ha^{-1} mm, g L^{-1}). The results obtained under the given soil and climate conditions can be compared only in approximately the same temporal distance because the genetic potential of plant yields was smaller in the past, but also, growing practices have been significantly modified [49]. Furthermore, a few reports on hemp water use efficiency (WUE) are difficult or even impossible to compare due to the fact that different bases were used to calculate the WUE value of hemp (bark yield, [6]; dry biomass production, [27,50]; stem dry weight, [5]). In general, smaller amounts of water added by irrigation increased the value of the IWUE coefficient indicating that the deficit of RAW in the soil did not occur in any subperiod of vegetation of the cultivated plant species [47]. In 2018, the IWUE values (Equation (2)) were 0.67 kg m^{-3} and 2.0 kg m^{-3} for variants I_2 and I_3, respectively, but the values of 9.0 kg m^{-3}, 20.7 kg m^{-3}, and 22.0 kg m^{-3} were calculated for the variants I_1, I_2, and I_3 (Equation (3)), respectively (Table 7). The IWUE value for the I_1 variant could not be calculated (Equation (2)) since the bark yield was lower than that obtained for I_0 (Table 3). In 2019, the IWUE values were lower regardless of the calculation method (I_1 variant 1.18, I_2 variant 0.14, and I_3 variant 0.43 kg m^{-3}, Equation (2); I_1 variant 4.27, I_2 variant 5.0, and I_3 variant 5.29 kg m^{-3}, Equation (3)) because on the one hand, fiber yields were lower, and on the other hand, more water was added through irrigation compared to 2018.

In both years of the study, the highest ETWUE values of 2.12 kg m^{-3} and 1.11 kg m^{-3} (Table 7) were determined for irrigation variant I_3 (Table 7). The value of plant evapotranspiration for the I_3 variant was identical to the irrigated (ET_m) and nonirrigated (ET_a) variants as both years of study were favorable for the production of hemp in the region, primarily in relation to the amount and distribution of precipitation. The calculated values of the water balance (Tables 5 and 6) clearly indicate that the seasonal precipitation in both years was sufficient to eliminate the water deficit in the soil, which had the effect of achieving high yields of hemp fiber even in the variant without irrigation. This confirms the statement of Kišgeci [44], who reported that during the growing period in the Vojvodina region, fiber hemp needs 250–350 mm of rainfall. The obtained results for ETWUE are very similar to the results given by Di Bari et al. [6], who determined the values of 0.84 to 1.84 g L^{-1} (kg m^{-3}) for full and deficit irrigation in the climatic conditions of southern Italy.

Information on the reaction of hemp plants to water stress and irrigation could be obtained using the yield response factor (K_y). K_y may be affected by factors other than the lack of water in the soil (soil properties, climate, length of growing season, inappropriate growing technology). The K_y values of 0.22 and 0.60 (Table 7) in 2018 and 2019, respectively, for the total crop season reveal that hemp for fiber production could be grown without irrigation in the temperate climate of Vojvodina region. This approach is not fully acceptable bearing in mind the supplementary characteristic of irrigation in the region, which is clearly confirmed by the hot and dry 2017 year when 320 mm of water was added to the hemp by irrigation [9]. The abovementioned information is in accordance with the observations of Cakir [51], who reported that the K_y values of a given crop varied from year to year even at the same location

5. Conclusions

Based on the obtained results on the effects of different irrigation schedule programs by using evaporation from the free water surface and the related crop plant coefficient on the fiber yield and quality parameters, it can be concluded that in the first year, irrigation did not significantly affect either the yield or the quality of fiber hemp. However, in the second year, the yield of the fiber hemp was statistically higher for the I_1 irrigation variant compared to the I_2, I_3, and I_o variants. The topping of plants is not recommended when the hemp is cultivated for fibers, since it significantly decreases the yield with no effect on the fiber quality. In addition, interrow spacing does not have a statistically significant effect on hemp fiber yield. The rate of hemp evapotranspiration is in an interval from 312 mm (ET_a) to 520 mm (ET_m). The highest values of IWUE and ETWUE in both years and bark yield in the first year detected for the I_3 irrigation variant indicated that the crop plant coefficient (K_c) of 0.6 could be recommended for the correction of E_o values when calculating the daily hemp evapotranspiration (ET_d) from June to August. The results for K_y with a value of 0.22 and 0.60 indicate that irrigation in the Vojvodina region has a supplementary characteristic; in some years, irrigation is not necessary for hemp production. However, such years are rare. Definitely, in order to obtain high yields and a good quality, the irrigation of fiber hemp is recommended in the mentioned region.

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