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Water consumption of industrial hemp (Cannabis sativa L.) from a site in northern Kazakhstan

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ABSTRACT

Purpose: This study investigated the water consumption (crop evapotranspiration) of industrial hemp on a newly established hemp field in Aqmola Region of Northern Kazakhstan. Methodology: The water consumption of hemp was investigated through direct measurements of the sapflow movement during the second half of the growing season 2021. These sapflow data yielded data on the water consumption. The water consumption of the first part of the growing season was assessed through the Penman-Monteith approach by FAO. Findings: The water consumption of hemp was 353 mm over the growing season at a stem yield of 10 t/ha. Under the water supply conditions of the study site, hemp offers higher yields than grasslands or grains. Originality/value: This is the first study that revealed data on water consumption of hemp for the region Central Asia as a potential raw material plant for bioeconomy.

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1. Introduction

Central Asia, located between the Caspian Sea in the west and Mongolia and northwest China in the east, is dominated by drylands (CACILM and ADB, 2010; Reyer et al., 2017). While agriculture in the southern part of the region depends on irrigation, such as in the Amu Darya and Syr Darya River basins, the northern part of Kazakhstan is dominated by rainfed agriculture with risks of crop failure due to inter annual fluctuations of precipitation. Climate change increases this risk of crop failure, because more and prolonged heat waves are foreseen for Central Asia (Reyer et al., 2017).

Against this background agricultural systems across Central Asia have to become more resilient against heat waves and periods of water scarcity (Thevs et al., 2019). Hemp (*Cannabis sativa*) has been investigated and promoted as a crop which attains marketable harvest under water limited conditions, e.g. less than 300 mm rainfall during the growing season, as shown by Struik et al. (2000). Lisson and Mendham (1998) measured stem yields of 10 t/ha and total biomass dry matter yields of 12 t/ha under rainfed conditions with rainfalls below 300 mm, which increased to a stem yield of 13.8 t/ha and a total biomass yield of 15.5 t/ha under additional irrigation of 120 mm over the growing season. Such yields are considerably higher than the productivity of grasslands (Eisfelder et al., 2014) and higher than grain yields (Kusainova et al., 2020) in Northern Kazakhstan.

At the same time, hemp is a multi-purpose crops, which delivers biomass as a raw material to a variety of different value chains, such as fibers and textiles, house construction, chemicals, or food applications (Amaducci and Gusovius, 2010; Moscariello et al., 2021). In particular, hemp as a fiber crop has the potential to deliver fibers to the textile industry, which has a long tradition in Central Asia. Globally, there is an increasing demand for biomass as a raw material for the bio-economy in the course of abandoning fossil raw materials. Hemp biomass can help to address this demand and provide new opportunities for rural regions (Ingrao et al., 2018).

The KazHemp Project (funded by the Ministry of Education and Research of Germany from 2019 till 2022) investigated to use hemp as a fiber crop on water stressed sites in Kazakhstan. As part of that project, this study aimed at investigating the water consumption (crop evapotranspiration – ET_c) of industrial hemp.

2. Methods

The water consumption of hemp was investigated on a newly established hemp field located in Shchuchinsk (52°50′02.64″N, 70°21′24.52″E) in Aqmola Region in northern Kazakhstan, 243 km north of the city Nursultan, during the growing season 2021 (Table I).

Table I. Climate of Shchuchinsk and Kökshetau (Climate data, 2021)

Climate feature	Shchuchinsk	Kökshetau
January average temperature [°C]	-15.1	-14.7
July average temperature [°C]	18.4	19.3
Annual precipitation [mm]	471	455
January monthly precipitation [mm]	18	18
July monthly precipitation [mm]	88	85

The hemp variety Santina 70 was sown on 15 May 2021 with a density of 30-60 seeds per m^2. The soil was ploughed and harrowed before seeding. Before seeding, 100 kg of nitrogen fertilizer (Selitra) were applied per hectare.

The water consumption of hemp was investigated through direct measurements of the sapflow movement (12 Aug till 20 Sep) and the FAO approach after Allen et al. (1998) to calculate ET_o and ET_c for the time periods not covered by the sapflow measurements.

The sapflow measurement was done after the method by Granier et al (1985). This method uses pairs of sensor needles, that are inserted into the hydrocative tissue, which carries the water flow inside plant stems. The upper needle is heated for one minute followed by recoding the temperature difference between the two needles. This procedure was repeated every 10 min. The sapflow is calculated as follows:

In a first step, the dimensionless flow index k is calculated:

$$k = \frac{\Delta T_{max} - \Delta T}{\Delta T} \quad (1)$$

ΔT is the temperature difference between the two sensor needles. ΔT_{max} is the maximum temperature difference within a given time span, during which the daily course of ΔT is similar between days (usually no more than a week). ΔT_{max} was determined with the software Baseliner, which had been developed for this purpose by Oishi et al. (2016).

The k values are used to calculate the sap velocity v [ml/cm^2 min] after Clearwater et al. (1999) and Smith and Allen (1996):

$$v = 0.714\, k^{1.231} \tag{2}$$

Finally, the absolute sap flow F_s [ml/min] was calculated:

$$F_s = v \cdot A \tag{3}$$

with A [cm²] being the hydroactive sapwood area.

Six representative hemp plants (named E1, E2, E3, W1, W2, and W3) were equipped with pairs of 10 mm long sensor needles on 12 Aug. The needle pairs were shielded with aluminum foil to avoid direct solar insolation onto the needles. The sensors E1-E3 and W1-W3 were connected to one data logger respectively and recorded data every 10 min. These loggers and needles were purchased from UP GmbH, Germany. These measurements were aggregated to daily data of water consumption per single plant and ET_c for the stand of hemp around the sapflow measurement. The plant density at that stand was 50 plants per m². Further explanations on the sapflow measurements and related calculations are given in Baier et al. (2021) and Strenge et al. (2018).

The FAO approach (Allen et al., 1998) takes daily climate data to calculate a so-called reference evapotranspiration (ET_o), which in fact is the evapotranspiration of a 12 cm high grass vegetation of 100% vegetation coverage, which is not water limited:

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T + 273}\, u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34 u_2)} \tag{4}$$

with ET_o - reference evapotranspiration [mm/d], R_n - net radiation [MJ/m² d], G - soil heat flux [MJ/m² d], T - air temperature at 2 m height [°C], u_2 - wind speed at 2 m height [m/s], e_s - saturation vapor pressure [kPa], e_a - actual vapor pressure [kPa], Δ - slope vapor pressure curve [kPa/°C], and γ - psychrometric constant [kPa/°C]

Daily climate data were only available for Kökshetau (Reliable prognosis, 2021), which has a similar climate as Shchuchinsk, as shown in Table I. In a second step, ET_o is converted into crop evapotranspiration (ET_c) by multiplying ET_o with crop and location specific crop coefficients (k_c):

$$ET_c = ET_o \cdot k_c \tag{5}$$

The k_c values differ within a given cropping season and are given for the following development stages of annual crops:

- Initial stage – from seeding until the vegetation coverage exceeds 10%
- Development stage – after initial stage until flowering
- Mid stage – from flowering till fruiting
- Late stage – from fruiting till harvest

Detailed explanations on those calculations are available from Allen et al. (1998) and from Thevs et al. (2019) for examples from Central Asia.

ET_o was calculated for the whole growing season 2021 based on daily data for air temperature, air humidity, and wind speed from the station Kökshetau (Reliable prognosis, 2021). Data for radiation were calculated as extra-terrestrial radiation multiplied with a transmissivity of 0.6 (Thevs et al., 2019). The sapflow measurements and the resulting data of ET_c and corresponding ET_o allowed to calculate a crop coefficient for hemp, which was used to adjust existing crop coefficients for hemp (Garcia-Tejero et al., 2014) to the conditions in Shchuchinsk. These adjusted K_c values were then used to convert ET_o into hemp's ET_c for the time periods not covered by the sapflow measurements.

3. Results

The hemp plants on which sapflow was measured attained an average stem height of 209 cm and an average stem diameter of 13 mm (Table II). This corresponds to an accumulated stem area of 6637 mm^2/m^2. The stem yield averaged over the hemp field was 10 t/ha, which corresponded to an average stem height of 156 cm, which is significantly lower than the average stem height of the plants on which sapflow was measured.

Table II. Diameter and plant heights of hemp plants with sapflow sensors

Plant number	Height [cm]	Stem diameter in 10 cm height basis [mm]
E1	205	12
E2	204	12
E3	206	12
W1	235	12.5
W2	212	15
W3	189	14
Average	209	13

The daily water consumption of the six individual hemp plants ran mostly concordantly (Figure 1), in particular the peak water consumption on DOY 247 and the low water consumption on DOY 250-251 are shared by all six plants. The former is associated with a fairly high daily average temperature of 21.5°C and wind speed of 7.8 m/s, while the latter is associated with rains during those two days and low wind speed of 2.6 m/s. The plant W2 showed the highest water consumption almost throughout the whole measurement period. That plant had an average height, but the largest diameter. E3 had the lowest water consumption during the measurement period. E3 had the smallest diameter, but had an average height. Though the plant E1 and E2, which have similar heights and diameters as E3, they consumed more water than E3 throughout the measurement period.

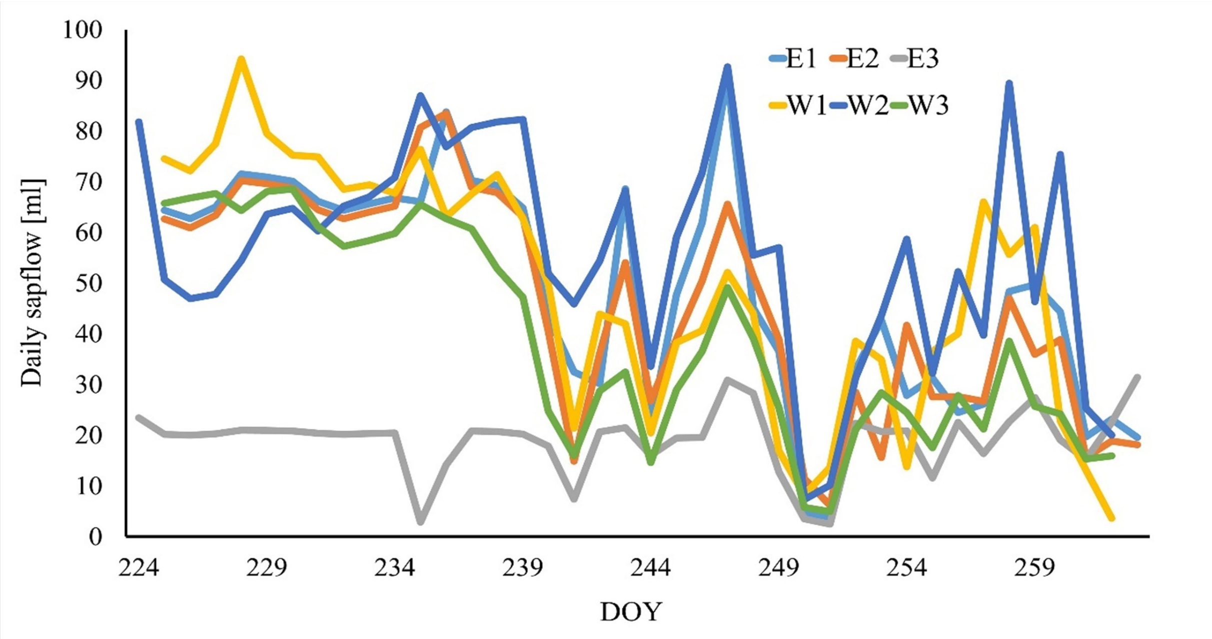

Figure 1. Daily water consumption (sapflow measurement) [mi/d] of the six single hemp plants as measured from DOY 224 till DOY 263 (12-Aug till 20-Sep).

The daily ETo for the whole growing season 2021 is plotted in Figure 2, while the daily average temperature, air humidity, wind speed, and ET_o are listed aggregated by month in Table III. The two ET_o maxima, DOY 146 with an ET_o of 13 mm/d and DOY 184 with an ET_o of 12 mm/d, fell on days with air temperatures of 31°C and 31.5°C, respectively, which is well above monthly averages from Table II and corresponds with below average air humidity values. Wind speed during those two days (7.5 m/s and 6.8 m/s, respectively) was above monthly average as well. The low ET_o on DOY 195 corresponded to a low air temperature of 10.5°C and an air humidity close to 100%.

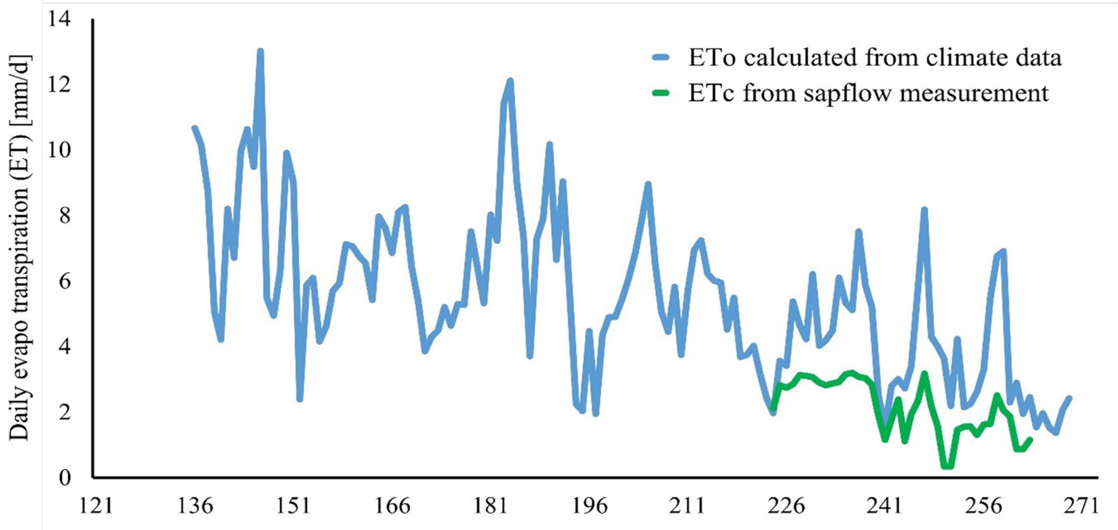

Figure 2. ETo calculated from climate data over the growing season 2021 from DOY 136 (16-May) till DOY 269 (26-Sep) and ETc from sapflow data from DOY 224 (12-Aug) till DOY 263 (20-Sep). The x-axis stretches from 1-May till 30-Sep.

Table III. Daily average climate data and ET_o for the months May through September 2021 at the station Kökshetau

Month	Temperature [°C]	Air humidity [%]	Wind speed [m/s]	ET_o
May	18.8	43	5.8	7
June	18.3	50	5.1	6
July	21.2	57	5.5	6.3
August	19.3	67	4.5	4.5
September	9.9	64	6.4	3.1

The measured ET_c, based on the sapflow measurements (Figure 1), ran concordantly to ET_o, which stemmed from the climate data.

The k_c values for the mid stage and the late stage were taken from trendlines as shown in Figure 3. Thereby, the k_c value at the beginning of the sapflow measurement period (DOY 224) was taken as k_c for the mid stage, while the further k_c values until DOY 263 were taken as daily k_c values for the late stage. The monthly averages of times of seeding, harvest, and the crop developments stages with their respective k_c values are listed in Table IV.

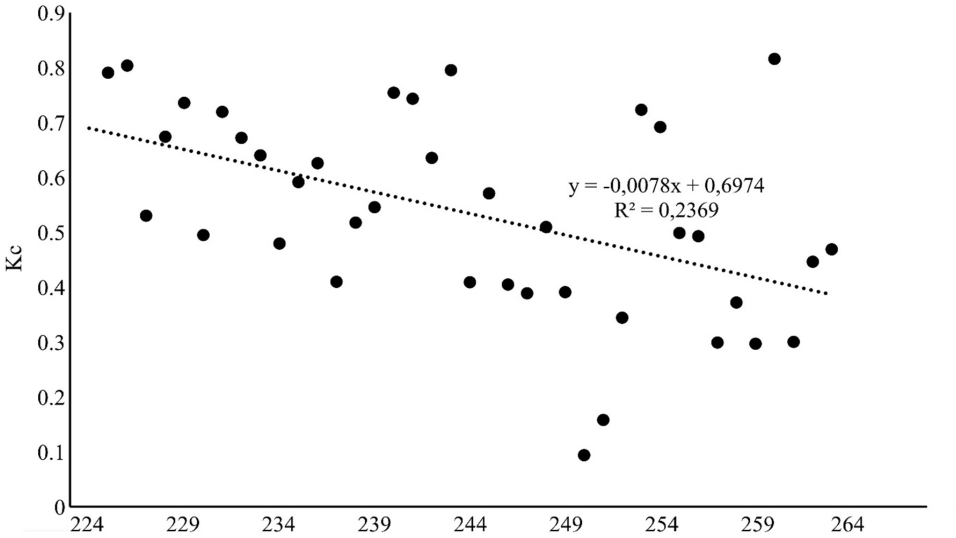

Figure 3. k_c values calculated from the measured water consumption and ETo during the sapflow measurement time period. This time period covers the late stage and expresses the k_c of the mid stage.

Table IV. Crop development stages and respective k_c values

Time (DOY in brackets)	Hemp crop development stage	k_c
16-May (136)	Seeding	
16-May till 15-Jun (136-166)	Initial stage	0.3
16-Jun till 16-Jul (167-197)	Development stage	Daily linear increase from 0.3 to 0.7
17-Jul till 11-Aug (198-223)	Mid stage	0.7
12-Aug till 26-Sep (224-269)	Late stage	Daily linear decrease from 0.7 to 0.38
26-Sep (269)	Harvest	

The total water consumption of hemp for the growing season 2021 summed up to 353 mm (Table V), with monthly water consumptions being below monthly average precipitation in July and August.

Table V. Water consumption (ET_c) of hemp [mm] per month

Month	Average daily ET_c	Minimum daily ET_c	Maximum daily ET_c	Total ET_c in given month	Monthly average precipitation
May	2.5	1.3	3.9	40	43
June	2.1	0.7	4	63	61
July	4	1.4	6.4	125	88

Table V *(continued)*.

Month	Average daily ET_c	Minimum daily ET_c	Maximum daily ET_c	Total ET_c in given month	Monthly average precipitation
August	2.9	1.2	5.1	91	63
September	1.8	0.4	3.2	36	38
Total	2.6	0.4	6.4	353	

4. Discussion

The sapflow measurement method after Granier (1985), which was employed in this study, has the limitation that individual plants with a diameter of less than 1 cm cannot be measured. Therefore, this measurement only was applicable for the later development stages of the hemp plants. A literature review (Flo et al., 2019) on sapflow calibration studies revealed that sapflow measurements as used here underestimated sapflow by 40 %. In conclusion, this literature review suggests that the results of this study may underestimate real sapflow.

Lisson and Mendham (1998) reported a water consumption of hemp of 359 mm, which is very close to the results of this study, and a stem yield of 10 t/ha from a field trial in NW Tasmania under rainfed conditions with rainfalls of below 300 mm during the growing season. Obviously, hemp was able to use soil moisture that had been accumulated through precipitation before the growing season. This is similar to this study, in which ET_c exceeded rainfall during July and August, so that hemp also made use of soil moisture from snow melt and rainfall before onset of this growing season. In Southern Italy, under a semi-arid climate, Consentino et al. (2013) found that hemp needed 250 mm to 450 mm water depending on hemp cultivar. Both studies published water consumptions and stem yield which were in the same range as the ET_c and stem yield of hemp in this study. As the sapflow hemp plants of this study were larger than the average hemp in Shchuchinsk, it can be concluded that the water consumption across the hemp field in Shchuchinsk is lower than the water consumption of the hemp plants which were equipped with the sapflow sensors. This would compensate for a potential under estimation of the real sapflow as suggested by Flo et al. (2019). As a final conclusion, the ET_c of 353 mm as a result of this study is considered the upper boundary of ET_c of hemp at the investigated site in Northern Kazakhstan for the year 2021.

Noghabi et al. (2021) measured the water consumption (ET_c) of hemp and ET_o of grass reference vegetation in lysimeters under conditions of sufficient water supply in Iran, which resulted in an ET_c of hemp of 689 mm over the growing season. The k_c values under those not water-limited conditions were 0.28, 0.68, 1.01, and

0.54 for the initial, development, mid, and late stage, respectively. The difference in ET_c is due to the sufficient water supply in this lysimeter trial, while hemp on the site in Shchuchinsk faced limited water supply. Also, the k_c values by Noghabi et al. (2021), in particular for the mid stage, were higher than the k_c values from this study (Table II), because hemp was able to transpire more water under the sufficient water supply than under the field conditions in Shchuchinsk.

Babaei and Ajdanian (2020) found that hemp can tolerate water deficit conditions of up to 50% of ET_o. The k_c of 0.7 (Table II), which was found for the mid stage in this study, indicates that the hemp in Shchuchinsk has not received sufficient water, but also has not reached its minimum water supply. With better water supply or during years with higher rainfall, higher yields than during the growing season 2021 can be expected.

The hemp stem yields found in this study are higher than grassland biomass productivities of 4.5 t/ha as reported by Eisfelder et al. (2014) and grain yields of 1-1.5 t/ha (Kusainova et al., 2020) both of northern Kazakhstan. Considering the use options of hemp, which are more diverse than from steppe grass biomass, hemp would offer opportunities as a raw material source for rural areas, despite the water supply limitations. As hemp can endure more water stress than the actual water supply during the growing season 2021, hemp will produce certain amounts of biomass even in years with lower rain fall, which makes it a crop that is resilient to rain fall fluctuations and heat waves.

5. Conclusion

The water consumption of industrial hemp from a field plot in Aqmola Region in Kazakhstan was investigated through sapflow measurements on a number of individual plants and calculation of the crop evapotranspiration after the Penman-Monteith Approach, which is based on weather data. The water consumption during the growing season 2021 (May to September) was 353 mm, which was more than the rainfall during those months. This allows for the conclusion that hemp is able to exploit soil moisture that has been accumulated ahead of the growing season through snow melt and groundwater. Therefore, hemp is considered a crop which is very suitable for conditions with prolonged summer draughts as they are common in the steppe region of Kazakhstan. In particular, in the course of necessary adaptation to climate change, which mainly is adaptation to stronger heat and draught, hemp has the potential to play its role as industrial crop with a wide range of applications.

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