

EFFECT OF DIFFERENTIATED NITROGEN NUTRITION ON ABOVEGROUND BIOMASS OF SELECTED CULTIVARS OF *CANNABIS SATIVA* L. CULTIVATED UNDER CENTRAL EUROPEAN CONDITIONS

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Hemp (*Cannabis sativa* L.) is one of the traditional crops currently being newly re-introduced in Slovakia and cultivated for multi-purpose uses, while still there is a lack of crop biomass yield data. The main objective of the paper is to document the yield of aboveground biomass of selected cultivars of hemp ('Bialobrzeskie', 'Felina', 'Santhica', 'Epsilon', and 'Futura'), which were tested in the pilot open-field experiments conducted during 2009–2012, immediately after a wave of legislative changes. The trial was agronomically designed including three nitrogen treatments as follows: (i) T1 30 kg N/ha (the full 30 kg/ha in the phenophase BBCH 31), (ii) T2 60 kg N/ha (dividing on 30+30 kg/ha in the phenophase BBCH 31 and 51, respectively), and (iii) T3 90 kg N/ha (dividing on 30+30+30 kg/ha in the phenophase BBCH 31, 51 and 59, respectively); whereas NPK 15-15-15 in the dose of 200 kg/ha was applied before the sowing all across the treatments. The total average dry matter (DM) yield of 9.49 t/ha was achieved, ranging from 2.12 to 16.80 t/ha. DM yield was affected mainly by years (F -ratio 337.40, P -value 0.0000), followed by nitrogen treatment (F -ratio 47.86, P -value 0.0001), then by cultivars (F -ratio 22.37, P -value 0.0019) and finally by replications (F -ratio 0.65, P -value 0.58). However, the need for further studies aimed to quantify more precisely the response of the cultivars to the weather and soil conditions is necessary, especially the cultivars of new and foreign origin.

Key words: hemp (*Cannabis sativa* L.), dry matter yield, nutrition, nitrogen fertilisation

Hemp (*Cannabis sativa* L.), which originated in Central Asia, is considered one of the oldest plants used by people for food, oil, textile fibres, and medicinal purposes. This crop has been used since ancient times, in the second half of the 20th century, however, it stopped being cultivated because of different reasons including competition from other plants to produce textiles such as cotton and synthetic fibres, due to high labour costs and the prohi-

bition of cultivation due to the abuse of hemp as a narcotic (Struik *et al.* 2000; Amaducci *et al.* 2015). Currently, a renewed interest in growing hemp for multi-purpose production is evident, and for the first time in 2015, it was grown on more than 20,000 ha in Europe as a dual-purpose crop for seed and fibre (Tang *et al.* 2017; 2022). Interest in the cultivation of field-sown technical hemp is constantly growing thanks to the acquisition of innovative biomaterials

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of old and introduced energy crops. Among the potential energy crops providing fibre and other components for the industry is *Cannabis sativa* L., while little information is available on yield and agrotechnical of cultivation (Tang *et al.* 2022).

Hemp is an ancient plant formerly grown in Slovakia, as it is historically well documented, and even a weedy hemp population is present in some regions of the country where the crop was cultivated (Tóth *et al.* 2015). These plants represent a crop with great economic and environmental value (Porvaz *et al.* 2011; Lančaričová *et al.* 2021). Hemp has a wide range of uses, which generates it as a multi-purpose plant that contains a low-narcotic compound known as tetrahydrocannabinol (THC), its stem contains cellulose of high quality, flowers contain valuable resins, while seeds are rich in nutritious oil and proteins. Hemp is a source of approximately 25,000 products, from fabrics to building materials, nutritious foods and cosmetics. Hemp contains highly innovative biomaterials that are applicable in several industries. Its cultivation is considered environmentally friendly and extremely sustainable (Crini *et al.* 2020). Since it is an undemanding plant to grow in terms of nutritional requirements and soil-climatic conditions (it does not require high doses of additional nutrients N, P, K, or minimal weed pressure), it is possible to achieve a high biomass yield with relatively low economic inputs (Struik *et al.* 2000; Van der Werf 2004; Schumacher *et al.* 2020).

The level of mineral nutrition and plant density per unit area are two important agronomic factors in hemp cultivation (Amaducci *et al.* 2015; Tang *et al.* 2017). Fertilisation is important for the yield and quality of hemp biomass and poses a risk of eutrophication of the environment when is overdone (Van der Werf 2004; Schumacher *et al.* 2020). Nitrogen (N), phosphorus (P), and potassium (K) have considerable influence on the yield of *Cannabis sativa* L. proved in Europe (Zheng *et al.* 2012; Aubin *et al.* 2015; Tang *et al.* 2017; Yang *et al.* 2019). On fertile soil, the effect of biomass output on nitrogen fertiliser was negligible (Prade *et al.* 2011). However, a statistically significant effect in the production of biomass was recorded on poorer soils at nitrogen doses of 60 kg/ha (Papastylianou *et al.* 2018). In general, increasing nitrogen fertilisation intensity positively affects hemp biomass yield, including

plant height and inflorescence indices. It follows that hemp responded well to the nitrogen fertiliser.

Van der Werf *et al.* (1995) found a negative effect on the bark content of hemp stems caused by N fertilisation. A negative side of nitrogen fertilisers is the risk of escape from the agroecosystem into groundwater (Kintl *et al.* 2018). However, only a few studies were devoted to the effect of phosphorus and potassium fertilisation on hemp production. Aubin *et al.* (2016), reported that P and K fertilisation in amounts up to 100 kg/ha and 200 kg/ha, respectively, had a very limited effect on hemp biomass yield in Canada. Other authors in Ireland (Finnan & Brendan 2016 a, b) did not find a significant effect of K fertilisation (up to 150 kg/ha) on hemp biomass yield. However, some other studies (Ivonyi 1997) showed that P and K fertilisation has a synergic effect with nitrogen fertilisation when applied together.

Planting density in relation to the cost of seeds, has also a large effect on plant morphology and stem bark content. Higher densities of plants generally develop more slender stems than at lower densities (Tang *et al.* 2017). Slender stems are needed for fibre production, due to their high bark content (Van der Werf *et al.* 1995). Therefore, higher planting densities (100–300 plants/m²) were recommended to harvest slender stems (Van der Werf *et al.* 1995; Tang *et al.* 2017; Ma *et al.* 2021).

Despite the more than ten-year period that has passed since the wave of legislative changes which led to hemp re-development and emphasized cultivation while dealing not only with Central European countries (Porvaz *et al.* 2011; Tóth *et al.* 2015), there is still a lack of the crop above-ground biomass yield data, eventually, scientific studies based on the hemp cultivation under the conditions of Slovakia. However, the yield and quality of the seeds are better documented (Lančaričová *et al.* 2021). Therefore, the paper aims to document the yield of aboveground biomass of selected hemp cultivars, which were tested in pilot technological experiments conducted under open-field conditions immediately after the wave of legislative changes. The trials were agronomically designed, while the effect of differentiated nitrogen nutrition on the hemp dry matter yield was verified.

MATERIAL AND METHODS

Five cultivars of hemp (*Cannabis sativa* L.), namely 'Bialobrzieskie', 'Felina', 'Santhica', 'Epsilon', and 'Futura', were tested from 2009 to 2012 in the experimental workplace of NPPC-Research Institute of Plant Production, Institute of Agroecology located in Milhostov nearby Trebišov on Eastern Slovakian Lowland. The site is typical of the heavy Gleyic fluvisol as well as the moderate continental climate of Central Europe, while no irrigation was used in the hemp trials. The selected soil chemical properties are presented in Table 1, weather conditions in Figure 1. The main characteristics of weather conditions were obtained from the official SHMU network observation station the nearest to the trial site, which is located exactly at a distance of 1 km from the experiment. A closer description of the site can be found in related works (Šoltysová 2013; Tóth *et al.* 2013).

The pilot experiment was conducted as an open-field poly-factorial small-plot trial (Figure 2), where 60 plots (size of plots was 10.00 m × 1.20 m, the total net area of the trial was 720 m² consisting of 5 cultivars × 3 treatments × 4 replications) were arranged in randomized block design, while yearly established from 2009 to 2012. All the cultivars were sown at a sowing rate of 0.4 million germinating seeds per hectare. A closer description of used

agronomy can be found in a related paper (Porvaz *et al.* 2011).

Besides the five cultivars of the crop as the first key factor, the second factor tested was nutrition, which included three N treatments (Table 2). Nitrogen was used in NPK 15-15-15 dose of 200 kg/ha (30 kg N/ha), applied before the sowing. Divided doses during the vegetation were applied in ammonium nitrate: (i) T1 treatment – 30 kg N/ha (the full 30 kg/ha in the phenophase BBCH 31), (ii) T2 treatment – 60 kg N/ha (dividing by 30+30 kg/ha in the phenophase BBCH 31 and 51, respectively), and (iii) T3 treatment – 90 kg N/ha (dividing on 30+30+30 kg/ha in the phenophase BBCH 31, 51 and 59, respectively). The control treatment in this study was considered the lowest nutrition level, T1 treatment. The third factor considered was the year of trial evaluation.

During all trial years, we did not register the occurrence of any diseases (fungal, bacterial, or virus origin) or pests (higher animal or insect origin), most probably due to the pilot cultivation of the crop (Il'ková & Sutoova 2022). During the trial period, the production parameters of the formation of aboveground biomass were evaluated with the calculation of dry matter yields of hemp cultivars. Multi-factorial analysis of variance (MANOVA) with subsequent *post-hoc* Fisher's least significant difference (*LSD*) test were performed to evaluate the obtained results using Statgraphics 15.2.14.

Table 1

The average content of nutrients in the soil (0–30 cm), the initial status in the spring of 2009–2012

Year	Nt [%]	P [mg/kg]	K [mg/kg]	Ca [mg/kg]	Mg [mg/kg]	pH/KCl	C-ox [%]	Humus [%]	C/N, No.
2009	0.157	68.7 suitable	276.4 middle	4710.7 middle	346.4 middle	6.29 neutral	1.570	2.705 middle	10.00 * low
2010	0.163	66.2 suitable	276.9 suitable	4622.7 middle	352.0 middle	6.19 neutral	1.622	2.796 middle	9.95 * low
2011	0.163	70.4 suitable	266.4 middle	4675.3 middle	363.0 middle	6.15 neutral	1.589	2.738 low	9.75 * low
2012	0.170	71.9 suitable	271.1 middle	4540.6 middle	360.7 middle	6.10 neutral	1.624	2.798 low	9.55 * low

* low – low total nitrogen content concerning carbon content (calculated using the Sotakova method) and values/categories determined according to the Mehlich 3 method (P, K, Ca, and Mg), Kjeldahl method (Nt), Tjuri's method (C-ox, Humus), and potentiometric method (pH/KCl).

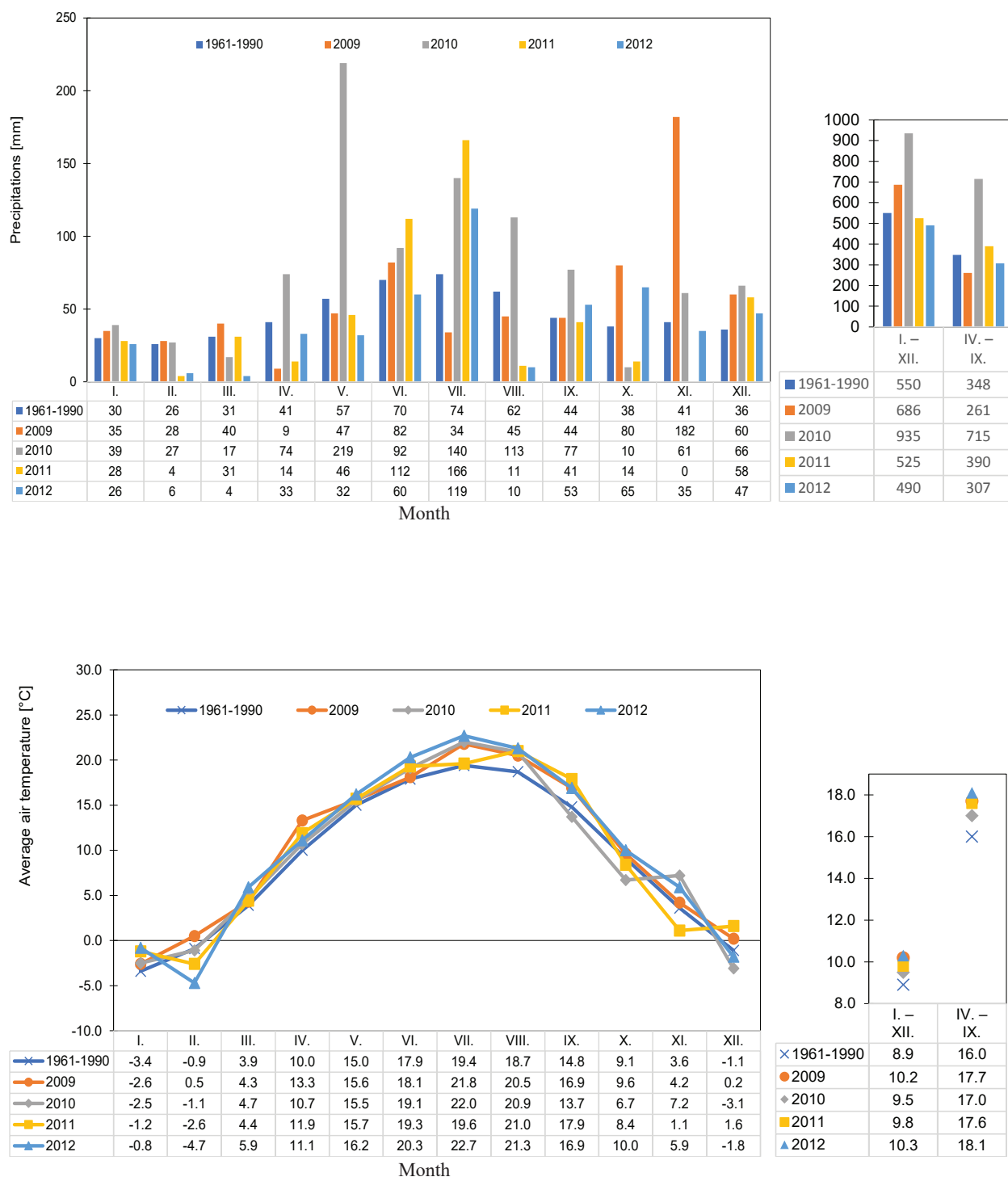


Figure 1. Precipitations and average air temperature of the field trial according to months from 2009 to 2012. The period 1961 – 1990 represents the long-term normal by Mikulová *et al.* 2008.

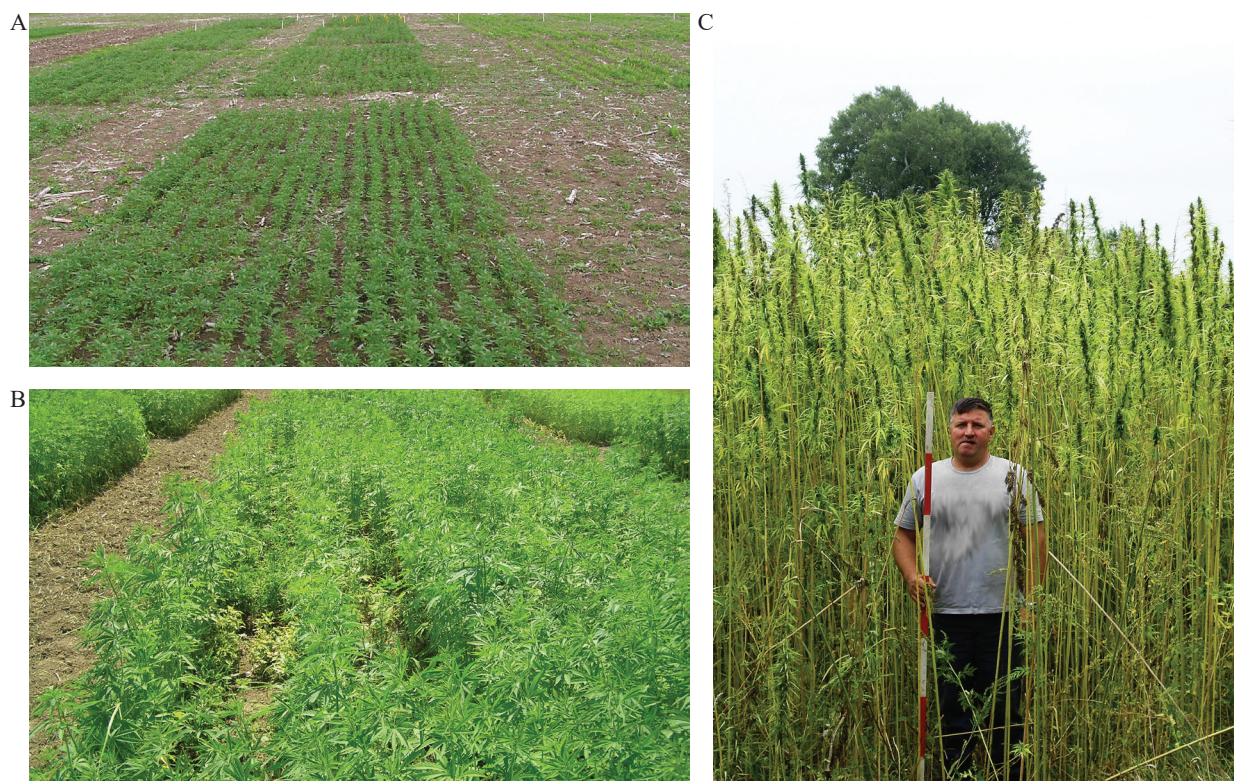


Figure 2. Pilot trial with the cultivation of hemp (*Cannabis sativa* L.) conducted on heavy Gleyic fluvisol, experimental working place of NPPC-Research Institute of Plant Production, Institute of Agroecology located in Milhostov, 2012: A – April, B – May, C – August, photo Š. Tóth.

T a b l e 2

The dosage of mineral nutrients NPK (kg/ha, PK in oxide form) according to the treatments

Treatment	N	P	K	Σ NPK
Pre-sowing treatment				
T1	30	30	30	90.0
T2	30	30	30	90.0
T3	30	30	30	90.0
Treatment during the vegetation period				
T1	30.0	0.0	0.0	30.0
T2	60.0	0.0	0.0	60.0
T3	90.0	0.0	0.0	90.0

RESULTS AND DISCUSSION

The highest average dry matter (DM) yield of hemp aboveground biomass from all four years of cultivation was recorded for the cultivar 'Bialobrzieskie' 10.99 t/ha, the second was the cultivar 'Futura' 10.22 t/ha, followed by 'Felina' 9.45 t/ha, 'Epsilon' 8.43 t/ha, and 'Santhica' 8.35 t/ha, while the

total average DM yield of 9.49 t/ha was achieved (Table 3). The highest statistically significant difference in DM yield was achieved by the 'Bialobrzieskie' cultivar compared to the 'Epsilon' and 'Santhica' cultivars (Table 4). Despite the achieved order of the cultivars (by DM yield), the most frequented cultivar in Slovakia due to the cultivation of content substances is the 'Futura' cultivar, followed by

'Bialobrzeskie' and 'Santhica' cultivars (Porvaz *et al.* 2011). Compared to the tested cultivars by years and treatments, the 'Bialobrzeskie' cultivar achieved the highest DM yield of 16.80 t/ha (2011, T3 treatment), while the lowest DM yield of 2.12 t/ha was found at 'Santhica' (2009, T1 treatment).

The introduction of cultivars into suitable growing areas is one of the most important criteria of regionalization, considering the various require-

ments of cultivars for the soil and climatic conditions. Regionalization of hemp cultivars sown in different growing areas is a guarantee of achieving optimal production of aboveground biomass and seeds. The universal cultivar grown in Slovakia in the past was the cultivar from the Polish province of Bialobrzeskie (Porvaz *et al.* 2011). Currently, the list of cultivars is very extensive, and the cultivation amplitude of *Cannabis sativa* L. is also very wide.

T a b l e 3

Dry matter yields [t/ha] of tested *Cannabis sativa* L. cultivars, according to the treatments and years with standard deviation (SD)

Cultivar	Treatment	Years								Average	
		2009		2010		2011		2012		DM	SD
		DM	SD	DM	SD	DM	SD	DM	SD		
Bialobrzeskie	T1	4.67	0.1191	10.80	0.1885	14.45	0.3684	9.13	0.1593	9.76	3.5211
	T2	5.23	0.0572	12.30	0.1923	15.28	0.1670	10.53	0.1837	10.84	3.6577
	T3	5.87	0.0918	13.65	0.2382	16.80	0.2627	13.18	0.2061	12.38	4.0108
	Average	5.26	0.4990	12.25	1.1824	15.51	1.0121	10.95	1.6895	10.99	3.8864
Futura	T1	2.90	0.0506	14.89	0.2328	11.70	0.1829	7.13	0.1244	9.16	4.5469
	T2	2.93	0.0747	15.60	0.2722	11.26	0.1965	10.89	0.2776	10.17	4.5772
	T3	4.21	0.0460	16.50	0.1804	12.45	0.1947	12.23	0.1337	11.35	4.4603
	Average	3.35	0.6134	15.66	0.6983	11.80	0.5273	10.08	2.1673	10.22	4.6162
Santhica	T1	2.12	0.0331	12.16	0.1901	10.13	0.1107	4.57	0.0797	7.25	4.0607
	T2	2.29	0.0400	13.38	0.2335	12.00	0.1876	4.57	0.1165	8.06	4.7277
	T3	3.98	0.0695	15.66	0.3993	12.76	0.1995	6.60	0.0721	9.75	4.6747
	Average	2.80	0.8411	13.73	1.4790	11.63	1.1182	5.25	0.9613	8.35	4.6173
Felina	T1	3.87	0.0605	12.36	0.1933	8.23	0.0900	8.13	0.0889	8.15	3.0044
	T2	8.89	0.0679	12.95	0.2260	8.74	0.1367	11.37	0.1778	9.24	3.4380
	T3	4.62	0.0806	15.57	0.3970	10.40	0.1815	13.22	0.2307	10.95	4.0963
	Average	4.13	0.3559	13.63	1.4242	9.12	0.9371	10.91	2.1110	9.45	3.7249
Epsilon	T1	4.52	0.0707	9.81	0.1072	7.66	0.1337	6.37	0.0696	7.09	1.9291
	T2	4.95	0.0864	10.50	0.1642	9.79	0.1531	8.16	0.1276	8.35	2.1428
	T3	5.62	0.1433	12.84	0.2241	10.32	0.1801	10.59	0.1848	9.84	2.6334
	Average	5.03	0.4646	11.05	1.3080	9.26	1.1602	8.37	1.7347	8.43	2.5196
Average	T1	3.62	0.9767	12.00	1.7273	10.43	2.4732	7.07	1.5602	8.28	3.6818
	T2	3.86	1.1330	12.95	1.6659	11.41	2.2470	9.10	2.5290	9.33	3.9660
	T3	4.86	0.7609	14.84	1.4024	12.55	2.3632	11.16	2.4795	10.85	4.1559
	Average	4.11	1.1085	13.26	1.9925	11.46	2.5156	9.11	2.7913	9.49	4.0786

DM – dry matter

In recent years, the 'Futura' cultivar has been grown more and more in larger areas in Slovakia, which in our experiment achieved the second highest DM yield on average in the monitored years (Porvaz *et al.* 2011; Lančaričová *et al.* 2021). Cultivar 'Futura' contains a high amount of essential oil and Lorenzo *et al.* (2010) found that essential oils from industrial hemp have a strong antimicrobial effect. It can be supposed that essential oils from industrial hemp, especially from the cultivar 'Futura', may have riveting applications.

The mean factors (the years, levels of nitrogen treatment, and cultivars) were evaluated by the statistical method of MANOVA (Table 4). Repetitions as an additional factor to detect statistical differences were not significant ($P > 0.05$, authentic data not shown), indicating the homogeneity of testing as well as an excellent quality of the experiment. The years had the most significant effect on the DM yield

of the crop, even though cultivars of different origin and differentiated levels of nutrition were included. The second factor, which had a less statistically notable effect on the DM yields was the nutrition treatments. Finally, the cultivars had a third place within the statistical impact order.

According to the MANOVA, the years were shown to be the main determining factor that influenced the amount of aboveground DM production in the monitored period 2009–2012. The year 2010 (13.26 t/ha) proved to be a highly pronounced year of cultivation, depending on the cultivars, compared to the years of cultivation in 2009, 2010, and 2012 (Table 3). The average sum of annual precipitation within the monitored period 2009–2012 was at the level of 120% – 659 mm compared to the long-term normal, and the average precipitation of the growing seasons for the observed period was also higher than

T a b l e 4

Parameters of statistical analyses of variance for data of hemp dry matter yields

IO	Factor	Sum of squares	df	F-ratio	P-value	Homogenous groups		LS Mean	LS Sigma
1.	Years	2833.25	3	337.4	0.0000	d	2009	4.11	0.2159
						a	2010	13.26	0.2159
						b	2011	11.46	0.2159
						c	2012	9.11	0.2159
2.	Nutrition treatments	267.89	2	47.86	0.0001	c	T1	8.28	0.1870
						b	T2	9.33	0.1870
						a	T3	10.85	0.1870
3.	Cultivars	250.47	4	22.37	0.0019	d	'Epsilon'	8.42	0.2415
						d	'Santhica'	8.35	0.2415
						c	'Felina'	9.44	0.2415
						a	'Bialobrzeskie'	10.99	0.2415
						b	'Futura'	10.22	0.2415
4.	Replications	5.44	3	0.65	0.5800	a	I.	9.64	0.2159
						a	II.	9.35	0.2159
						a	III.	9.63	0.2159
						a	IV.	9.33	0.2159
	Residual	928.49*	227	–	–	–	–	–	–
	Total	4944.73	239	–	–	–	–	–	–

IO – impact order, an order according to F – ratio; df – degree of freedom; * – mean square (for residual); P -value – significant levels; LS Mean – data of mean values; LS Sigma – least significant difference; a–d – homogenous groups.

the long-term normal, 120% – 418.25 mm (Figure 1).

The increasing precipitations proportionally increased the production of aboveground biomass during the observed period. The year 2009 was favourable from the point of view of the annual total precipitation, but unsatisfactory for the growing season. In 2009 the highest DM yield was achieved by the Bialobrzieskie under treatment T3 – 5.87 t/ha, the most productive cultivar under the most intensive nitrogen treatment was able to respond best to the precipitation deficit in April and May 2009. The annual sum of precipitations in 2009 achieved 125% of the long-term values, but the total for the growing season was at a level of almost 75%. The difference in the crop production between the years 2009 and 2010, 2011 and 2012 lies in the late date of sowing (May 13, 2009), which resulted in a high deficit of precipitation and high average temperatures in May during the period of establishment and involvement in the growth. As a result of these weather conditions, the field development of stands of the cultivars differed in the interval at the level of 50–60% of plants/ha.

The year 2010 was above average in terms of precipitation compared to the long-term normal for the annual period of 170% and the growing season of 205%. The amount of precipitation in June and July was above normal, which was also reflected in the aboveground biomass yields of the 'Futura' T3 treatment – 16.50 t/ha and 'Santhica' T3 treatment – 15.66 t/ha cultivars.

The year 2011 was at the annual level of 95% in terms of precipitation and 112% in terms of vegetation period compared to the long-term normal. Nutrition treatment T3 – 16.80 t/ha of aboveground DM in the 'Bialobrzieskie' cultivar, which is the highest biomass yield for the entire investigated period, whereas the harvest interval of the achieved production of DM was in the range of 14.45–16.80 t/ha (Table 3). The year 2012 was also the most favourable for the 'Bialobrzieskie' cultivar, but the 'Felina' cultivar achieved a slightly higher production of DM on T2 (11.37 t/ha) and T3 treatment (13.22 t/ha), despite the year 2012 showed a deficit of annual precipitation at the level of 89% of the long-term normal and 88% at the level of the vegetation period.

The average annual temperature for the monitored period 2009–2012 was higher at the level of

112%–9.95°C compared to the long-term normal (8.9°C) (Figure 1). However, in 2010 the course was very favourable. The average temperature for the period of April – September in the vegetation period increased the production of aboveground biomass of tested cultivars (Table 3). The year 2009 was slightly favourable in terms of average annual temperature at 115% compared to the long-term normal, but for the growing season 111% unsatisfactory in terms of increasing average temperature for the growing season by 1.7°C and precipitation deficit at 75% of the long-term normal.

The temperature in 2010 was standard compared to the long-term normal for the season of 107% and the growing season of 106%. The temperature course every month did not markedly exceed the long-term normal and corresponded to the average temperature for the growing season. The year 2011 had the average annual temperature and vegetation values at a higher level compared to the long-term normal. The given temperatures were markedly higher compared to the temperatures according to the long-term normal. In September, at the time of the physiological ripening of the seeds, the average temperature increased to 17.9°C which represented an increase in temperature by an average of 21% compared to the long-term normal. The year 2012 was favourable with the total annual temperature at 116% of the long-term normal. However, the course of average temperatures from May to August was higher at the level of 113%. Overall, the temperature in 2012 was higher compared to the monthly temperatures of the long-term normal. According to Baldini *et al.* (2020), higher temperature above 30°C during the grain filling phase affects seed quality and seed oil accumulation.

Hemp is considered a multipurpose crop in Europe (Amaducci *et al.* 2015; Salentij *et al.* 2015; Tang *et al.* 2017). The authors report and evaluate the outcomes of five commercial hemp cultivars tested for dual-purpose production in Italy over a four-year period. The average yield over years and cultivars (8 t/ha), is very similar to the average stem yield (7.3 t/ha). Based on the analysis of seeds of the cultivar 'Fedora', the interphases in the production and synthesis of fatty acids in plants, are affected by temperature changes, amount of light and humidity, and growing conditions (Mahnaz *et al.* 2020).

The level of differentiated nitrogen nutrition sig-

nificantly corresponded with the intensity of nutrition to the height of aboveground DM production (Tables 3 and Table 4). The T1 nutrition treatment was chosen as a control treatment. The difference in DM production compared to the increase in the intensity of nutrition had a positive upward trend. We achieved the most marked difference in the average aboveground DM production between the nutrition treatments T3 (10.85 t/ha) and T1 (8.28 t/ha) – 2.57 t/ha DM (Table 3) in statistical term difference was significant, but a statistically significant was also T2 treatment (Table 4). We also noted a statistically significant difference between the fertilisation treatments T1 and T2 in favour of the nutrition treatment T2 (1.05 t/ha). Tang *et al.* (2022) attained comparable results of achieved *Cannabis sativa* yields with increasing fertilisation intensity. However, according to them, it is important to optimize the level of nutrition regarding the seeding density depending on the environmental conditions. They observed that increasing the fertilisation level with substantially higher doses of NPK influenced stem, leaf, and seed production, but not fibre content. Also, in their experiment, the influence of fertilisation has not shown to be important based on investigations of industrial hemp cultivars sown technical. Bernstein *et al.* 2019 when examining industrial hemp cultivars in terms of their internodal properties, found that higher plant densities caused smaller internode diameter and longer internode length, while row spacing showed a statistically noteworthy effect by cultivar. Distance between rows could mean more intense intraspecific competition. Fertilisation of differentiated nitrogen nutrition (N) and fertilisation with phosphorus (P) and potassium (K) according to Taja *et al.* (2019), crucially affected the cannabinoid content of the flowers and the leaves of inflorescence. These effects were specific to organs and compounds. For example, while P and NPK treatment did not change THC or CBD levels in flowers, the other side THC in inflorescence leaves was reduced by 16 to 19%. The opposite effect was observed on CBG levels, where neither P nor NPK treatment affected inflorescence leaf content. However, NPK fertilisation reduced THC levels in flowers and leaves by 36 to 38%.

Tang *et al.* 2017 studied the effect of planting density and nitrogen fertilisation on stem yield. No relationship was found between those factors, nei-

ther with cultivar nor harvest time. Increasing the planting density from 30 to 120 plants/m² and increasing the rate of nitrogen fertilisation from 0 to 60 kg N t/ha increased the stem yield by 29% and 32%. Further, increasing the planting density and nitrogen fertilisation had only a small effect on the stem yield, which is a very important conclusion. The seed yield ranged from 0.3 to 2.1 Mg t/ha which was not affected by planting density between 30 and 240 plants/m², nor by nitrogen fertilisation. Nitrogen fertilisation rates at 60 kg N/ha were generally sufficient in the tested environments. In our trial, the influence of the differentiated level of nitrogen nutrition was highly evident with the intensive nutrition treatment of 10.85 t/ha (Table 3) of the aboveground biomass to the control treatment and evident with the medium intensity of nutrition (T2, 9.33 t/ha).

The influence of soil and climatic conditions had a demonstrable effect on the content of cannabinoids by the HPLC method in 15 tested cultivars in Slovenia. All cultivars showed a significant reaction to the increasing content of cannabinoids depending on the soil and climatic conditions of the locations (Landi *et al.* 2019). Tang *et al.* (2022) point to considerable differences in the cannabinoid content of cultivars (*Cannabis sativa* L., subsp. *Sativa*) from the catalogue of cultivars not only in Slovenia but also in other European countries. Pagnani *et al.* (2018) and Tang *et al.* (2022) found large differences in cannabinoid content between cultivars grown under uniform conditions (ANOVA $p < 0.05$) and within a single cultivar. Sausserde *et al.* (2013) investigated the level of nitrogen nutrition in the cultivar 'Futura'. The effect of the dose of nitrogen fertilisers was significant for biomass production in the tested years, it had a rising curve up to the maximum quantity of the level of nitrogen nutrition. The highest green aboveground biomass over 63 t/ha was achieved by applying 180 kg N/ha. However, the level of nitrogen nutrition above this limit had a decreasing effect on the aboveground biomass of hemp sown in the cultivar 'Futura'.

Nitrogen fertilisation affected cellulose and hemicellulose concentrations in biomass, but the overall response was minimal. Phosphorus and potassium fertilisation had also very limited effects on biomass, its yield, and seed composition in all environments. Aubin *et al.* (2015) claim that while

industrial hemp was positively affected by nitrogen fertilisation up to 200 kg N/ha, the response to phosphorus and potassium fertilisation remained neglectable. However, the best option to evaluate lignocellulose quality is to provide the valuation in terms of quality content and quality yield as well, while an important impact on nutrition can be expected (Kron *et al.* 2017; Tóth & Duplák 2023).

Pagnani *et al.* (2018) also recorded the positive effect of plant growth-promoting rhizobacteria (PGPR) on the aboveground biomass of hemp, as well as the accumulation of plant secondary metabolites and consequently antioxidant capacity. Even the lowest concentration of PGPR made the same effect as recommended nitrogen fertilisation in a dose of 60 kg N/ha. These results underline the potential of the PGPR application in hemp plants for higher biomass accumulation and phytochemical composition. That also supports environmental goals such as increasing soil biodiversity and reducing chemical inputs on it. This leads to the potential application of PGPR in hemp cultivation and could be the basis for large-scale evaluations in the future.

CONCLUSIONS

A pilot field experiment with selected cultivars of *Cannabis sativa* L. was conducted in Eastern Slovakia on a heavy Gleyic fluvisoil, under non-irrigated conditions during 2009–2012. Total average aboveground dry matter (DM) yields of *Cannabis sativa* L. cultivars were 9.49 t/ha while ranging from 2.12 to 16.80 t/ha. The effect of fertilisation significantly corresponded with the intensity of the level of nitrogen nutrition. Overall, the highest DM yield was achieved in the most intensive nutrition treatment T3 by the 'Bialobrzeskie' cultivar in 2011–16.80 t/ha, this cultivar can be considered the most suitable for cultivation in Slovakia. The 'Santhica' cultivar achieved the lowest DM yield – 2.12 t/ha in 2009 with the lowest nitrogen nutrition (T1 treatment). Differences in the production of DM of the tested cultivars were caused by the climatic conditions of the site as well as by the individual production potential of the cultivars. From this point of view, further studies are needed to quantify more precisely the response of the cultivars to the weather

and soil conditions as well, while including especially the cultivars of new origin.

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