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The yield of green phytomass of *Siplhium perfoliatum* L., newly-introduced energy crop tested on marginal heavy soils under Central European continental climate

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Úroda fytomasy Presilfia zrastenolistého, novo-introdukovanej energetickej plodiny testovanej na marginálnych ťažkých pôdach v podmienkach kontinentálnej klímy strednej Európy

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ABSTRACT

This research was focused on a production potential of cup plant *Silphium perfoliatum* L. grown in marginal heavy soils with the following intensity of mineral nutrition: (i) intensive 245.0 kg/ha NPK, (ii) semi-intensive 122.5 kg/ha NPK and (iii) untreated control 0.0 kg/ha NPK. The large-scale pilot field experiments with ÓVÁRI-ÓRIÁS cultivar were carried out on 2 sites under semi-humid to humid Central European temperate climate during 4 years. Overall, it was achieved 13.59 t/ha of dry matter yield on average and the yields varied from 2.37 t/ha to 42.56 t/ha. During the three productive years (2018 – 2020) the crop yield was affected mainly by years (F-ratio 70.67, P-value 0.00), then by nutrition (F-ratio 30.50, P-value 0.00), followed by sites (F-ratio 1.92, P-value 0.17) and finally by replications (F-ratio 0.00, P-value 1.00). In general, cup plant productivity was increasing by a higher number of utility years and similarly, by increasing of nutrition intensity. Although the effect of the sites seems to be almost negligible, the present study does not include sites with arid or semi-arid climate, where the crop productivity may be completely different, especially if the soils are easy soils with an already drying water regime. This study focused on cup plant is probably one of first original research papers published as study based on large-scale experiments conducted in Slovakia, the crop is recognized as suitable perennial crop for energy as other purposes and therefore further agronomic as follow-up studies are needed.

Keywords: cup plant, *Silphium perfoliatum*, green phytomass yield, marginal soils, mineral nutrition

ABSTRAKT

Predkladaný výskum bol zameraný na úrodový potenciál Presilfia zrastenoltisého *Silphium perfoliatum* L. pestovaného na marginálnej veľmi ťažkej pôde, pričom úroveň výživy bola diferencovaná na (i) intenzívnu 245,0 kg/ha NPK, (i) semi-intenzívnu 122,5 kg/ha NPK a (iii) kontrolu bez výživy 0,0 kg/ha NPK. Rozsiahly pilotný poľný pokus s odrodou ÓVÁRI-ÓRIÁS bol uskutočnený na 2 lokalitách v stredoeurópskych klimatických podmienkach v semi-humídnej a humídnej oblasti počas 4 rokov. Celkovo bola dosiahnutá priemerná úroda sušiny 13,59 t/ha, pričom úrody kolísali od 2,37 t/ha do 42,56 t/ha. Počas troch úžitkových rokov (2018 – 2020) úroda bola ovplyvnená najmä rokom (F 70,67; P 0,00), potom výživou (F 30,50; P 0,00), následne lokalitou (F 1,92; P 0,17) a nakoniec opakovaniami (F 0,00; P 1,00). Úroda Presilfia zrastenolistého narastala pribúdaním úžitkového roku a podobne aj zvyšovaním intenzity výživy. Napriek tomu, že vplyv lokalít sa javí takmer zanedbateľným, predložená štúdia nezahŕňa polosuché až suché lokality, kde môže byť úroda plodiny úplne odlišná, najmä na lokalitách s ľahkými pôdami vyznačujúcimi sa vysychavým vodným režimom. Táto štúdia zameraná na Presilfium zrastenolisté je jednou z prvých pôvodných výskumných prác zverejnených ako štúdia na základe rozsiahlych polo-prevádzkových pokusov uskutočnených na Slovensku, pričom plodina je rozpoznaná ako vhodná trváca plodina na energetické aj iné účely, preto sú potrebné ďalšie agronomické štúdie.

Kľúčové slová: Presilfium zrastenolisté, *Silphium perfoliatum*, úroda fytomasy, okrajové pôdy, minerálna výživa

INTRODUCTION

Cup plant *Silphium perfoliatum* L. is one of the most promising perennial herbaceous plants, mainly due to its high biomass yield and multiple uses. It can be grown as a fodder, ornamental, pharmaceutical and honey crop, also for different energy purposes. Despite the considerable qualities of this crop, the cultivation area in Europe is small (Bury et al., 2020).

The main limiting factor is associated with high initial planting costs when establishing stands by transplantating seedlings (Cumplido-Marin et al., 2020) and similarly, by low quality of seeds when establishing stands by sowing (Gansberger et al., 2017, Von Gehren et al., 2016). In terms of durability, it is typical for the crop an efficient crop stand with a long useful life of more than 10-15 years (Shäfer et al., 2018, Gerstberger et al. 2016). Despite the fact that cup plant develops a profound root system, contributing decisively to the drought tolerance of this crop (Schoo et al., 2017), the main possible challenges can be the low yields in low rainfall areas and so far less clarified agronomy (Cumplido-Marin et al., 2020, and others).

However, under appropriate environmental conditions, cup plant were found to provide large yields over sustained periods of time with relatively low levels of management and could be used to produce large energy surpluses, either through direct combustion or biogas production (Cumplido-Marin et al., 2020). Other potential uses of the crop for energy purposes include fibre use for bioethanol production by 2nd generation technologies (Emmerling, 2016).

Based on the lack of cultivation experience with cup plant in Slovakia, agronomically designed field trials was conducted. The main aim of this work was to determine the production potential of cup plant grown in marginal heavy soils under semi-humid to humid climatic conditions.

MATERIAL AND METHODS

Plant material, trial sites and agronomy

Large-scale pilot field trial with newly-introduced energy crop cup plant *Silphium perfoliatum* L. was established on 2 sites located under continental Central European climate on marginal soil conditions. The trial was done in cooperation with local farmers not far distant from the department place in Michalovce:

- Site-1, locality Pozdišovce, altitude 115 m, total flat, Gleyic Fluvisol – heavy soil and semi-humid climate, latitude N 48.744099, longitude E 21.861136;
- Site-2, locality Košický Klečenov, altitude 340 m, slope, Stragnic Cambisol - heavy soil and humid climate, latitude N 48.748984, longitude E 21.508565.

Soil analyses were done prior to the trial. Topsoil samples from a depth of 0-30 cm were taken and their results are presented in Tables 1 and 2. The trial was established in the autumn of 2016 and was running up to 2020. Soil tillage was done into a depth of 24 cm on each site in the autumn followed by high-quality pre-sowing preparation aimed to achieve optimal soil-bed for successful germination and emerging. The sowing date, 12 September 2016, was the same in both sites, as was the sowing rate, 0.3418 millions of germinating seeds per hectare, and the sowing depth was 5 cm. Mineral nutrition was different, there were three NPK treatments including untreated control in the trial so that the intensive and semi-intensive nutrition were solved. The tested doses of NPK are presented in Table 3. The nutrition treatment was done in spring of every year, in the beginning of the vegetation period at end of March (2018-2020). The experimental lay-out was randomized block design.

Cup plant *Silphium perfoliatum* L. ÓVÁRI-ÓRIÁS cultivar was used, closer description of the cultivar is given by Makai et al. (Makai et al., 2008). The seed used for sowing had a weight of thousand seeds of 17 g, a germination of 44.7% and a bulk density of 182 g/l.

Table 1. Soil type, based on clay content in a topsoil layer (0-30 cm)

Site / parameter	Site-1	Site-2
1st fraction, %	22.50	31.81
2nd fraction, %	26.76	24.43
3rd fraction, %	35.38	24.38
4th fraction, %	13.22	15.57
5th fraction, %	2.16	3.83
content of first category particles in %, (soil type)	49.25 (clay-loamy soil / heavy soil)	56.23 (clay-loamy soil / heavy soil)

Note: 1st fraction (<0.001 mm), 2nd fraction (0.01–0.001 mm), 3rd fraction (0.05–0.01 mm), 4th fraction (0.25–0.05 mm), 5th fraction (2.0-0.25 mm), content of the first category particles (sum of 1st and 2nd fraction).

Soil conditions on the sites were similar in terms of both stated aspects, as type of soil (Table 1) as chemical properties of soil (Table 2). The sites differ mainly in altitude and subsequently also in climatic conditions the average values of which are given in Tables 4 and 5, while presented weather data are related to the period after the sowing as well as the main growing season of 2017-2020. During that main vegetation period, April – September, soil-climate was also monitored, whereas soil temperature and humidity as well as soil electrical conductivity were measured twice a day and was recorded in a topsoil layer (a depth of 15 cm) and also in a subsoil layer (a depth of 45 cm).

Harvest and laboratory analyses

The crop was harvested once in year, during September in regard to the optimal stage. The harvest dates are presented in Table 6. The samples of fresh phytomass for dry matter content analyses were taken at harvest and dry matter content was determined gravimetrically by laboratory analyses.

In 2020 at harvest, some soil samples were taken to determine the most important soil chemical properties. Both soil samples, taken at the beginning of the trial (i) initial (2016) and at the end (ii) final (2020) were taken from a topsoil (the depth of 0-30 cm) and each of 6 plots in total was sampled (2 sites x 3 nutrient treatments). Soil sampling as well as sample storage and processing were done according to Slovak Law No. 151/2016, Law Digest. Laboratory analyses of the soil samples were done according to the Mehlich 3 method, for soil texture parameters it was used Novak method.

Table 2. Average content of nutrients in the soil (0-30 cm) (values/categories determined according to the Mehlich 3 method, initial status of 2016)

	Nt, mg/kg	P, mg/kg	K, mg/kg	Ca, mg/kg	Mg, mg/kg	pH / KCl	C-ox, %	Humus, %	C/N, no
Site-1	1647	44.3	238.3	3627.5	446.6	5.20	1.617	2.79	9.75
		low	suitable	middle	high	acidic		middle	*middle
Site-2	1353	68.4	399.9	4543.5	660.9	5.59	1.416	2.44	10.52
		suitable	high	high	very high	weakly acidic		middle	*middle

*middle - middle nitrogen content in relation to carbon content.

Table 3. The dosage of mineral nutrients NPK and Ca (kg/ha, P and K in oxide form)

Treathment / NPK dosage	N	P	K	∑ NPK	Ca
intenstive nutrition	125.0	60.0	60.0	245.0	24.0
semi-intensive nitrition	62.5	30.0	30.0	122.5	12.0
untreated control	0.0	0.0	0.0	0.0	0.0

Table 4. Weather conditions after sowing date (from autumn of 2016 to spring of 2017)

Month	Site-1		Site-2	
	average daily temperature, °C	sum of precipitations, mm	average daily temperature, °C	sum of precipitations, mm
August	20.2	74.2	18.4	89.4
September	17.6	35.8	16.2	29.4
October	9.1	140.6	7.6	130.7
November	4.4	69.2	2.9	54.1
December	-1.9	24.7	-3.5	13.5
January	-6.3	36.6	-7.8	39.5
February	0.8	35.9	-0.3	12.0
March	7.7	27.3	6.2	16.5

Table 5. Data of weather conditions and soil conditions during the main vegetation period (April – September) of 2017-2020

Site / year	Weather condition		Soil conditions, depth 15 cm			Soil conditions, depth 45 cm		
parameter	AT, °C	SP, mm	M, % VWC	T, °C	EC, mS/cm	M, % VWC	T, °C	EC, mS/cm
2017								
Site-1	18.4	288	24.3	17.4	0.119	31.7	16.2	0.299
Site-2	16.6	363	41.4	17.2	0.623	46.9	15.5	1.074
2018								
Site-1	20.0	221	20.7	19.9	0.067	28.7	17.4	0.274
Site-2	18.6	259	34.7	18.8	0.395	43.7	16.5	0.802
2019								
Site-1	18.4	445	32.3	17.5	0.165	28.3	16.1	0.273
Site-2	16.8	516	41.6	17.9	0.555	39.5	15.9	0.750
2020								
Site-1	17.3	388	28.2	17.4	0.150	32.8	16.0	0.255
Site-2	16.0	468	31.6	17.3	0.702	46.9	15.5	1.086
average (of years)								
Site-1	18.5	335	26.4	18.0	0.125	30.4	16.4	0.275
Site-2	17.0	401	37.3	17.8	0.569	44.3	15.9	0.928

AT - average day air temperature, SP - sum of precipitation, M – moisture, T – temperature, EC - electrical conductivity

Table 6. Crop harvest dates

Year / site / harvest day	2018	2019	2020
Site-1	26 September	23 September	8 September
Site-2	26 September	23 September	8 September

Statistical methods

Totally 288 crop data (yield, dry matter content, stand height and coverage) and 216 soil chemical properties data as well as 5,760 weather data plus 17,280 soil-climate and conductivity data were statistically evaluated.

A multi-factorial ANOVA was performed to identify significant factors having influence on yield variability using Statgraphics 15.2.14, the valuation is presented in Table 7. Moreover, (i) correlation analysis or mainly (ii) second order polynomial lines in the case of trend analyses were also used for statistical evaluation.

RESULTS

Green yield and the main effects

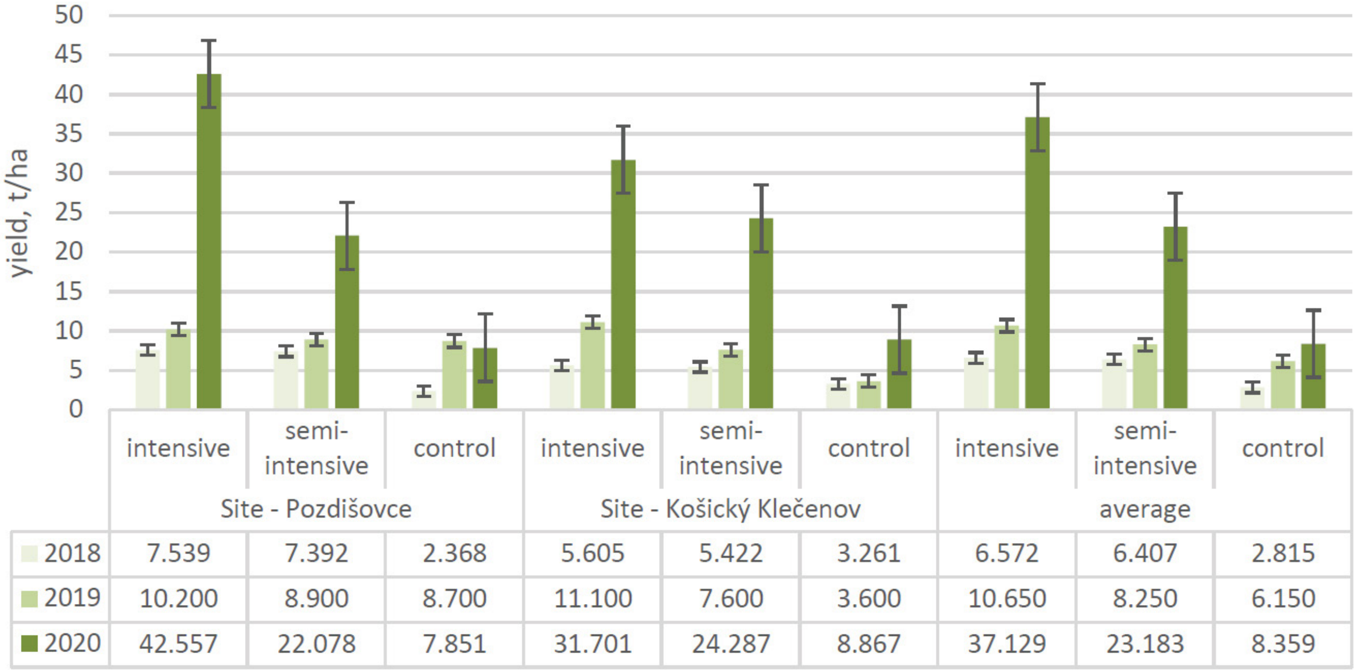
Data of green phytomass yield are presented in Figure 1, while MANOVA of the data is presented in Table 7. Overall, it was achieved 13.59 t/ha of dry matter on average and the yields varied from 2.37 t/ha to 42.56 t/ha, whereas the phytomass produced in the first year (2017) was not quantified because the crop stayed in the stage of the ground leaf rosette. Obtained yield was mainly affected by years (F-ratio 70.67), then less by nutrition (F-ratio 30.50), sites (F-ratio 1.92) and the least yield effect had replications (F-ratio 0.00) which confirms a high quality of the experiments.

Yields in regard to the included three years were as follows: average – minimum – maximum (i) 2020: 22.89 – 7.85 – 42.56 t/ha, (ii) 2019: 8.35 – 3.60 – 11.10 t/ha and (iii) 2018: 5.26 – 2.37 – 7.54 t/ha. Significantly higher yield was achieved only in the last (2020) of the evaluated three years (2017–2020). As to the nutrition treatments, the highest yield of 18.12 t/ha in average was found under intensive nutrition, while the yield of 12.61 t/ha under semi-intensive and the lowest yield of 5.77 t/ha was found under an untreated control, whereas these differences was significant. The average yield on the more fertile Site-Pozdišovce was 13.07 t/ha, on the less fertile Site-Košický Klečenov it was 11.27 t/ha, whereas the difference was not significant.

Table 7. MANOVA of the yield data

IO	Source of variability	Sum of squares	DF	F- ratio	P- value	Homogenous Groups		LS Mean	LS Sigma
4.	replications	0.0132617	3	0.00	1.0000	A	IV.	12.1478	1.2929
						A	I.	12.1666	1.2929
						A	II.	12.1731	1.2929
						A	III.	12.1854	1.2929
3.	sites	57.9031	1	1.92	0.1703	A	Site-2	11.2714	0.9142
						A	Site-1	13.0650	0.9142
1.	years	4252.81	2	70.67	0.0000	A	2018	5.2645	1.1197
						A	2019	8.3500	1.1197
						B	2020	22.8902	1.1197
2.	nutrition	1835.17	2	30.50	0.0000	A	control	5.7745	1.1197
						B	semi-intensive	12.6132	1.1197
						C	intensive	18.117	1.1197
	residual	1895.56	63	*30.08					
	total	8041.46	71						

IO - impact order, an order according to F-ratio; DF – degree of freedom; * - sum of square (for residual)



	Site - Pozdišovce			Site - Košický Klečenov			average		
	intensive	semi-intensive	control	intensive	semi-intensive	control	intensive	semi-intensive	control
2018	7.539	7.392	2.368	5.605	5.422	3.261	6.572	6.407	2.815
2019	10.200	8.900	8.700	11.100	7.600	3.600	10.650	8.250	6.150
2020	42.557	22.078	7.851	31.701	24.287	8.867	37.129	23.183	8.359

Figure 1. The dry matter yield according to sites and treatments, standard deviation added

Generally, cup plant productivity was increasing by a higher number of utility years and similarly, by increasing of nutrition intensity.

Plant height and crop coverage

The harvest was done once a year (Table 6), whereas in the time of harvest it was recorded the data (Table 8) on plant height and stand coverage, as the phytomass samples were taken for laboratory quantification of dry matter content. Within the three productive years (2018–2020) the height of cup plant was 181 cm on average and ranged from 45 ± 2 to 315 ± 16 cm, the coverage was 73% on average and ranged from 25 ± 1 to 95 ± 5% and the dry matter content was 33.6% on average and ranged from 27.5 ± 1 to 47.4 ± 3%.

The yields of cup plant were in a medium correlation with crop coverage ($r = 0.4165$) and in a stronger correlation with plant height ($r = 0.7607$). Adequate reliability indexes $R^2 = 0.1735$ and 0.5787 respectively, are presented in Figure 2 within second-order polynomic course of the dependence of crop yield on plant height and crop coverage, whereas both of subfigures AB are optimized to show the whole data cluster.

The height and coverage of cup plant had the following average values according to years and treatments in order to intensive – semi-intensive – control:

- 2017: height: 19 – 15 – 11 cm, coverage: 45 – 38 – 23%,
- 2018: height: 102 – 94 – 68 cm, coverage: 60 – 44 – 29%,
- 2019: height: 248 – 228 – 161 cm, coverage: 95 – 94 – 94%,
- 2020: height: 285 – 275 – 170 cm, coverage: 83 – 83 – 80%.

Dry matter content at harvest

Stands of cup plant were harvested with regard to an optimal harvest maturity in terms of high content of dry matter. There was no variable harvest date during the three productive years, whereas cup plant was mature in the middle of September regularly (Table 7). Cup plant contained 33.6% of dry matter on average at harvest, while the content ranged from 27.5% to 47.4%.

According to the plots the values of dry matter content at harvest are presented in Table 8, whereas it was achieved 35.7% on Site-Pozdišovce and 31.4% on

Site-Košický Klečenov in average. The parameter had the following average data according to the three productive years and treatments in order to intensive – semi-intensive – control:

- 2018: 34.3 – 39.5 – 30.5%,
- 2019: 34.2 – 33.2 – 28.6%,
- 2020: 34.6 – 35.5 – 30.6%.

Table 8. Plant height, crop coverage and dry matter content at harvest

Site / cultivar year / treatment		Site-1			Site-2		
		intensive	semi-intensive	control	intensive	semi-intensive	control
plant height, cm	2017	21 ± 4	17 ± 4	13 ± 3	16 ± 4	13 ± 3	9 ± 3
	2018	63 ± 3	73 ± 4	45 ± 2	141 ± 7	115 ± 6	90 ± 5
	2019	230 ± 12	210 ± 11	173 ± 9	265 ± 13	245 ± 12	149 ± 7
	2020	255 ± 13	248 ± 12	160 ± 8	315 ± 16	302 ± 15	179 ± 9
crop coverage, %	2017	46 ± 4	39 ± 4	27 ± 4	43 ± 4	37 ± 4	19 ± 4
	2018	65 ± 3	45 ± 2	33 ± 2	55 ± 3	43 ± 2	25 ± 1
	2019	95 ± 5	93 ± 5	92 ± 5	95 ± 5	95 ± 5	95 ± 5
	2020	70 ± 4	70 ± 4	70 ± 4	95 ± 5	95 ± 5	90 ± 5
dry matter content at harvest, %	2017	-	-	-	-	-	-
	2018	36.3 ± 2	34.5 ± 2	33.1 ± 2	34.1 ± 2	33.2 ± 2	32.3 ± 2
	2019	35.4 ± 2	47.4 ± 3	32.1 ± 2	33.2 ± 2	31.5 ± 2	29.0 ± 1
	2020	36.7 ± 2	36.5 ± 2	29.7 ± 1	31.7 ± 2	30.0 ± 2	27.5 ± 1

- The crop was not harvested in 2017.

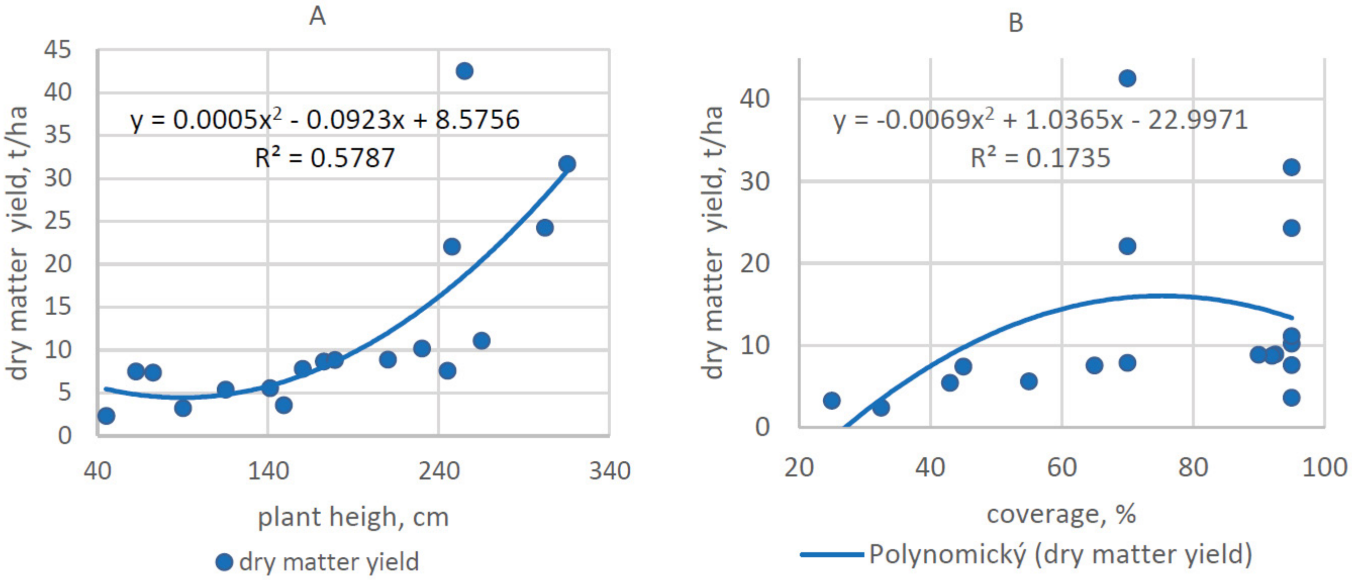


Figure 2. The polynomic trend of yield dependence on crop height (A) and crop coverage (B)

These results of dry matter content at harvest make clear that cup plant contain high amount of moisture in fresh phytomass under both of semi-humid and humid climate conditions, regardless to nutrition intensity and utility year.

Weather and soil-climate conditions

The crop was sowed in the late summer of 2016, actually on same day of 12th September on both of experimental sites. Likewise, on both of the sites the germination as well as emergence of the crop seeds occurred in spring of 2017. During these time period, from sowing to germination and emergence, the seeds remain in rest in the soil, whereas climatic conditions of that period are revealed in Table 4.

Although the weather was similar in both the sites on average over the four years and typical for the continental mild climate, also it was varied by sites during the years and therefore correlations between the yields and the weather conditions were calculated (Figure 3) and linear courses of the relations are revealed (Figure 4). Similarly, the yields and the soil-climate relations are presented (Figure 3 and 5) by nutrition treatments when polynomic courses are preferred because of higher reliability indexes in comparing to linear ones.

There is an evident negative correlation (in order to nutrition treatments r = -0.513, -0.715 and -0.553 respectively) between the cup plant yields and the increase in the average day air temperature, which ranged between 16.0 and 20.0 °C. And in contrary to that, there is an evident positive correlation (in the same order r = 0.275, 0.541 and 0.644) between the crop yields and the increase in sum of precipitations, which ranged between 221 and 516 mm.

This correlations (Figure 3) proved, whereas the revealed dependences of yield on air temperature and precipitation (Figure 4) are confirming, that intensity of nutrition is a very important yield factor that dampens the some of adverse effects of weather and, on the other hand, increases the use of some of its favorable elements. The similar is valid for the nutrition intensity in relation to the solved soil-climate parameters (Figure 5).

Main soil chemical properties and soil nutrient content

The nutrient content and the main chemical properties of soil were determined for each of 6 plots (2 sites x 3 treatments), whereas laboratory analyses were done in two replications for both initial (2016, average by sites, Table 2) as well as terminal status (2020, authentic values, Table 9).

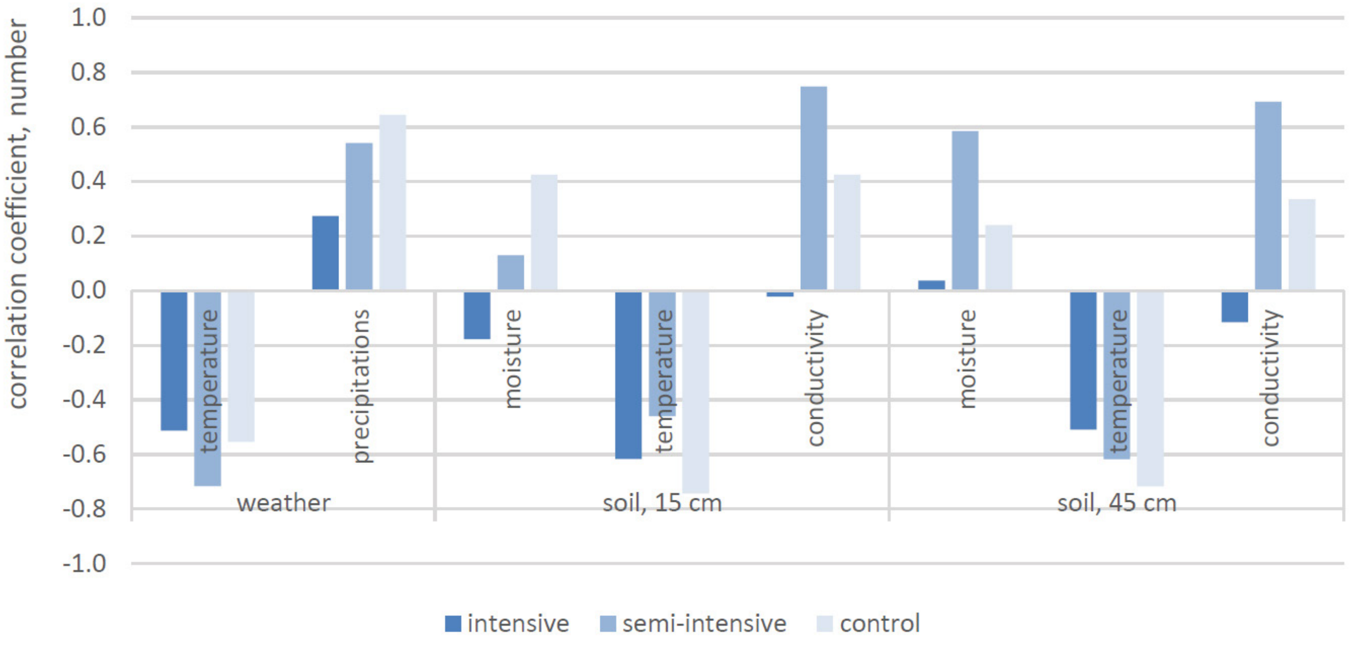


Figure 3. The correlation coefficients of yield and weather and soil-climate condition relations

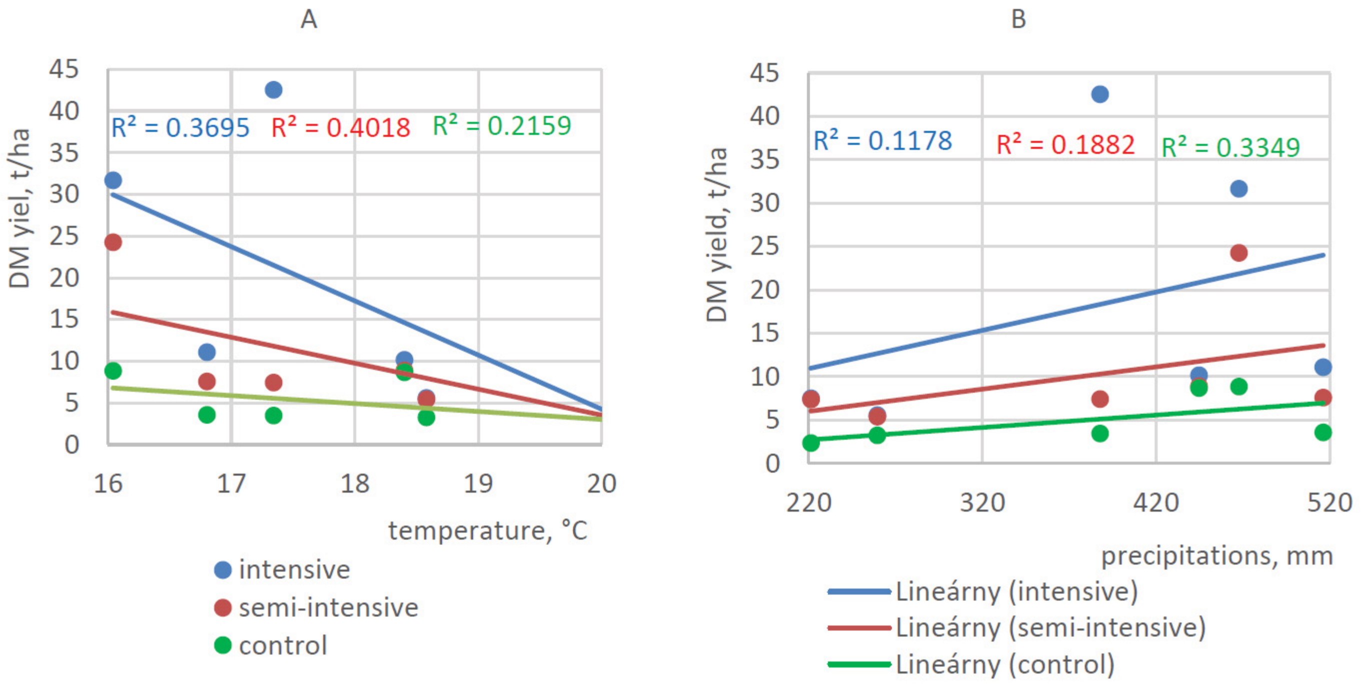


Figure 4. The linear course of dependence of yield on air temperature (A) and the linear course of dependence of yield on precipitations (B)

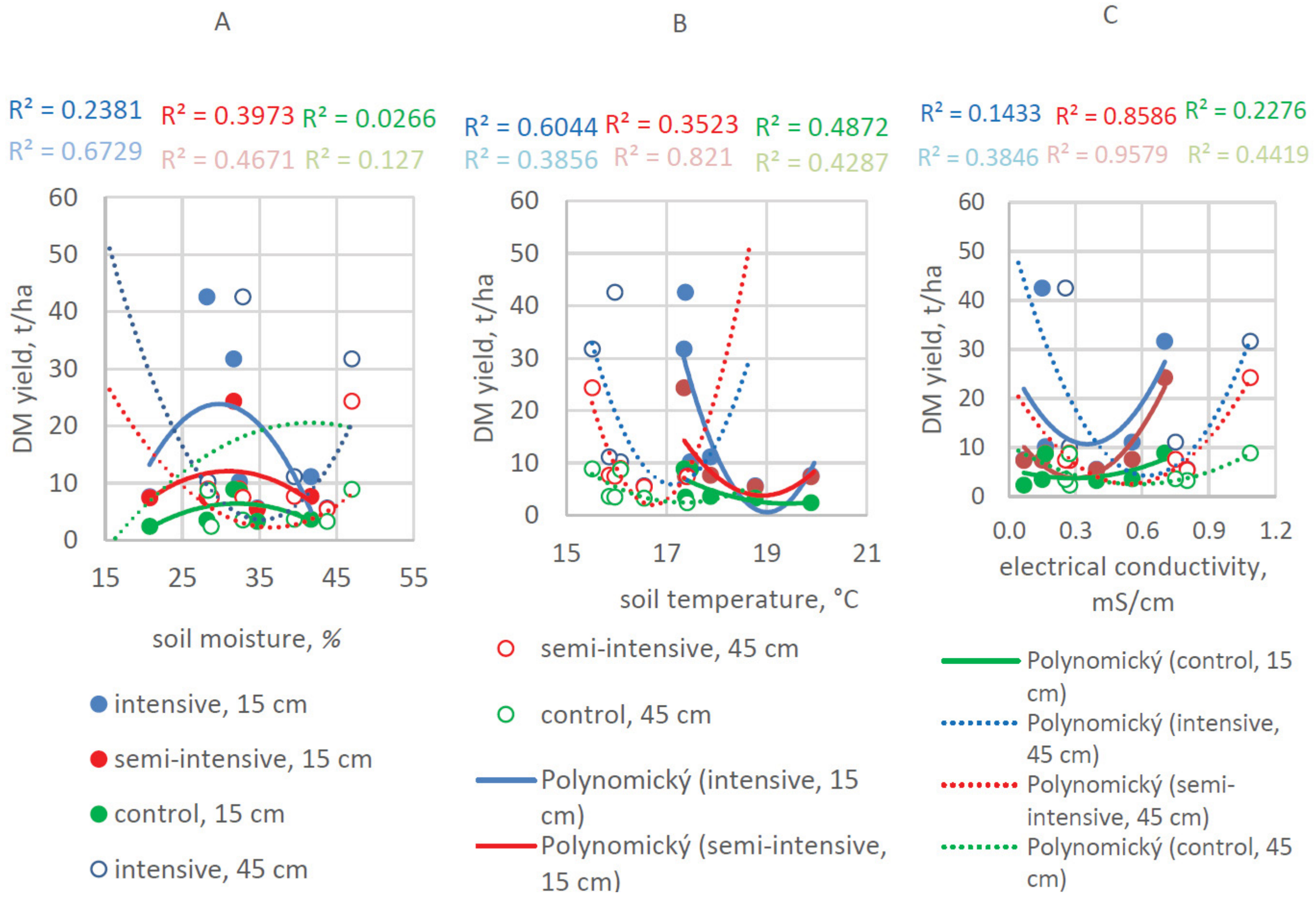


Figure 5. The polynomic course of dependence of dry matter yield on soil moisture (A), soil temperature (B) and soil electrical conductivity (C), depths of 15 cm and 45 cm

Table 9. Content of nutrients in the soil (0-30 cm) (values/categories determined according to the Mehlich 3 method, final status of 2020)

Site / parameter	Nt, mg/kg	P, mg/kg	K, mg/kg	Ca, mg/kg	Mg, mg/kg	pH / KCl	C-ox, %	Humus, %	C/N, no
Site-1, intensive	1321	145.7	284.5	2489.5	217.9	4.47	1.634	2.815	12.37
		very high	middle	suitable	suitable	extremly acidic		middle	*low
Site-1, semi-intensive	1489	177.6	314.6	4127.4	253.1	6.36	1.645	2.835	11.05
		very high	middle	middle	middle	weakly acidic		middle	*low
Site-1, control	1583	20.9	148.0	5515.0	380.3	6.07	1.578	2.720	9.97
		low	low	high	high	weakly acidic		middle	*middle
Site-2, intensive	1517	94.9	486.8	4898.4	806.3	6.17	1.546	2.664	10.19
		middle	high	high	very high	weakly acidic		middle	*middle
Site-2, semi-intensive	1174	56.8	405.9	5383.4	752.2	5.35	1.331	2.293	11.34
		suitable	high	high	very high	acidic		middle	*low
Site-2, control	1368	53.5	306.9	3348.5	424.4	5.26	1.372	2.365	10.03
		suitable	middle	middle	high	acidic		middle	*middle

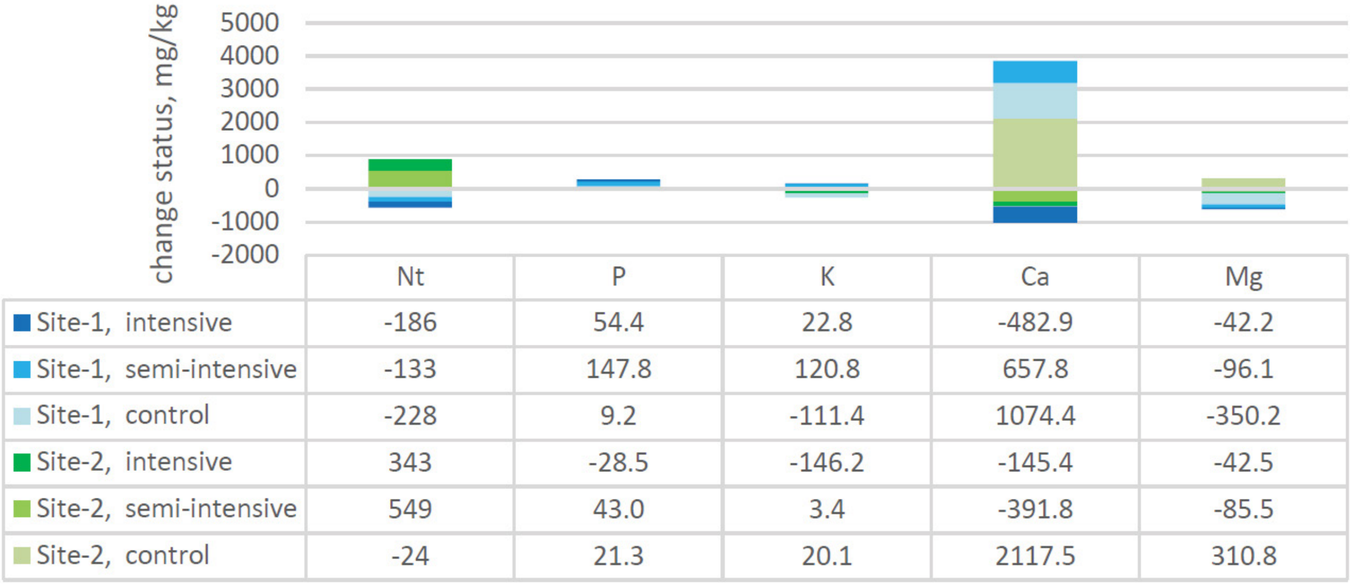
*low/middle – low/middle nitrogen content in relation to carbon content.

Finally, a change status was calculated as a difference between the terminal and the initial status, whereas the two data set of the authentic values were used and the obtained results are presented in Figures 6 and 7, while each of the solved parameter of soil is included.

In average, the highest change was recorded for soil Ca content (471.6 mg/kg), then lower for Nt (53.5 mg/kg), Mg (-50.9 mg/kg), P (41.2 mg/kg), K (-15.1 mg/kg) and humus content (0.286 %), C/N ratio (0.743), while C-ox content (0.166 %) and pH (0.350 pH/KCl) was changed at the least in comparison with the other parameters. However, the change is a result of complex activities, including availability processes and the values are affected by soil non-homogeneity probably also, the changes related to nutrition treatment may be associated with nutrition intensity and therefore also with increased consumption by increased crop yield.

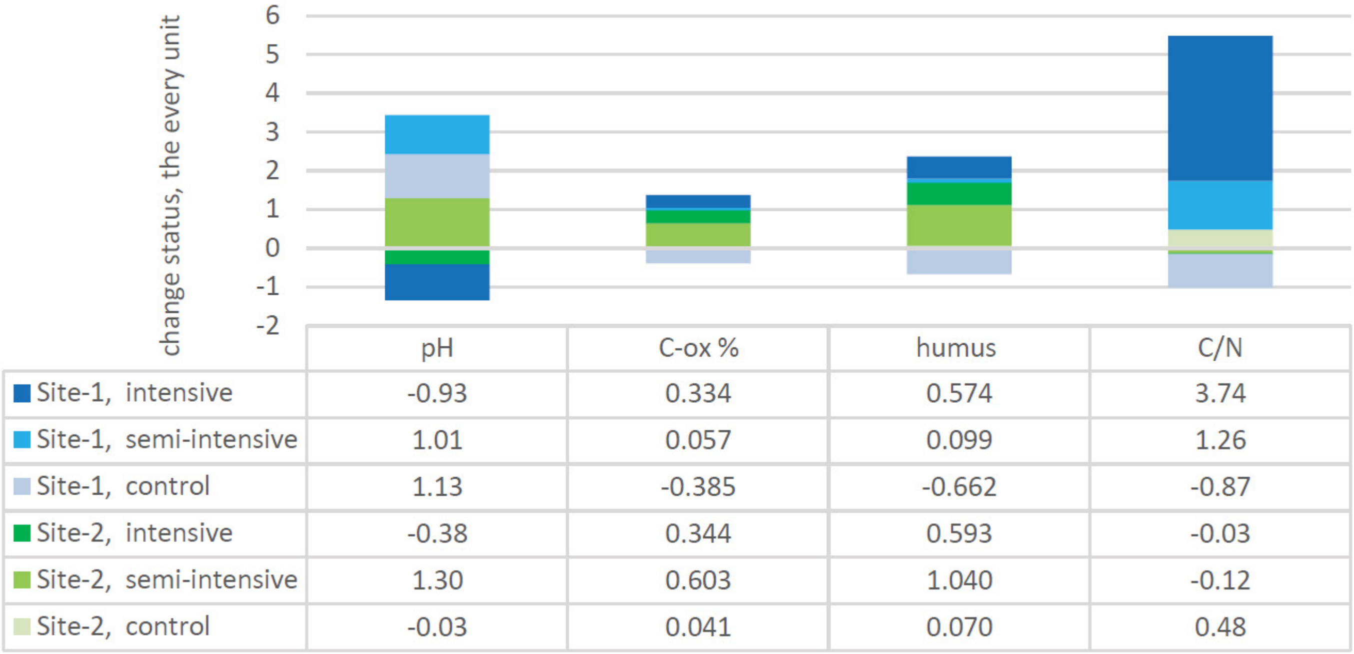
In general, the positive change of soil content of total nitrogen Nt may indicate, that the production potential of the crop was reached. However, this can be applied more to Site-Košický Klečenov with a lower yield, while at Site-Pozdišovce with higher yield the change in total nitrogen content was negative what may indicate a limited yield and therefore still some reserves in yield potential of the crop on the site.

As mentioned before, the average change of C_{ox} content was 0.166%, that means an increase of 0.747 t/ha C_{ox} during 4-year period or increase of 0.187 t/ha C_{ox} per year. The change of C_{ox} content ranged from -1.733 t/ha to 2.714 t/ha during 4-year period and the polynomial course of dependence of C-ox change on yields is presented in Figure 8, while the reliability index ($R^2 = 0.4886$) consider a high correlation ($r = 0.699$) within the dependence.



	Nt	P	K	Ca	Mg
Site-1, intensive	-186	54.4	22.8	-482.9	-42.2
Site-1, semi-intensive	-133	147.8	120.8	657.8	-96.1
Site-1, control	-228	9.2	-111.4	1074.4	-350.2
Site-2, intensive	343	-28.5	-146.2	-145.4	-42.5
Site-2, semi-intensive	549	43.0	3.4	-391.8	-85.5
Site-2, control	-24	21.3	20.1	2117.5	310.8

Figure 6. The change of main plant nutrient content (total nitrogen Nt, P, K, Ca, Mg) in the soil (in mg/kg)



	pH	C-ox %	humus	C/N
Site-1, intensive	-0.93	0.334	0.574	3.74
Site-1, semi-intensive	1.01	0.057	0.099	1.26
Site-1, control	1.13	-0.385	-0.662	-0.87
Site-2, intensive	-0.38	0.344	0.593	-0.03
Site-2, semi-intensive	1.30	0.603	1.040	-0.12
Site-2, control	-0.03	0.041	0.070	0.48

Figure 7. The change of the C-ox (%), C/N ratio, humus (%) and soil pH/KCl

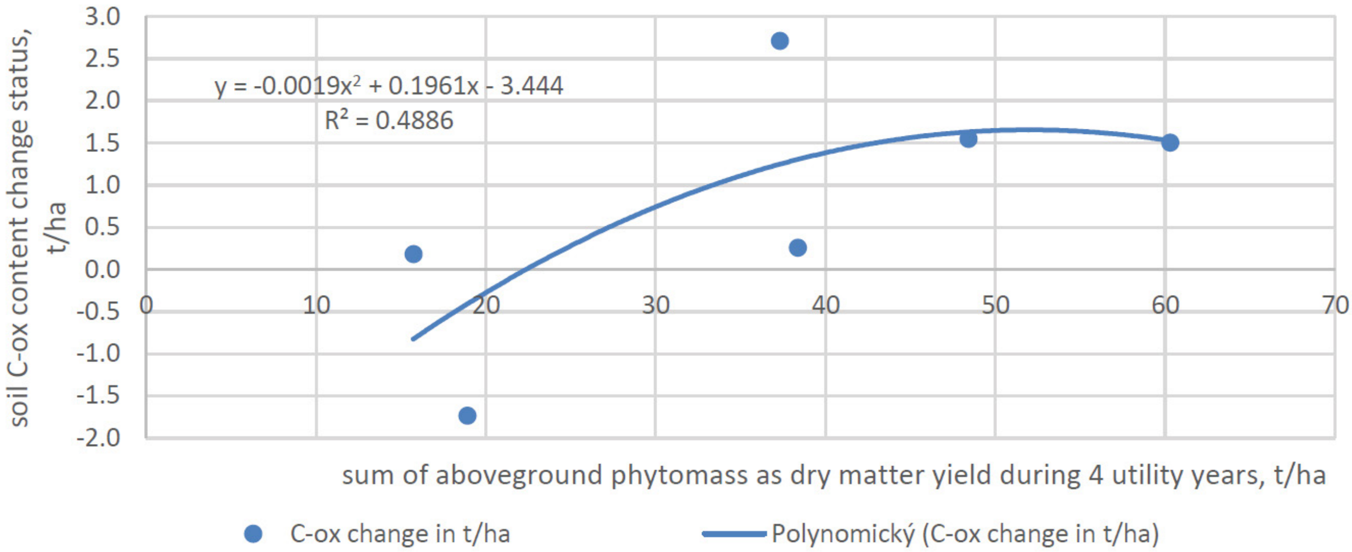


Figure 8. The polynomic course of dependence of soil C-ox change on total yield during 4 growing years

DISCUSSION

Dry matter yield and conditions

By results of a growth experiment of Franzaring et al. (2015), cup plant remains in the leaf rosette stage in the first year. According to one of the first works focused on the crop yielding by Šiaudinis et al. (2012) the cup plant dry matter productivity was 4.42–8.51 t/ha in first year after the year of experiment establishing, while in the next year it considerably increased and reached 11.37-21.94 t/ha.

In the presented work, the slow initial development of the cup plant was recorded with leaf rosette in 2017 and average DM yield of 5.26 t/ha in 2018, while the work is focused on the ÓVÁRI-ÓRIÁS cultivar and it is probably one of the first original papers that examines this cultivar more closely. Also by Pichard (2012) cup-plant exhibits a rosette growth habit during the first year of growth, while the experiment was conducted under similar subhumid and weakly acidic to acidic soil conditions as in the presented work (the pH values 5.20–5.59). The measurements of his huge study, were begun in the second spring after planting and were taken during two consecutive growing seasons, whereas field experiments were established in subhumid climate on three distinct Andisols of volcanic origin with pH values of 5.2 to 5.6. According to the closer conclusions of this research, based on a series of studies conducted to evaluate the adaptation and productivity of cup plant across a range of plant densities (104,000 – 208,000 plants/ha), cutting stages (early vegetative to seed formation), and different levels of N (0 – 400 kg N/ha) and P (0 – 400 kg P_2O_5/ha) fertilization, the plant density over 120,000 plants/ha did not affect dry matter yield, which ranged from 15 to 20 t/ha. Stem number and thickness did vary due to plant density, but height and leaf/stem ratio were not affected by crop density. In the submitted study with ÓVÁRI-ÓRIÁS cultivar it was achieved wider range of DM yield, which varied from 2.37 t/ha to 42.56 t/ha.

According to study of Stolarski et al. (2022) aimed to determine the yield and phytomass quality during double harvest in three vegetation periods, the highest DM yield of 7.7 t/ha was obtained from the first harvest of cup plant in June, whereas second harvest was not so high and total harvest (June and October) was 11.6 t/ha. By their conclusion, the yield of cup plant harvested twice in one growing period, obtained in the third year of the study, were lower compared with the yield obtained in the first and second year. Double harvesting in the present experiment was not observed due to more suboptimal Slovakian conditions.

In field study of Ruf and Emmerling (2022) aimed to verify the results of a former pot experiment in which cup plant showed early sprouting, fast biomass development and higher yields under a soil water regime typical for Stagnosols with periodically stagnant water, it was confirmed the crop benefited likely from the higher soil water availability and yearly produced average biomass yields of 14.3 t/ha being about 40% higher than on well-drained soils. This conclusion partially explains the differences that were achieved on the two sites of the presented work, however Site-2 with higher soil moisture was less productive than Site-1 (Table 7, Figure 1). In regard to relatively small differences in soil moisture (Table 5), the cup plant productivity was more related to the electrical conductivity of the soil (Figure 5 A, C), causally it depended on the higher availability of nutrients at Site-1.

By results of Hryniewicz et al. (2021) based on two years' experiments (2018 and 2019) for different fertilizer doses (45, 90 and 135 kg N/ha), maximal yield of cup plant could be achieved for fertilizer doses of 85 kg N/ha. In the presented work, NPK doses of 245.0 and 122.5 kg were tested, while the yield response of the crop was significant and remain expressive.

According to study of Tsugkiev et al. (2021) from Republic of Ossetia-Alania, cup plant is an introduced perennial crop with high-yield potential, yielding up to 150 t/ha of green mass in climatic conditions of the south Caucasian juncture of Europe and Asia. By worldwide review of Peni et al. (2020), higher yields of cup plant phytomass can be obtained at higher precipitation levels, with the use of fertilizers and an adequate type of plantation, whereas the mean dry matter yield of the crop was 13.3 t/ha, ranged from 2 to over 32 t/ha. In the presented work, it was achieved maximal DM yield of 42.56 t/ha, while DM content of 36.7% and the yield of green phytomass of 115.97 t/ha.

According to conclusions of research of Bury et al. (2020) the yield of cup plant significantly differed between the years and methods of establishing the plantation. The phytomass dry matter yields increased in the first two years of full vegetation from 9.3 to 18.1 t/ha, then decreased in the third year of vegetation to 13 t/ha because of drought. Significantly higher yield was obtained by sowing seeds compared to the planting method, 13.9 vs. 13.0 t/ha due to the higher plant density after the sowing method compared to the planting method. By former conclusions of more extensive study of Bury et al. (2019) the dry matter yields of cup plant ranged between 10-27 t/ha depending on the year of growth and the site. By preliminary results of similar team (Facciotto et al., 2018) the yield of cup plant during the second year ranged from 14.5 t/ha when harvested once at the end of the vegetative period to 25.7 t/ha when harvested twice per year (in June and October) in Poland. By field experiments of Šiaudinis et al. (2019) carried out in Western Lithuania on a naturally acid moraine loam Retisol with a pH of 4.3-4.9, the dry matter yield of the cup plant consistently increased from 2.83 to 12.86 t/ha over four experimental years. By former field experiments of Šiaudinis et al. (2017a, b) carried out on Albeluvisol, the highest productivity of cup plant was recorded in the 3rd harvest year when average fresh matter yield was 45.20 t/ha and that of dry matter was 13.45 t/ha. According to results of field experiments carried out by Usťak and Munoz (2018) in Czech Republic on areas with less favorable conditions, cup plant can be considered as a promising novel crop for biogas production due to high yields of dry matter ranging between 12-18 t/ha. All of that fully agree with the results presented, excluding the planting method which was not included in the study, nor twice harvest per year.

Plant nutrients

By results of experiment of Usťak and Munoz (2018), cup-plant has higher requirements on all tested nutrients (N, P, K, Ca, Mg and S) except N, and selected microelements (B, Fe, Mn, Co, Cu, Mo, Ni and Zn) except Cu and Zn, comparing with maize. Within nutrients the highest uptake differences between cup-plant and maize were at B (about 11× higher), followed by Mg (3.5×) and K (1.8×). Within microelements, the highest uptake differences were B at (about 9× higher), followed by Co

(5×), Fe, and Mn (2×). Therefore, increasing yields of cup-plant after using these nutrients and microelements for compensative fertilizing can be expected. In the presented work, the main plant nutrients were followed only, while the change status was evaluated and high nitrogen consumption was confirmed mainly, especially on Site-1 with a higher yield.

According to results of Lunenberg and Hartmann (2016) the Ca uptake of Ca by cup plant is 22 kg per t of phytomass DM, what is classified as high in comparison to maize with 2 kg. In addition, large fluctuations were observed depending on the year of harvest, whereas the Mg uptake was about twice as high as in silage maize, the nutrient uptakes for N and P were lower than for silage maize. With regard to K, a tendency of decreased nutrient uptake was observed with increasing age of the plants. This conclusion partially explains the differences that were achieved on change status of Ca and Mg (Figure 6), causality of the treatments when a fertilizer with content of Ca and without Mg (Table 3) was applied within the trial presented.

By results of four year investigations of Jasinskas et al. (2014 a) it was revealed that growing conditions and N rate of 120 kg/ha had the highest impact on cup plant dry mass productivity. Also the use of 6.0 t/ha $CaCO_3$ liming material had a positive effect on cup plant productivity. By the similar study of Jasinskas et al. (2014 b) the highest cup plant DM yield 17.98 t/ha was obtained in the fourth year of the experiment, whereas an increase in soil pH from 4.2-4.4 up to 5.6-5.7, resulting from 6.0 t/ha $CaCO_3$ application, increased cup plant DM yield by 27.4%.

Fertilization with 120 kg N/ha significantly increased cup plant DM yield 26.7% in compare with the treatment without N fertilization. According to the results presented in the submitted work, a DM yield of 5.77 t/ha was achieved on the untreated variant, while 12.61 t/ha when using 122.5 kg/ha of NPK and 12.0 kg/ha of Ca, what means an increase of 118.5%. The increase even of 214% was achieved on the treatment when using 245.0 kg/ha of NPK and 24.0 kg/ha of Ca, what means cup plant production potential is strongly affected by nutrition intensity, the growing practice respectively.

Finally, Figures 9 and 10 shows a part of the semi-operational pilot field trial, while in the foreground are the co-working local farmers with whom the trial was carried out.

Figure 9. Cup plant *Silphium perfoliatum* L. on Site-1 (Pozdišovce, August 2019)

Figure 10. Cup plant *Silphium perfoliatum* L. on Site-2 (Košický Klečenov, August 2019)

CONCLUSIONS

The influence of marginal heavy soil condition on the yield of green phytomass of cup plant was verified, while the effect of mineral nutrition was also tested under Central European semi-humid to humid sub-climate. Overall, it was achieved 13.59 t/ha of dry matter on average and the yields varied from 2.37 t/ha to 42.56 t/ha.

The phytomass produced in the first year (2017) was not quantified because the crop stayed in the stage of the ground leaf rosette. During the next three productive years of the trial (2018 – 2020), the crop yield was affected mainly by years (F-ratio 70.67, P-value 0.00), then by nutrition (F-ratio 30.50, P-value 0.00), followed by sites (F-ratio 1.92, P-value 0.17) and finally by replications (F-ratio 0.00, P-value 1.00). In general, cup plant productivity was increasing by a higher number of utility years and similarly, by increasing of nutrition intensity.

The studied ÓVÁRI-ÓRIÁS cultivar of the cup plant can reach full production potential of green phytomass under conditions of Central Europe. However, the cup plant is a perennial crop that reaches the full productivity slowly, tested in the semi-humid to humid conditions of marginal heavy soils it was only in the second year after the establishment of the trials by autumn sowing. The full production potential is dependent on appropriate climatic conditions and adequate intensity of nutrition, what is supported by the analysis of the biometric data as well as monitoring of the basic chemical properties of the soils and selected weather and soil-climate parameters. Although the effect of the sites seems to be almost negligible, the present study does not include sites with arid or semi-arid climate, where the crop fertility may be completely different, especially if the soils are light sandy soils with an already drying water regime.

This study focused on cup plant is probably one of first original research papers published as study based on large-scale experiments conducted in Slovakia, the crop is recognized as suitable perennial crop for energy as other purposes and therefore further agronomic as follow-up studies are needed.

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