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THE EFFECT OF LEAF AREA REDUCTION ON THE YIELD AND QUALITY OF SUGAR BEET (*BETA VULGARIS* L. VAR. *ALTISSIMA* DÖLL)

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Abstract

CERKAL, R., DVOŘÁK, J., VEJRAŽKA, K., KAMLER, J.: *The effect of leaf area reduction on the yield and quality of sugar beet (Beta vulgaris L. var. altissima Döll).* Acta univ. agric. et silvic. Mendel. Brun., 2007, LV, No. 5, pp. 37–44

The yield of sugar beet is directly affected by LAI (leaf area index) and values of LAD (leaf area duration). The integral leaf area plays, except for other factors, an important role during the damage or reduction of leaf apparatus. There are many sources of leaf damage**:** natural disasters (hailstorm), diseases, pests (including game browsing) etc. The intensity of the root production and quality differs in relation to the growth stage of the damage plant. The aim of this study was to evaluate the extent of losses in the root yield and the quality of sugar beet upon gradual reduction of the leaf area. Two diploid varieties Monza and Compact were used in the small-plot trials conducted in years 2004 to 2006 (in the experimental station Žabčice – maize production region, zone K2, average altitude 184 m, soil type was classified as gley fluvisoil, soil is medium heavy to heavy, clay-loam to loam type). The leaf area was manually reduced by 25% and 50% at BBCH 18–19 growth phase (8–9 leaves unfolded). The results were statistically evaluated by analysis of variance and testing by Tukey test (at the significance level α = 5%). Reduction of the leaf area was reflected on the decrease of the root yield by 1 to 10% depending on the year of harvest. In addition, the stressful state of the plants after defoliation resulted in the decrease of the yield of polarization sugar per hectare, namely by 0.45 to 1.66 $t.ha^{-1}$. In 2005, the leaf area reduction caused a rise of the α-amino nitrogen content. The rise in the potassium and sodium cations content caused by the leaf area reduction also increased the sugar content in the treacle (by 0.1 to 0.16%). The increasing leaf area reduction lead to decreasing of yield of polarization sugar. However, this descent was statistically significant in harvest year 2006 only.

damage caused by game, defoliation, sugar beet

A wide range of sources that cause damage to the plants' leaf apparatus, mainly natural disasters, pests, and diseases, is known from agricultural practices (BACHMANN, 1993). Nevertheless, the size of the leaf apparatus has a significant impact on the productivity of plants and vegetation. The individual reaction of the damaged plant depends upon its growth phase and the extend of the leaf area reduction. The leaf damage, or the loss of leaf parts, can be the cause of yield loss as well as drop in the production quality. The decrease of both the root yield and the dry mass of the roots of sugar beet can be primarily associated with the relation between the leaf area duration (LAD) and the plants' productivity. In this context, LANGNER (1997) points out the importance of the relation between the leaf area index (LAI) values of damaged leaves and the subsequent sugar beet roots production.

The moment when the damage to the plants exceeds the limit at which the decrease of the economic yield or the production quality occurs is critical. However, establishing a general relation between the extent of defoliation and decrease of yield or production quality proves rather complicated in practice. The extend of the yield losses in experimental damaging may not correspond with the real damage values due to many additional factors (nutrition status of plants, presence of diseases, pests, weather conditions, etc.) (ŠROLLER and PULKRÁBEK, 1999). The very early growth phases are the most critical ones for the plants of sugar beet. The situation deteriorates if the weakened plants are further damaged or damaged again, e.g. by game consumption. Herbivores prefer the parts of the meristem tissue that are actively growing. The protection of these tissues by the plants' own protective mechanisms is low (BLÁHA *et al.,* 2003), therefore, this type of damage can lead to death of the affected plant.

Generally, sugar beet belongs to crops that lack the ability to self-regulate its yield formation components. Still, it is a crop that is exposed to abiotic stress agents as well as diseases and pests. It is also a crop that is heavily consumed by game (OBRTEL *et al.,* 1984). In some locations, the high number of game causes serious problems to land users, because the plant damage caused by game often results in substantial production losses (KALUZINSKI, 1982; CONOVER *et al.,* 1995; IRBY *et al.,* 1996; VAN TASSELL *et al.,* 1999). This situation is partly caused by the imbalance between the game and the environment; however, the damage is also influenced by other factors, including agrotechnical measures (WEST and PARKHURST, 2002). The extend of the long term production losses caused by game has led to searching for means of their evaluation (ENGEMAN and STERNER, 2002) as well as for possibilities to reduce the losses by using. The individual reaction of the damaged plant depends upon its growth phase and the extend of the leaf area reduction (BELANT *et al.,* 1997) and game management (CONOVER, 2001).

The aim of this work was to evaluate the yield and the quality of sugar beet after simulated damage – the plants' leaf area reduction. Acquired results will be used for compiling an authoritative evaluation methodology for field crops damage caused by game.

MATERIAL AND METHODS

In 2004–2006, the influence of the leaf area reduction on the yield and the quality of sugar beet roots was monitored at the experimental station of the School Agricultural Enterprise of the Mendel University of Agriculture and Forestry in Brno situated in Žabčice (maize production region, zone K2, average altitude 184 m, soil type was classified as gley fluvisoil, soil is medium heavy to heavy, clay-loam to loam type) within a half series of small-plot trials. After harvesting the forecrop, farmyard manure in the amount of 40 $t.ha^{-1}$ was spread over the plot and then processed by subsoil ploughing into the soil. Dipped (fungicide, insecticide) and calibrated seed (3.75/4.75 mm) was used for sowing, and there were 111 000 seeds sown per hectare (spacing 0.5 × 0.18 m). In the course of all the examined years, the simulated damage represented leaf area reduction by 25% and 50%, the control plot was without reduced leaf area. All experimental variants were established in three (2004) or four repetitions. The leaf area was reduced manually with scissors during the BBCH 18–19 growth phase (8–9 leaves unfolded). During this particular phase, the herbivores' high attraction to the sugar beet plants has been observed in agricultural practice. The leaf apparatus of all plants of the relevant variants was reduced on the whole area of the 25 m^2 plot. On harvesting, the yield of roots was established and samples (10 roots) were taken in order to determine technological characteristics – sugar content, α-amino nitrogen content, potassium and sodium content, and sugar ratio in PCM(B) treacle.

The plants' reaction to the leaf area reduction was evaluated in two varieties – Monza (in 2004 and 2006) and Compact (in 2005). Monza (year of registration 2003) and Compact (year of registration 2001) are diploid varieties of the normal (N), respectively intermediate (NC) type, with medium resistance to cercospora (*Cercospora beticola*). The Compact variety is also mildew resistant (*Erysiphe betae*).

Tab. I shows the agricultural engineering of the experiments in 2004 to 2006. Tab. II displays the average month temperatures and precipitation figures. Plots were harvested by using a lifter, the roots were cleaned and weighted. An average sample of ten roots was sent for qualitative analyses to an accredited laboratory.

RESULTS AND DISCUSSION

During the first year of the trials, the extent of the leaf area reduction was reflected mainly in the root yield. A yield of 69.76 $t.ha^{-1}$ was achieved in the non-reduced control variant (Tab. III). Upon reducing 25% of the leaf area, a statistically indecisive decrease of the yield by 3.82 $t.ha^{-1}$, i.e. by 5.5% occurred. This particular level of reduction was the most crucial in regard to the establishment of the root yield. Reducing 50% of the leaf area did not result in further substantial decrease of the yield. The root yield was only by 1.12 $t.ha^{-1}$ lower than the yield in the previous case (and by 7.1% lower than the control variant yield). This may have been caused by the fact that only parts of leaves had been cut off (parts of lamina). As a result, the plants did not undergo the same amount of stress that would have followed entire leaf reduction. Because the leaf area reduction occurred at an early growth phase (eight to nine true leaves unfolded), further leaves were able to grow from adventitious buds (ŠROLLER and PULKRÁBEK, 1999) and form the necessary assimilation area. DRAYCOTT and CHRISTENSON (2003) indicate that once there is a sufficient nitrogen supply available for the sugar beet plants, the leaf attains its final size in approximately 60 days. As the plants did not have to form whole leaves including the leaf-stalk, the energy and nutrients expenditure was distinctly lower and the expected decrease of yield was inconclusive.

Because of the high yield achieved in the control variants, a certain dilution effect regarding the sugar content was established. However, the higher sugar content in the trial variants with reduced leaf area was in no case able to compensate for the drop in the polarization sugar yield. The stressful state of plants induced by removing parts of the leaf area at the beginning of the vegetation was reflected in an indecisive lower yield of the polarization sugar per hectare, namely by 580 to 740 kg.ha^{-1} (Fig. 1). Lower digestion in the control variant was negatively manifested in the ash contents and led to a slight rise of the sugar ratio in treacle (Tab. III).

In 2005, the highest root yield was again achieved in the control variant (75.62 t.ha^{-1}). Analogous to 2004, the leaf area reduction at the beginning of the vegetation resulted in an inconclusive decrease of the root yield by 7.1% and 1.2% respectively. In addition, the leaf area reduction led to a drop in the sugar content of roots, which enhanced the differences in the polarization sugar yield per hectare (Fig. 1). The control variant provided more polarization sugar per hectare (by 1076 kg and 452 kg, respectively) than variants with reduced leaf area.

Lower sugar content of roots is usually related to a higher content of harmful nitrogen and monovalent treacle-forming cations (ZAHRADNÍČEK *et al.,* 2005). This conclusion was confirmed in the experiment in 2005. A considerably higher α-amino nitrogen content and a high content of potassium and sodium cations adversely increased the sugar ratio in treacle in the reduced leaf area variants. The timing of the harvest as well as the weather conditions, especially during July and August, probably played a vital role, too (Tab. II). The plots were not harvested at a technologically optimal time and the precipitation amount was substantially higher during the above mentioned months in comparison to the previous year, which had created ideal conditions for nutrients intake and root growth, and it was subsequently reflected in the yield. However, the roots were not sufficiently mature. The question is whether postponing the harvest would have resulted in a better technological quality of the roots, or not. According to JOZEFYOVÁ *et al.* (2002), a later harvest may contribute to the weight increase of roots approximately by 4.5 g.day^{-1} and of sugar content by 0.66 g.day^{-1}. Therefore, the dilution effect related to the increase of dry mass may contribute to the decrease of the potassium and sodium content, the intake of which ends in August (HŘIVNA *et al.,* 2003). Nevertheless, it is not warranted that the content of harmful nitrogen can be reduced by postponing the harvest, because the intake of nitrogen lasts through the whole vegetation season (HŘIVNA *et al.,* 2004).

The most significant decrease of the yield and sugar content of roots due to the leaf area reduction occurred in 2006. The partial loss of the leaf apparatus was not compensated for by the plants during the rest of the vegetation season in spite of favourable weather conditions (adequate precipitation and higher average temperatures) and sufficient supplies of available nutrients. The leaf area reduction caused an average decrease of root yield by 5–10% (Tab. III). The drop in the LAI values caused the reduction of sugar content in roots by 0.87 and 0.57%. The total loss of polarization sugar eventually reached 1.34–1.66 t.ha^{-1} (Fig. 1).

The established results indicate that the leaf area reduction of the sugar beet plants at an early stage of vegetation can negatively affect the plants' development and decrease the yield of roots and polarization sugar per hectare. It may also negatively influence the technological quality of the roots by increasing the α-amino nitrogen and ash contents in roots, and subsequently cause a further loss by decreasing the sugar yield. Even heavier loss can be expected upon a more severe leaf area reduction or a complete elimination of the leaf apparatus. Reducing leaf area of plants that are fully capable of regeneration leads to smaller losses than reducing leaf area of plants already weakened e.g. by diseases (DRACHOVSKÁ *et al.,* 1960). A partial loss of the leaf apparatus at the beginning of the vegetation season is less harmful as sugar beet first uses assimilates to form new leaves, and therefore, it can fast compensate for the loss incurred at this point. It is because the change in the dynamics of the roots and leaves growth occurs approximately upon unfolding 20th to 25th leaf, at which time the increment of roots exceeds the growth of the leaf mass (ŠROLLER and PULKRÁBEK, 1999). The peak leaf size is achieved in the second half of August when almost 85% of the dry mass of roots has already been formed. At the end of the vegetation season (middle of September, October – harvest) when the intensity of the sun radiation drops, the leaf area reduction affects the root yield to a significantly lower extent.

I: *Agrotechnics of experiments used in all experimental variants from 2004 to 2006*

Operating step	Year		
	2004	2005	2006
Autumn – fertilization (superphosphate + potassium salt)	90 kg.ha^{-1} P_2O_5 + 120 kg.ha^{-1} K_2O		
Seedbed preparation	harrow + land leveller		
Fertilization before sowing	NPK 15:15:15 (300 kg.ha^{-1})		
Pre-emergent herbicide application	Goltix Top (5,5 l.ha^{-1})		
Sowing	28. 4.	25. 4.	9. 5.
First divided application of herbicides (BBCH 12)	Betanal Expert (1 l.ha^{-1})		
	-	Lontrel 300 (1,5 l.ha^{-1})	-
Fertilization	LAV 27 (40 kg.ha^{-1} N)		
Second divided application of herbicides (5 days after first application)	Pantera 40 EC (1,5 l.ha^{-1})		
	-	-	Betanal Expert + Goltix Top (1,5 l.ha^{-1})
Leaf area reduction (BBCH 18 – 19)	16.6.	13.6.	11.7.
Harvest (growing season)	12.10. (167 days)	20.10. (178 days)	11.10 (155 days)

II: *Average month temperatures and total precipitation in years 2004–2006, normal temperatures and precipitation from years 1961–1990 and 1991–2000 (Žabčice; SVOBODA, 2003)*

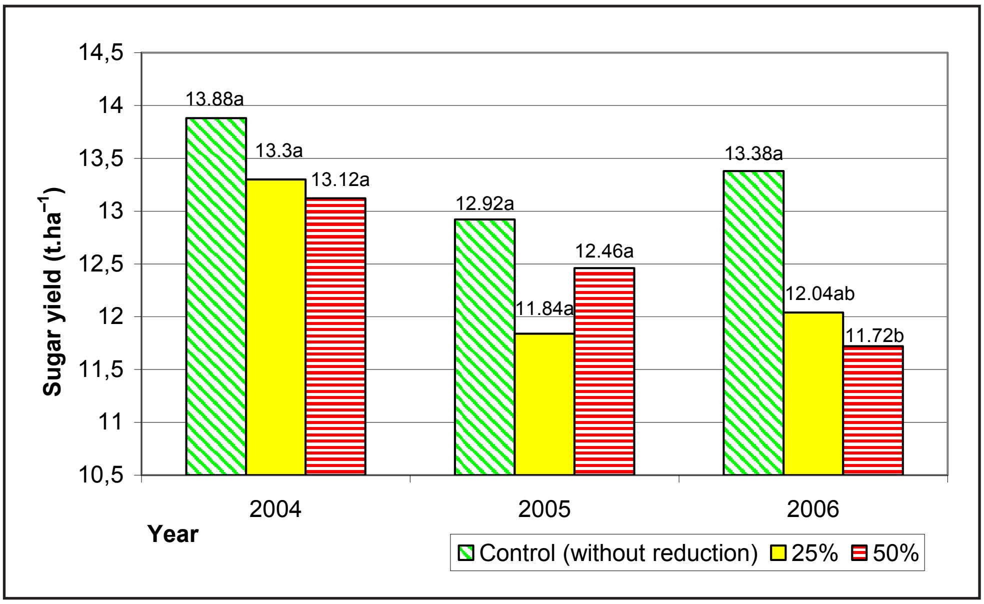
Month/Year	2004		2005		2006		**1991–2000**		**1961–1990**	
	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm
January	–2.9	41.9	0.1	19.4	–6.1	22.2	–0.6	15.6	–2.5	24.6
February	2.1	27.6	–2.0	44.4	–2.2	26.4	0.7	14.6	–0.3	23.8
March	4.3	59.8	2.6	5.8	1.9	46.2	4.9	28.5	3.8	24.1
April	11.8	34.0	11.0	49.5	11.1	50.5	10.7	30.8	9.0	31.5
May	13.9	28.3	15.0	66.8	14.7	75.3	15.7	48.7	13.9	61.0
June	18.0	65.2	17.9	46.2	18.7	71.4	18.9	56.6	17.0	72.2
July	19.6	28.6	19.9	103.1	22.6	78.4	20.6	78.3	18.5	63.7
August	20.1	33.2	18.1	80.7	16.8	151.3	20.5	56.7	18.1	56.2
September	14.6	43.8	16.1	33.2	16.8	9.0	15.2	50.7	14.3	37.6
October	11.0	66.2	9.9	6.2	11.1	13.9	9.5	27.8	9.1	30.7
November	4.5	35.0	2.8	23.4	6.4	21.4	4.1	39.9	3.5	37.4
December	0.0	18.0	–0.9	30.2	2.7	20.8	–0.2	27.3	–0.6	27.1
Veg. period	16.4	233.1	16.4	379.5	16.8	435.9	16.9	321.7	15.1	322.2
Average/Total	9.8	481.6	9.2	508.9	9.6	586.8	10.0	483.0	8.7	489.9

III: *Average values of examined characteristics for varieties Monza (2004 and 2006) and Compact (2005) and results of leaf area reduction level difference (testing by Tukey test, α = 5%)*

Year	Leaf area red. [%]	N	Root yield [t.ha⁻¹]			Sugar content [%]			**α-N [mmol/100g]**		
			$\bar{x}$	%	V	$\bar{x}$	%	V	$\bar{x}$	%	V
2004	0%	3	69.76[a]	100	2.56	19.90[a]	100	1.81	0.68[a]	100	24.48
	25%	3	65.94[a]	94.5	10.39	20.17[a]	101.3	0.76	0.72[a]	105.9	5.56
	50%	3	64.82[a]	92.9	13.20	20.27[a]	101.8	1.59	0.61[a]	90.2	17.96
2005	0%	4	75.62[a]	100	4.65	17.08[a]	100	3.75	3.89[a]	100	2.41
	25%	4	70.26[a]	92.9	10.46	16.85[a]	98.7	1.24	4.01[a]	103.1	7.91
	50%	4	74.72[a]	98.8	13.73	16.68[a]	97.7	3.96	4.30[a]	110.4	2.78
2006	0%	4	77.59[a]	100	1.58	17.25[a]	100	7.48	2.20[a]	100	15.18
	25%	4	73.51[b]	94.7	1.24	16.38[a]	95	2.02	2.21[a]	100.5	15.84
	50%	4	70.29[c]	90.6	3.28	16.68[a]	96.7	1.50	2.15[a]	97.7	14.85

Year	Leaf area red. [%]	n	Na [mmol/100g]			K [mmol/100g]			PCM(B) [%]		
			$\bar{x}$	%	V	$\bar{x}$	%	V	$\bar{x}$	%	V
2004	0%	3	0.36[a]	100	21.70	4.4[a]	100	4.10	1.21[a]	100	5.61
	25%	3	0.32[a]	89.8	4.72	4.3[a]	97.7	6.04	1.21[a]	99.5	1.73
	50%	3	0.34[a]	94.4	28.97	4.1[a]	93.2	4.40	1.16[a]	95.6	3.76
2005	0%	4	1.51[a]	100	10.45	5.55[a]	100	6.62	2.26[a]	100	2.53
	25%	4	1.68[a]	111.6	12.99	5.86[a]	105.6	8.71	2.35[a]	103.9	6.01
	50%	4	1.50[a]	99.5	7.26	6.05[a]	109.0	5.84	2.42[a]	107.0	2.85
2006	0%	4	1.27[a]	100	22.55	4.20[a]	100	8.04	1.66[a]	100	4.93
	25%	4	1.51[a]	118.9	12.61	4.01[a]	95.5	6.12	1.67[a]	100.6	6.86
	50%	4	1.37[a]	107.9	15.25	4.38[a]	104.3	7.32	1.69[a]	101.8	7.59

Explanatory notes: Average values marked with different letters represent statistically significant differences at the significance level of 95%; V – variation coefficient (%).



1: *The yield of polarization sugar (t.ha⁻¹) by variants of leaf area reduction (2004–2006)*
Explanatory notes: Average values marked with different letters represent statistically significant differences at the significance level 95%.

SOUHRN

Vliv redukce listové plochy na výnos a kvalitu cukrovky
(*Beta vulgaris* L. var. *altissima* Döll)

Výnos bulev řepy cukrové bezprostředně závisí na velikosti listové plochy (LAI – leaf area index) a hodnotách LAD (leaf area duration). Integrální listová plocha přitom hraje (kromě jiných faktorů) klíčovou roli v případech poškození nebo ztráty části listového aparátu. V zemědělské praxi existuje mnoho příčin vedoucích k poškození listového aparátu – přírodní živly (např. krupobití), choroby, škůdci (včetně zvěře) a další. Intenzita produkce sušiny bulev a jejich kvalita se liší v závislosti na růstové fázi rostliny, ve které k poškození došlo. Cílem práce bylo posoudit rozsah ztrát na výnosu a kvalitě bulev řepy cukrové při stupňované redukci listového aparátu rostlin. V maloparcelních polních pokusech realizovaných na ŠZP v Žabčicích (kukuřičná výrobní oblast, podoblast K2, průměrná nadmořská výška 184 m n. m., půdní typ byl klasifikován jako fluvizem glejová, půda středně těžká až těžká, půdní druh jílovitohlinitá až jílovitá) v letech 2004 až 2006 byly použity dvě diploidní odrůdy – Monza (N) a Compact (NC). Listová plocha byla redukována z 25 a 50 % manuálně nůžkami v růstové fázi BBCH 18–19 (osm až devět listů rozvinutých). Výsledky byly statisticky zhodnoceny analýzou variance a následně testovány podle Tukeye (na hladině významnosti $\alpha = 5$ %). Redukce listové plochy se projevila poklesem výnosu bulev v rozmezí 1 až 10 % v závislosti na ročníku sklizně. Stres rostlin po odstranění části listové plochy vedl k menšímu výnosu polarizačního cukru z hektaru, a to o 0,45 až 1,66 t.ha^{-1}. Redukce listové plochy byla v roce 2005 příčinou nárůstu obsahu α-aminodusíku, zvýšil se podíl kationtů draslíku a sodíku, který nepříznivě zvyšoval podíl cukru v melase (o 0,1 až 0,16 %). Ze získaných výsledků je zřejmá tendence poklesu výnosu polarizačního cukru se zvyšujícím se poškozením listové plochy. Avšak pouze v roce 2006 byl tento pokles statisticky průkazný.

škody působené zvěří, defoliace, řepa cukrová

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