REGULATION OF PRODUCTION PERFORMANCE OF CHICORY PLANTS BY FOLIAR APPLICATION OF BIOLOGICALLY ACTIVE SUBSTANCES

REGULÁCIA PRODUK ČNEJ VÝKONNOSTI RASTLÍN ČAKANKY FOLIÁRNOU APLIKÁCIOU BIOLOGICKY AKTÍVNYCH LÁTOK

Marek KOVÁR[1*] and Ivan ČERNÝ[2]

[1]Department of Plant Physiology, Faculty of Agrobiology and Food Resources, The Slovak University of Agriculture in Nitra, Slovak Republic, Tr. A. Hlinku 2, 949 76 Nitra, tel.: +421-37-6414 440, e-mail: Marek.Kovar@uniag.sk *correspondence

[2]Department of Crop Production, Faculty of Agrobiology and Food Resources, The Slovak University of Agriculture in Nitra, Slovak Republic, Tr. A. Hlinku 2, 949 76 Nitra

ABSTRACT

In this study were evaluated both the growth and yield potentials of three chicory (Cichorium intybus var. sativum) varieties ('Fredonia Nova', 'Oesia' a 'Maurane') growing in natural agro-ecological conditions from 2006 to 2008. Regulation of the crop productivity by foliar application of biologically active substances (Atonik, Polybor 150, and Biafit Gold) was also studied. Evaluation of growth-production performance of chicory was realized as: leaf area index (LAI), photosynthetic potential (LAD), net assimilation rate (NAR), crop rate growth (CGR), relative growth rate (RGR), harvest index (HI), root yield and inulin content in root. During three-years of experimental seasons, the highest average yield of chicory roots was observed in variety 'Fredonia Nova' (value 2.08 kg m^{-2}), with average LAI reached on value 1.88 and average NAR on value 2.15 g m^{-2} d^{-1}. The highest average HI was observed in variety 'Oesia' (64.0 %) and the lowest in variety 'Maurane' (57.3 %). The highest average inulin root content reached variety 'Fredonia Nova' up to value 205.9 mg g^{-1} dry weight. In this study we discussed in detail observed interaction between individual growth-production characteristics. Finally we observed that application of biologically active substances (BAS) is an important tool for optimalization of growth-production potential in chicory plant. Our results showed that application of BAS (and mainly of Atonik) in all the varieties and experimental years significantly increased the growth-production performance and modified source – sink relationships.

Keywords: chicory, biological active substances, growth analysis, leaf area index, inulin

DETAILED ABSTRACT

V súčasnom období zaznamenávame neustále narastajúci dopyt po funkčných potravinách s vysokým obsahom dieteticky významných látok. To dostáva do popredia otázky pestovania netradičných alebo menej bežných plodín v okrajových produkčných zónach. Jednou z takýchto plodín je koreňová forma čakanky obyčajnej (*Cichorium intybus* var. *sativum*), ktorá je bohatým zdrojom inulínu. Celosvetovo je rozširovanie pestovateľských plôch s čakankou dané zvýšenými požiadavkami potravinárskeho priemyslu po inulíne. V našej práci hodnotíme rastový a úrodový potenciál troch odrôd čakanky obyčajnej ('Fredonia Nova', 'Oesia' a 'Maurane'), pestovaných v prirodzených agroekologických podmienkach na Experimentálnej báze Nitra - Dolná Malanta v rokoch 2006 až 2008. Neoddeliteľnou súčasťou našej štúdie bola analýza možnosti regulácie rastovo-produkčného procesu čakanky foliárne aplikovanými biologicky aktívnymi látkami (Atonik, Polybor 150, Biafit Gold). Počas vegetačného obdobia boli analyzované parametre ako: index listovej pokryvnosti (LAI), fotosyntetický potenciál (LAD), pomerná olistenosť (LAR), čistý výkon fotosyntézy (NAR), rýchlosť rastu porastu (CGR), relatívna rýchlosť rastu (RGR), úroda koreňa, zberový index (HI) a obsah inulínu v sušine koreňa. Rastovo-produkčná analýza ukázala odrodové diferencie v tvorbe fotosyntetických, aj hospodársky cenných orgánov čakanky. Počas sledovaného trojročného obdobia, najvyššiu priemernú úrodu koreňov dosiahla odroda 'Fredonia Nova' na úrovni 2,08 $kg.m^{-2}$, s priemerným LAI 1,88 a priemerným NAR 2,15 $g.m^{-2}.d^{-1}$ za vegetačné obdobie. Odroda 'Oesia' dosiahla najvyšší priemerný HI 64,0 %. Obsah inulínu v koreni sa pohyboval v intervale od 185,3 $mg.g^{-1}$ hmotnosti sušiny koreňa (odroda 'Maurane' v roku 2007) po 214,7 $mg.g^{-1}$ (odroda 'Oesia' v roku 2008). V práci tiež diskutujeme pozorované interakcie medzi veľkosťou produkcie a jej kvalitou a rastovo-produkčnými parametrami v meteorologicky kontrastných rokoch. Výsledky súčasne potvrdili oprávnenosť aplikácie biologicky aktívnych látok (BAS) v optimalizácii rastovo-produkčného procesu rastlín čakanky. Foliárna aplikácia BAS vo všetkých troch odrodách výrazne zvýšila rastovo-produkčnú výkonnosť a modifikovala vzťahy medzi zdrojom a akceptorom asimilátov. Najvýznamnejší efekt bol pozorovaný pri aplikácii prípravku Atonik a to na rozvoji listovej pokryvnosti rastlín (priemerné zvýšenie LAI o 18,84 %). Väčšia listová pokryvnosť porastu indukovaná aplikáciou BAS rezultovala do nárastu čistého výkonu fotosyntézy (NAR) a maximálnej rýchlosti rastu porastu (CGR) vo všetkých troch experimentálnych rokoch. Analýza produkčnej výkonnosti odrôd ukázala, že nárast poolu asimilátov indukovaný aplikáciou BAS bol primárne využitý na tvorbu orgánov nadzemnej časti. Priemerná úroda koreňov sa aplikáciou prípravku Atonik zvýšila o 15,36 % (najvýznamnejšie pri odrode 'Fredonia Nova'). Z kvalitatívneho hľadiska (dané obsahom inulínu) sa aplikácia BAS prejavila najmenej pozitívne (priemerné zvýšenie o 10 %), najvýznamnejšie použitím prípravku Atonik. Možno tak konštatovať, že BAS ovplyvňujú z produkčného hľadiska najmä zdroj asimilátov, s rôznou odrodovou citlivosťou.

Kľúčové slová: čakanka, biologicky aktívne látky, rastová analýza, index listovej pokryvnosti, inulín

INTRODUCTION

Development of civilization diseases in the human population poses challenges not only for medical and pharmaceutical industry, but also for the production of food resources. For several decades, it is known the beneficial effect of the fructans on human health (Roberfroid et al., 1998). The fructans are group of storage polysaccharides, which the human body is unable to metabolize (Ritsema and Smeekens, 2003). Therefore, the fructans are considered dietary functional food ingredients (Fuchs, 1991; Ritsema and Smeekens 2003). FAO statistics show that the production of inulin in the world is growing almost exponentially, while its use is almost exclusive in the food industry (Sommer, 1997). From a biological point of view one of the most important sources of inulin is a root form of chicory plants (*Cichorium intybus* var. *sativum*) (Černý andJavor, 2004; van Laere and van Den Ende, 2002).

Yield formation of chicory, despite of its high productive potential (Beart and van Bockstaele, 1992) is significantly limited by environmental factors (Meijer and Matthijsen, 1992a; Thome and Kühbauch, 1987). Knowledge that have been accumulated in recent decades by studying of the physiological nature of chicory yield formation shows that the tool of stabilizing or increasing of yields is the maximalization its yield potential (Baert and van Bockstaele, 1992; Monti et al., 2005). In addition, an important factor in intensification of yield production is the selection of suitable varieties for specific environmental conditions and optimalization of agro-technical activities also a foliar application of the biologically active substances (BAS) (Černý et al., 1999; Oosterhuis and Robertson, 2000; Černý et al., 2007). For BAS are considered substances that promote or inhibit and / or otherwise modify the morphogenetic and physiological processes of plants (Amaducci and Pritoni, 1997). Most substances of this group are chemically attributed to phytohormones or to their chemical analogues, respectively. After application of the BAS on the leaf and its penetration into symplast chemical compoudns are involved in metabolic processes of cells. After entering into cell metabolism the BAS induce homeostatic metabolic reactions, directly and / or indirectly involved in the regulation of the biosynthesis of proteins with potential protective function (stress proteins) (Amaducci and Pritoni, 1997) and many evidences also show for the metabolism regulation of endogenous hormones (Djanaguiraman et al., 2004). The effects were also identified at the level of regulation of carbon and nitrogen metabolism (Sharma et al., 1984), as well as synthesis of secondary metabolites (Endt et al., 2002). The result of biologically active substances induced synergistic metabolic effects is influencing of the accumulation of organic matter (Guo et al., 1994).

Generally, this is observed not only in species but also in the sensitivity of varietal growth-production process on applied biologically active substances. The aim of this work was to study the effects of foliar applied biologically active substances (Atonik, Polybor 150 and Biafit Gold) on the growth and production dynamics of three varieties ('Fredonia Nova', 'Oesia' and 'Maurane') of chicory plants. Through the parameters quantification of the production process, we identified in three consecutive years (2006-2008) the sensitivity of the production performance of varieties of chicory on applied biologically active substances.

MATERIAL AND METHODS

Experiments with chicory (*Cichorium intybus* var. *sativum*) plants of the three varieties ('Fredonia Nova', 'Oesia' and 'Maurane') were made in the years 2006-2008 on an Experimental Base of Faculty of Agrobiology and Food Resources Slovak Agricultural University in Nitra - Dolná Malanta (lat. 48°19'00", lon. 18°09'00", alt. 175 m). The experimental station is located in warm agro-climatic areas in brown soil proluvium loess sediments. The agro-technical management was in line with the principles of farming, with minimal labor-intensive (stubble ploughed, conventional tillage, nutrition and fertilization of the planned harvest 30 t ha^{-1}, mechanical cultivation and harvesting). The previous crop was winter wheat (*Triticum aestivum* L.). Sowing dates were 14th, 10th and 18th April (2006, 2007 and 2008, resp.). The herbicidal protection has been applied in both pre-emergent and post-emergent.

Plant seeds were sown f or planting row distance 115 mm and 0.40 m between rows. Performed twice during the post-emergent herbicidal protection (just before the crop closing and 4 weeks after the first application; BBCH 13 and 18) were foliar applied preparations of biologically active substances in the variants: i) Atonik (Asahi Chem. Corp., Mfg. Ltd. Japan) at doses of 0.6 l ha^{-1}; ii) Polybor 150 (Fitohorm Kft., Baja, Hungary) in dose of 2.5 l ha^{-1} and iii) Biafit Gold (Agro-Bio-Chem 97, Berettyóújfalu, Hungary) at 5 l ha^{-1}. The control variant was being treated only by herbicidal protection. At maturity were chicory plants harvested on 25th, 18th and 27th September (2006, 2007 and 2008, resp.).

Five times during the vegetation (BBCH 15, 19, 42, 45 and 49; according to Feller et al., 2005) it was make a hand collected of plant material samples for growth production analysis. After the partition of biomass to individual organs was determined the size of leaf area (A) (Květ and Marshall, 1971). Fresh biological material was inserted into the drying chamber (OP60, LTE Sci, Oldham, England). Drying of the samples was carried out during 48 h at 80 °C and subsequently was established a dry weight (W). Assessment parameters of growth analysis (according to Květ et al., 1971) were: leaf area index (LAI), photosynthetic potential (LAD), net assimilation rate (NAR), crop growth rate (CGR) and relative growth rate (RGR), root yield and harvesting index (HI). Inulin content in root was determined by the Schoorl's method according to Černý *et al.* (2007).

Experiments were set-up by the block-based method with a random arrangement. The number of repetitions was 5, there were samples with five plants in one repetition. Results are presented as means±SE. Treatment means were compared for significance using Duncan's Multiple Range Test (at $P<0.05$). All statistical analyses were conducted using Statistica v. 7 (StatSoft, Inc., Tulsa, Oklahoma, USA).

RESULTS AND DISCUSSION

The growth analysis is an effective tool for study of efficiency and dynamics of physiological processes resulted in the redistribution of assimilates, activity of assimilation apparatus and storage organs, respectively. The study of source - sink relationships allows to evaluate the performance not only between crops, but also between individual varieties (Hay and Porter, 2006).

Experiments with chicory plants were carried out in natural environmental conditions. The course of the average monthly temperature and monthly precipitation in each experimental period (2006-2008) is documented in fig. 1. In 2006, during sprouting of chicory plants was sufficient precipitation, which led to a rapid development of above-ground biomass in all three chicory varieties. In contrast, the first third of the growing season of 2007 was characterized by deficiency of precipitation, which resulted in a slow growth. The second half of 2007 growing season was characterized by sufficient rainfall, which resulted in the growth and yield chicory root (tab. 1). The year 2006 was also characterized by deficiency of precipitation during June-July growth period and also in the years 2006 and 2008 during September (fig. 1), causing the limitation of production performance (tab. 1 and fig. 3). This limitation caused by unfavourable weather was partly compensated by application of biologically active substances (BAS).

Figure 1 Course of average month temperature (^{o}C) (full line) and total month precipitation (mm) (dashed line) in experimental years 2006, 2007 and 2008 at experimental base.

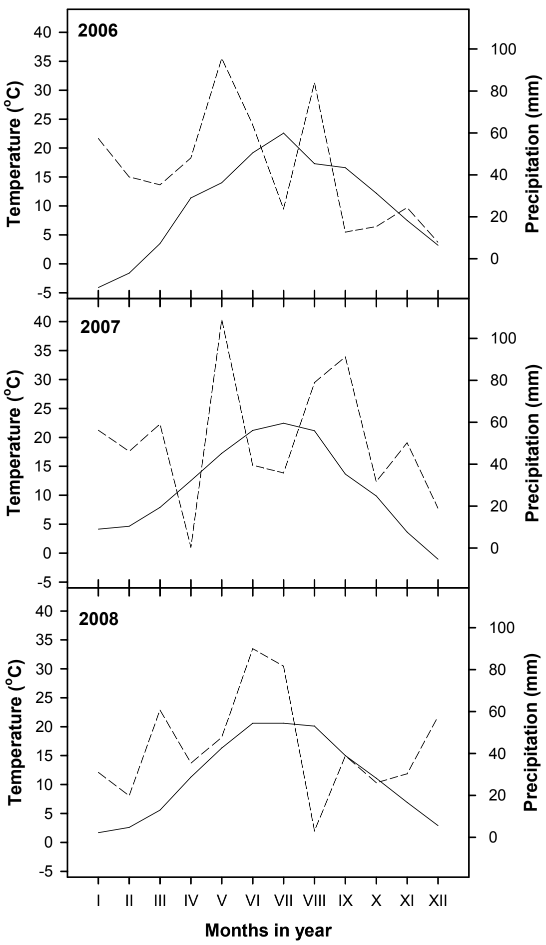


Table 1 Growth-production parameters of three varieties of chicory plants grown in 2006, 2007 and 2008 years and foliar treats with Atonik, Polybor 150 and Biafit Gold. The control plant represented non-affected plants by biologically active substances. Fresh weight, root weight and harvesting index were calculated on end of vegetation season; parameters of growth analysis were calculated in BBCH 15, 19, 42, 45 and 49 (see section Material and methods). Each value represents mean (n=5). Lower case letters indicates differences between treatments, upper case letters indicate differences (*P*<0.05) between years of cultivation.

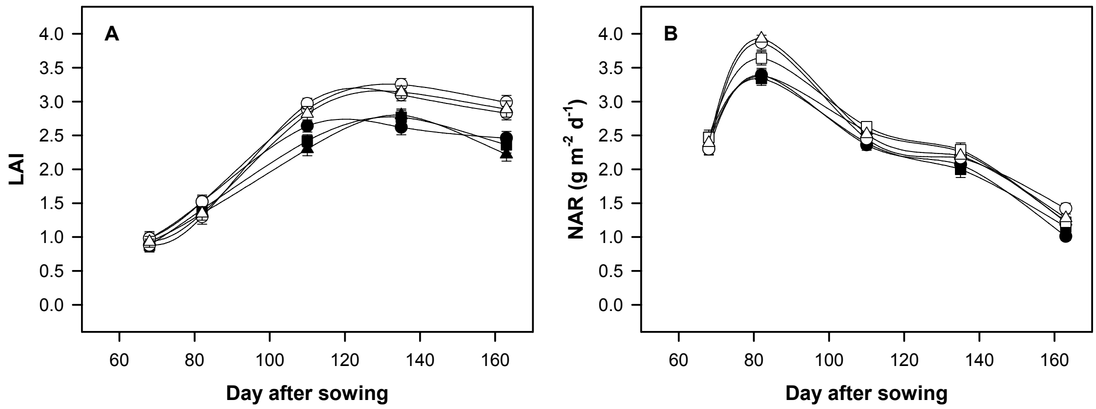
2006												
	'Fredonia Nova'				'Oesia'				'Maurane'			
	Control plant	Atonik	Polybor 150	Biafit Gold	Control plant	Atonik	Polybor 150	Biafit Gold	Control plant	Atonik	Polybor 150	Biafit Gold
Fresh weight 1 plant (g)	367.13 ^{aA}	435.66 ^{bB}	415.62 ^{abB}	381.39 ^{abB}	379.93 ^{aA}	438.37 ^{bA}	431.46 ^{bA}	364.56 ^{aA}	350.82 ^{aAB}	384.74 ^{bAB}	359.71 ^{aA}	356.07 ^{aAB}
Root weight 1 plant (g)	209.26 ^{aA}	270.10 ^{cA}	245.21^{bAB}	213.57 ^{aA}	243.15 ^{abA}	289.32 ^{cA}	271.81 ^{bA}	226.02 ^{aA}	192.95 ^{aA}	223.14 ^{bA}	205.03 ^{aA}	246.27 ^{bB}
Harvesting index (%)	57.00 ^{a}	62.00 ^{b}	59.00 ^{ab}	56.00 ^{a}	64.00 ^{ab}	66.00 ^{b}	63.00 ^{a}	62.00 ^{a}	55.00	58.00 ^{A}	57.00	54.00 ^{A}
LAI maximal	2.24 ^{aA}	2.61 ^{cA}	2.47 ^{bA}	2.32 ^{ab}	2.51 ^{aA}	2.88 ^{cA}	2.67 ^{bA}	2.63 ^{ab}	2.25 ^{aA}	2.56 ^{bB}	2.48 ^{bA}	2.31 ^{abA}
LAI average	1.84 ^{aAB}	1.97 ^{bA}	1.91 ^{ab}	1.83 ^{a}	1.86 ^{a}	1.96 ^{bA}	1.87 ^{a}	1.85 ^{a}	1.75 ^{A}	1.86 ^{A}	1.79	1.76
LAD ($m^2 m^{-2} d^{-1}$)	318.36 ^{a}	357.04 ^{bA}	325.29 ^{aA}	321.84 ^{a}	316.88 ^{a}	352.63 ^{b}	318.92 ^{a}	320.66 ^{a}	307.92 ^{a}	331.45 ^{bA}	329.98 ^{b}	312.53 ^{a}
LAR average ($m^2 kg^{-1}$)	2.76 ^{aB}	3.06 ^{bA}	2.83 ^{aB}	2.79 ^{aB}	2.97 ^{aA}	3.27 ^{bAB}	3.11 ^{abA}	3.02 ^{aAB}	2.39 ^{A}	3.48 ^{A}	2.43 ^{A}	2.35 ^{A}
NAR maximal ($g m^{-2} d^{-1}$)	3.27 ^{aA}	3.53 ^{bA}	3.49 ^{abB}	3.32 ^{aAB}	3.32 ^{aA}	3.56 ^{b}	3.43 ^{ab}	3.41 ^{ab}	3.19 ^{A}	3.35 ^{A}	3.33 ^{A}	3.28 ^{A}
NAR average ($g m^{-2} d^{-1}$)	2.08 ^{aA}	2.15 ^{bA}	2.12 ^{abA}	2.06 ^{aA}	2.11 ^{aA}	2.26 ^{bA}	2.21 ^{bA}	2.14 ^{aA}	2.07 ^{aA}	2.12 ^{bA}	2.09 ^{aA}	2.05 ^{aA}
CGR maximal ($g m^{-2} d^{-1}$)	6.23 ^{a}	6.71 ^{cA}	6.59 ^{b}	6.38 ^{ab}	6.50 ^{aA}	6.83 ^{bA}	6.57 ^{a}	6.62 ^{ab}	6.31	6.43 ^{A}	6.46 ^{A}	6.35
RGR maximal ($g g^{-1} d^{-1}$)	0.13 ^{AB}	0.15	0.14	0.13	0.12	0.16	0.16	0.14	0.12	0.13	0.12	0.11

2007												
	'Fredonia Nova'				'Oesia'				'Maurane'			
	Control plant	Atonik	Polybor 150	Biafit Gold	Control plant	Atonik	Polybor 150	Biafit Gold	Control plant	Atonik	Polybor 150	Biafit Gold
Fresh weight 1 plant (g)	486.24 ^{bB}	534.47 ^{cC}	493.21 ^{bC}	466.83 ^{aC}	462.75 ^{aB}	508.42 ^{bB}	485.44 ^{abB}	467.68 ^{aC}	438.92 ^{aB}	474.89 ^{bB}	464.51 ^{bB}	432.02 ^{aB}
Root weight 1 plant (g)	286.88 ^{bB}	326.02 ^{cC}	281.12 ^{bB}	247.41 ^{aB}	305.41^{aB}	345.72 ^{cB}	320.39 ^{bB}	294.63 ^{aC}	254.57 ^{aB}	284.93 ^{bB}	269.41 ^{abB}	241.93 ^{aB}
Harvesting index (%)	59.00 ^{b}	61.00 ^{b}	57.00 ^{ab}	53.00 ^{a}	66.00 ^{a}	68.00 ^{b}	66.00 ^{a}	63.00 ^{a}	58.00 ^{ab}	60.00 ^{bAB}	58.00 ^{ab}	56.00 ^{aA}
LAI maximal	2.64 ^{aB}	3.25 ^{bB}	2.85 ^{abB}	2.52 ^{a}	2.77 ^{bB}	3.10 ^{cB}	2.93 ^{bcB}	2.58 ^{a}	2.80 ^{bB}	3.14 ^{cC}	2.81 ^{bB}	2.53 ^{aB}
LAI average	2.04 ^{bB}	2.33 ^{cB}	1.96 ^{ab}	1.86 ^{a}	1.97 ^{ab}	2.22 ^{cB}	2.06 ^{b}	1.83 ^{a}	1.92 ^{abB}	2.23 ^{bB}	1.95 ^{ab}	1.74 ^{a}
LAD ($m^2 m^{-2} d^{-1}$)	339.94 ^{b}	384.45 ^{cB}	349.72 ^{bB}	319.04 ^{a}	325.05 ^{b}	366.31 ^{c}	334.20 ^{b}	309.87 ^{a}	316.86 ^{a}	367.95 ^{cB}	346.59 ^{b}	304.22 ^{a}
LAR average ($m^2 kg^{-1}$)	2.93 ^{abC}	3.71 ^{cB}	3.23 ^{bC}	2.81 ^{aB}	3.28 ^{abB}	3.54 ^{cB}	3.31 ^{bB}	3.11 ^{aB}	2.69 ^{abB}	3.06 ^{bB}	2.89 ^{bB}	2.54 ^{aB}
NAR maximal ($g m^{-2} d^{-1}$)	3.69 ^{abB}	3.87 ^{bB}	3.71 ^{abC}	3.48 ^{aB}	3.54 ^{abB}	3.68 ^{b}	3.55 ^{ab}	3.36 ^{a}	3.78 ^{aB}	3.93 ^{bB}	3.83 ^{abB}	3.75 ^{aB}
NAR average ($g m^{-2} d^{-1}$)	2.26 ^{aB}	2.39 ^{bB}	2.29 ^{abB}	2.21 ^{aB}	2.37 ^{abB}	2.51 ^{bB}	2.36 ^{abB}	2.28 ^{aB}	2.45 ^{B}	2.48 ^{B}	2.45 ^{B}	2.38 ^{B}
CGR maximal ($g m^{-2} d^{-1}$)	6.45 ^{a}	7.27 ^{cB}	6.73 ^{b}	6.48 ^{a}	6.78 ^{aB}	7.06 ^{bAB}	6.80 ^{ab}	6.74 ^{a}	6.33 ^{a}	7.53 ^{cB}	6.79 ^{bB}	6.43 ^{ab}
RGR maximal ($g g^{-1} d^{-1}$)	0.16 ^{aB}	0.19 ^{b}	0.17 ^{ab}	0.15 ^{a}	0.14 ^{a}	0.18 ^{b}	0.17 ^{b}	0.14 ^{a}	0.11	0.14	0.13	0.10

2008												
	'Fredonia Nova'				'Oesia'				'Maurane'			
	Control plant	Atonik	Polybor 150	Biafit Gold	Control plant	Atonik	Polybor 150	Biafit Gold	Control plant	Atonik	Polybor 150	Biafit Gold
Fresh weight 1 plant (g)	326.59 ^{aA}	394.65 ^{bA}	342.84 ^{aA}	339.73 ^{aA}	394.66 ^{aA}	423.07 ^{bA}	408.25 ^{abA}	406,38 ^{abB}	311.45 ^{aA}	344.59 ^{bA}	330.42 ^{bA}	308.67 ^{aA}
Root weight 1 plant (g)	182.89 ^{aA}	228.89 ^{bB}	188.56 ^{aA}	190.24 ^{aA}	244.68 ^{aA}	274.99 ^{bA}	257.19 ^{bA}	260,08 ^{bB}	183.75 ^{aA}	213.64 ^{bA}	191.64 ^{abA}	185.20 ^{aA}
Harvesting index (%)	56.00	58.00	55.00	56.00	62.00	65.00	63.00	64.00	59.00	62.00 ^{B}	58.00	60.00 ^{B}
LAI maximal	2.37 ^{aA}	2.65 ^{bA}	2.59 ^{abA}	2.41 ^{a}	2.51 ^{aA}	2.73 ^{bA}	2.53 ^{aA}	2.47 ^{a}	2.16 ^{aA}	2.28 ^{bA}	2.23 ^{bA}	2.21 ^{abA}
LAI average	1.75 ^{aA}	1.92 ^{bA}	1.86 ^{ab}	1.79 ^{a}	1.88 ^{a}	2.03 ^{bAB}	1.91 ^{ab}	1.86 ^{a}	1.70 ^{A}	1.82 ^{A}	1.75	1.68
LAD ($m^2 m^{-2} d^{-1}$)	309.34 ^{a}	344.82 ^{bA}	340.18 ^{bB}	321.73 ^{ab}	321.63 ^{a}	359.77 ^{b}	328.19 ^{a}	323.37 ^{a}	304.25 ^{a}	318.32 ^{bA}	311.17 ^{ab}	307.83 ^{a}
LAR average ($m^2 kg^{-1}$)	2.58 ^{aA}	2.93 ^{bA}	2.62 ^{aA}	2.55 ^{aA}	2.81 ^{aA}	3.15 ^{bA}	3.06 ^{abA}	2.84 ^{aA}	2.43 ^{aAB}	2.62 ^{bA}	2.57 ^{abA}	2.44 ^{aA}
NAR maximal ($g m^{-2} d^{-1}$)	3.18 ^{aA}	3.44 ^{bA}	3.25 ^{aA}	3.20 ^{aA}	3.35 ^{A}	3.59	3.41	3.32	3.27 ^{A}	3.41 ^{A}	3.40 ^{A}	3.35 ^{A}

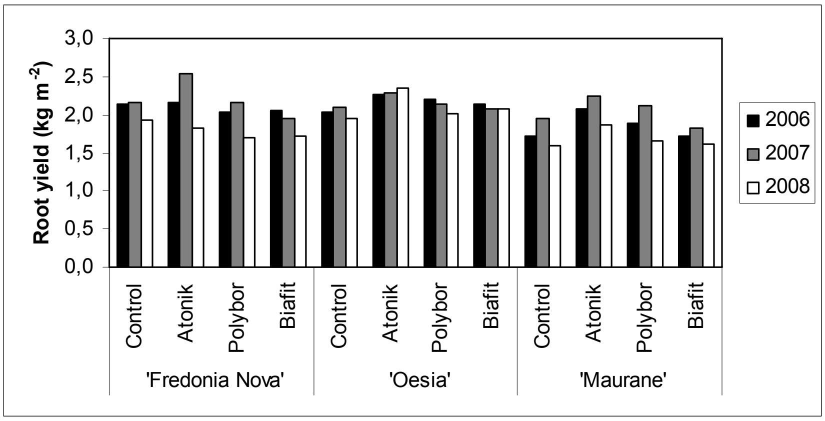
For a quantitative description of the radiation absorption by vegetation and thus the dynamics of formation of leaves, we used the parameter of leaf area index (LAI). The first stages of chicory ontogenesis are typical by the intensive growth of the assimilation apparatus (fig. 2A). Schittenhelm (1999) shows that the growth rate of chicory in the early period of ontogeny is very sensitive to temperature and adequate soil moisture. In our experiments, we identify the varietal differences in ability to formation the leaf area in the early growth stages. The variety 'Fredonia Nova' showed the highest values of LAI (1.52 ± 0.13) in the early stages of vegetation (till BBCH 19) during all three experimental years in comparison with the varieties 'Maurane' and 'Oesia'. In year 2007 the variety 'Fredonia Nova' first saturated the maximum size of assimilatory apparatus (average LAI_{MAX} for three years is 2.64) in the middle stage of ontogenesis (BBCH 42), while the varieties 'Oesia' and 'Maurane' further increased leaf area (BBCH 45) (average LAI_{MAX} 2.77 for 'Oesia' and 2.80 for 'Maurane') (fig. 2A). We also observed that the variety 'Oesia' was characterized by faster senescence of oldest leaves in all three years. Rate of senescence of assimilatory apparatus was faster in the variety 'Oesia' by 24.30 %, respectively about 18.76 % in comparison with 'Fredonia Nova' and 'Maurane' (data not shown). A similar conclusion is confirmed by the parameter of photosynthetic potential (LAD) (tab. 1).

Figure 2 Seasonal courses of leaf area index (LAI) development (A) and net assimilation rate (NAR; g m^{-2} d^{-1}) (B) of three varieties of chicory plants grown in 2007 years and foliar treats with Atonik. Parameters were calculated in BBCH 15, 19, 42, 45 and 49 (presented as day of sowing). ● - 'Fredonia Nova' ■ - 'Oesia' ▲ - 'Maurane'; full symbol – non-treated plant, empty symbol – treated plan by Atonik. Where no error bars are apparent, they are smaller than the size of the symbol.



Analysis of photosynthetic activity of three varieties of chicory was characterized by parameter net assimilation rate (NAR). The first part of the growing season 2007 is characterized by high assimilation activity of chicory plants, which is necessary for the rapid closing of the crop (LAI increase) (fig. 2B). During this period, the highest NAR values were recorded in variety 'Maurane' (NAR_{MAX}; tab. 1). Gradually, after closing of the crop there is a decrease in NAR (fig. 2B), which is generally due to impair distribution of radiation in the vertical structure of the plant. Due to the high production efficiency of crops it is so important to achieve optimal value of LAI (LAI_{OPT}) very quickly, while maintaining the photosynthetic activity of the oldest leaves provides powerful photosynthetic potential (LAD) (table 1). In accordance with the statement of Djanaquiraman et al. (2004), nitrophenolates in Atonik with its protective effect against oxidative damage to cells of the assimilation apparatus delayes the senescence of leaves. We found out that all varieties of plants treated with Atonik has a larger number of physiologically functional leaves (data not shown), which also confirms an increase of LAD (tab. 1).

Figure 3 Root yield (kg m^{-2}) of chicory plants of varieties 'Fredonia Nova', 'Oesia' and 'Maurane' in experimental years 2006-2008.



The parameter NAR was very significantly affected by BAS treatment. The average increase of maximal level of NAR (NAR_{MAX}) in all the varieties during three years was 2.7 % (tab. 1). The most significant increase was observed in the variety 'Fredonia Nova' when average level of NAR during three vegetation periodes increased from 2.15 g m^{-2} d^{-1} (untreated plants) to 2.27 g m^{-2} d^{-1} in plants treated by Atonik. The positive impact of the BAS is integrally reflected in the parameter crop growth rate (CGR) of chicory plants. The highest maximum value of CGR (CGR_{MAX}) reached after application of Atonik the variety 'Maurane' at level 7.53 g m^{-2} d^{-1} in 2007 and the lowest the variety 'Maurane after application of Biafit Gold at level 6.35 g m^{-2} d^{-1} in 2006 (tab. 1). After reaching CGR_{MAX} growth rate of the crop until the harvest period decreased with no significant differences between varieties.

The chicory production is given by the number of plants per unit area of soil and root weight or inulin yield, respectively. The highest yield of roots was observed in the variety 'Fredonia Nova' at 2.25 kg m^{-2} in 2007. On the other hand, the lowest root yield was observed in the variety 'Maurane' (1.59 kg m^{-2} in 2008) (fig. 3).

In intensive production systems in which the number of plants per unit of area reached 50 (numbers per m^{-2}), with strict control of weeds, additional irrigation and high doses of nitrogen fertilization were observed the yield of chicory root nearly doubled (35-40 t ha^{-1}; see Meijer and Matthijsen, 1992a, 1992b; Amaducci and Pritoni, 1997), as we achieved in our experiments. In intensive crop architecture however, reduced crop yield inulin per unit root dry weight was observed, as documented Amaducci and Pritoni (1997) who found the root inulin content in chicory at level just under 14 %.

Figure 4 Harvesting index (%) of chicory plants of varieties 'Fredonia Nova', 'Oesia' and 'Maurane' in experimental years 2006-2008.

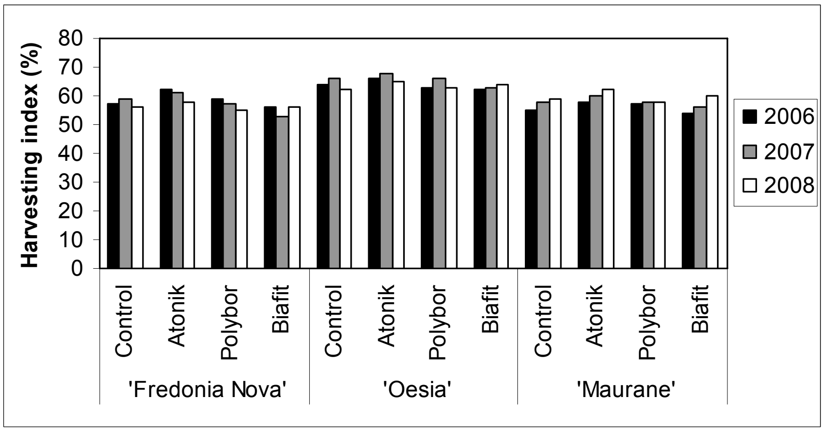
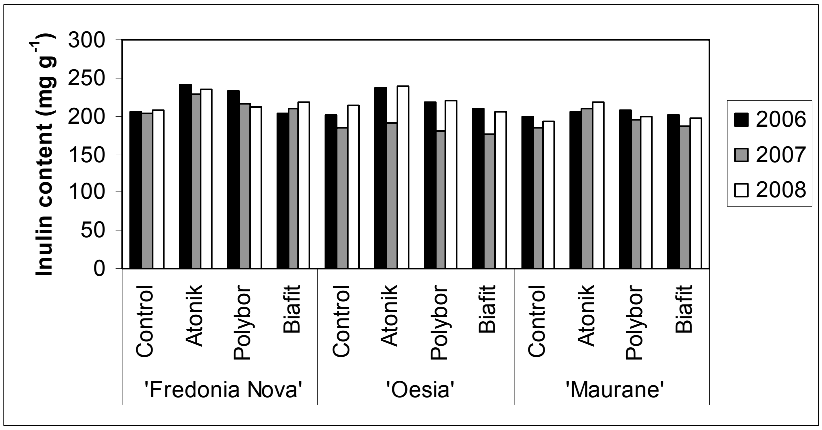


Figure 5 Inulin content (mg g^{-1}) in root of chicory plants of varieties 'Fredonia Nova', 'Oesia' and 'Maurane' in experimental years 2006-2008.



We found out that Atonik treatment increased the production of the root on average by 15.36 % (average yield of the roots of untreated plants was 2.04 kg m^{-2}, the average yield of treated plants by Atonik 2.35 kg m^{-2}). We observed that the highest positive effect of the Atonik treatment was in the variety 'Fredonia Nova', which was almost 13 % higher than in the variety 'Oesia' (the smallest effect of Atonik treatment) (fig. 3). In addition, to the quantitative dimension of the production, the Atonik treatment affected the quality of roots, when we recorded an average increase in root inulin content by 10.00 % to an average of 210 mg g^{-1} dry weight (fig. 5). Plants treated with the Polybor 150 increased the root yield during the experimental period an average only 1.53 % and application of Biafit Gold caused a reduction in average yield compared to untreated plants by 2.1 %.

The total amount of biomass production of chicory during the growing season compets with relatively small harvest index (HI) (fig. 4). The highest production of root in comparison with the total biomass reached the variety 'Oesia' (HI at 66.0 % in 2007). Nevertheless, the variety 'Fredonia Nova' reached the highest root yield, the average HI was only 57.3 % indicating a preferential consumption of assimilates for the development of the assimilation apparatus (the highest LAI). Parameter HI weakly responds to BAS treats (fig. 4). Since the primary action of nitrophenolates in Atonik are metabolic and physiological processes, there is a realistic assumption that in addition to photosynthetic processes (Bynum et al., 2007; Monti et al., 2005), nitrophenolates affect the processes of growth and maintenance of respiration, as well as the processes of redistribution of assimilates between the source and sink organs. Application of Atonik in all the varieties increased HI on average by 4,5 % to level 62,2 %. The most significant application of the Atonik manifested on HI increase in the variety 'Maurane' (three-year average from 57,3 % in control plants to 60,0 % in treated plants) (fig. 4). However, it must be noted, that chicory is rarely breeding crop (Baert and van Bockstaele, 1992) and the selection of varieties for improving the HI is a challenge to optimalize the production performance (van Stallen et al., 2005).

Chicory root accumulates the carbohydrate inulin. The optimum date of the harvest of roots is in non-physiological state and is given by the total content of sugars, as well as their ratio (Amaducci and Pritoni, 1997). The highest inulin content in root was observed in the variety 'Fredonia Nova' (205.9 mg g^{-1} dry weight), which is about 9.8 and 10.3 % more than in the varieties 'Maurane' and 'Oesia', respectively (fig. 5).

Baert (1997) concluded that the term of root harvest is not affected by the total amount of accumulated inulin in root, because the inulin accumulation is a function of variety. Date harvest depends on the mutual ratio between glucose and fructose (Dersch et al., 1993; Wilson et al., 2004). The inulin accumulation in a root depends on environmental conditions (especially drought and high temperature), physiological state of plants and is partially hydrolyzed under reduction of leaf area. In such cases the root has not the role of a sink but it becomes a source because the root provides carbon for the development of aboveground parts of plants.

The efficiency of chicory growing, is guaranteed on the one hand with relatively low-input and secondly by expanding the food and pharmaceutical industries with high demand for inulin. It is a suitable alternative in managing the economic profitability of the crop production. Of course, as well as our results show, it is necessary to optimalize the production in particular to ensure the improvement of allocation of assimilates into the root. One way is the biological regulation of production efficiency through the foliar application of biologically active substances (Černý et al., 2007). Our results showed that application of BAS (and mainly of Atonik) in all the varieties and experimental years significantly increased the growth-production performance of chicory and yield and quality of root. The second way of optimization the production of chicory is targeted breeding of varieties with high production potential and theirs ecological plasticity (Spranger et al., 1997; van Stallen et al., 2005).

ACKNOWLEDGMENTS

This study was supported by the Research project of the Scientific Grant Agency of the Slovak Ministry of Education and of Slovak Academy of Sciences number 1/3461/06 and 1/0388/09/8.

REFERENCES

Amaducci, S., Pritoni, G., (1997) Effect of harvest date cultivar on Cichorium intybus yield components in north Italy. Industrial Crops and Products 7 (2-3), 345-349.

Arteca, R.N., (1995) Plant growth substances: principles and applications. New York: Chapman Hall, 352 p.

Baert, J.R.A., (1997) The effect of sowing and harvest date cultivar on inulin yield and composition of chicory (*Cichorium intybus* L.) roots. Industrial Crops and Products 6 (3-4), 195-199.

Baert, J.R.A., Van Bockstaele, E.J., (1992) Cultivation and breeding of root chicory for inulin production. Industrial Crops and Products 1 (2-4), 229-234.

Bynum, J.B., Cothren, J.T., Lemon, R.G., Fromme, D.D., Boman, R.K., (2007) Field evaluation of nitrophenolate plant growth regulator (Chaperone) for the effect on cotton lint yield. Journal of Cotton Science 11 (1), 20-25.

Černý, I., Javor, D., (2004) Variety – important intensification factor of chicory cultivation (in Slovak Odroda - dôležitý intenzifikačný faktor pestovania čakanky obyčajnej). Naše pole 8 (5), 22–25.

Černý, I., Pačuta, V., Kovár, M., (2007) Yield and quality of chicory (*Cichorium intybus* L.) in dependence on variety and foliar application of Atonik and Polybor 150. Journal of Central European Agriculture 9 (3), 425-430.

Černý, I., Pačuta, V., Pulkrábek, J., (1999) Pestovanie semenných okopanín (Cultivation of root crop). Nitra: UVTIP, 105 p.

Dersch, G., Kammerer, S.; Praznik, W., (1993) Harvest dates and varietal effects on yield, concentration and composition of carbohydrates in chicory roots. In: Proceedings of the 2nd European Symposium on Industrial Crops and Products, Pisa.

Djanaguiraman, M., Devi, D.D., Shanker, A.K., Sheeba, J.A., Bangarusamy, U., (2004) The role of nitrophenol on delaying abscission of tomato flowers and fruits. International Journal of Food, Agriculture and Environment 2 (2), 183-186.

Endt, D.V., Kijne, J.W., Memelink, J., (2002) Transcription factors controlling plant secondary metabolism: what regulates the regulators? Phytochemistry 61 (2), 107-114.

Feller, C., Bleiholder, H., Buhr, L., Hack, H., Hess, M., Klose, R., Meier, U., Stauss, R., van den Boom, T., Weber, E., (1995) Phänologische Entwicklungsstadien von Gemüsepflanzen: I. Nachrichtenbl. Deut. Pflanzenschutzd. 47, 193-206.

Fuchs, A., (1991) Current and potential food and non-food applications of fructans. Biochemical Society Transactions 19 (3), 555-560.

Guo, C., Oosterhuis, D.M., Zhao, D., (1994) Enhancing mineral nutrient uptake of cotton plants with plant growth regulators. In: Proceedings of 21st Annual Meeting of Plant Growth Regulator Society of America, 1994, Portland, p.p. 244-251.

Hay, R.K.M., Porter, R.J., (2006) The physiology of crop yield. 2 ed. Wiley-Blackwell Publisher, Oxford, 328 p.

Květ, J., Marshall, J.K., (1971) Assessment of leaf area and other assimilating plant surfaces. In: Z., Šesták, J., Čatský, P.G., Jarvis, ed. (1971), Plant Photosynthetic production manual of methods. Hague: Junk, p.p. 517-555.

Květ, J., Ondok, J.P., Nečas, J., Jarvis, P.G., (1971) Methods of growth analysis. In: Z., Šesták, J., Čatský, P.G., Jarvis, ed. (1971), Plant Photosynthetic production manual of methods. Hague: Junk, p.p. 343-391.

Meijer, W.J.M., Matthijsen, E.W.J.M., (1992a) Crop characteristics and inulin production in chicory. European Journal of Agronomy 1 (2), 99-108.

Meijer, W.J.M., Matthijsen, E.W.J.M., (1992b) Experimental and simulated production of inulin by chicory and Jerusalem artichoke. Industrial Crops and Products 1 (2-4), 175-183.

Monti, A., Amaducci, M.T., Pritoni, G., Venturi, G., (2005) Growth, fructan yield, and quality of chicory (*Cichorium intybus* L.) as related to photosynthetic capacity, harvest time, and water regime. Journal of Experimental Botany 56 (415), 1389-1395.

Oosterhuis, D., Robertson, W.C., (2000) The use of plant growth regulators and other additives in cotton production. In: AAES Special Report 198, Proceedings of the 2000 Cotton Research Meeting, 2000, p.p. 22-32.

Ritsema, T., Smeekens, S., (2003) Fructans: beneficial for plants and humans, Current Opinion Plant Biology 6 (3), 223-230.

Roberfroid, M.B., van Loo, J.A., Gibson, G.R., (1998) The bifidogenic nature of chicory inulin and its hydrolysis products. The Journal of Nutrition 128 (1), 11-19.

Sharma, R., Sharma, B., Singh, G., (1984) Phenols as regulators of nitrate reductase activity in *Cicer arietinum*. Phyton 44, 185-188.

Schittenhelm, S., (1999) Agronomic performance of root chicory, Jerusalem artichoke and sugarbeet in stress and non-stress environment. Crop Science 39 (6), 1815-1823.

Spranger, N., Schellenbaum, L., van Dun, K., Boller, T., Weiken, A., (1997) Fructan synthesis in transgenic tobacco and chicory plants expressing barley sucrose: fructan 6G-fructosyltransferase. FEBS Letters 400 (3), 355-358.

Sommer, U., (1997) Production and use of inulin in the European Union. In: Proceedings from Seminar on Inulin, Braunschweig, Germany, 1997, p.p. 159-162.

Thome, U., Kühbauch, W., (1987) Alternatives for crop rotation. DLG-Mitteilungen, 18, p.p. 978-981.

van Laere, A., van Den Ende, W., (2002) Inulin metabolism in dicots: chicory as a model system. Plant, Cell and Environment 25 (6), 803-813.

van Stallen, N., Vandenbussche, B., Londers, E., Noten, V., de Proft, M., (2005) QTL analysis of production and taste characteristics of chicory (*Cichorium intybus* var. *foliosum*). Plant Breeding 124 (1), 59-62.

Wilson, R.G., Smith, J.A., Yonts, C.D., (2004) Chicory root yield and carbohydrate composition is influenced by cultivar selection, planting and harvest date. Crop Science 44 (3) 748-752.