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THE EFFECT OF PLANT AGE AND CROWN SIZE OF ASPARAGUS ON FERN GROWTH IN TERMS OF CARBOHYDRATE BALANCE

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Abstract. Asparagus plants cv. "Epos" were planted in the aeroponic system with recirculation in two cycles. The effect of asparagus plant age and crown size on fern growth were studied. The results show that the age of asparagus plants affected the number of ferns – the number of assimilation shoots increased with age – while the weight of asparagus crowns had an effect on the number and total weight of shoots. An increase in crown weight by about 1000 g caused an increase in the number of shoots by about 6, while the weight of one shoot increased by approx. 144 g. The age of aasparagus plants was also a significant factor for dry weight, % Brix and total carbohydrate contents in roots before the assimilation season as well as glucose, fructose, sucrose, GFS and total carbohydrate contents in roots after the assimilation season.

Key words: asparagus, ferns, shoots, crown size, sugars content

INTRODUCTION

In comparison with other vegetables, in asparagus current photosynthesis does not directly contribute to spear growth [Robb 1984]. Although all green tissues are capable of photosynthesis, fern (cladophylls) are the main assimilation site. After harvest spears are allowed to expand and developed into ferns. Growth rate is determined both by conditions found after harvest and the crown depletion rate, i.e. the number of remaining buds and the amount of reserve substances. Shoots are formed at the expense of utilized reserve substances. Newly formed assimilates are firstly translocated into storage roots and then utilized in spear growth during the next spring [Haynes 1987, Wooley et al. 1999]. A balance between the duration of harvest and the assimilation season

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is necessary to maximize yields and plant survival [Shelton and Lacy 1980, Taga et al. 1980]. A correlation between fern vigor in the previous year and the following year yield was documented [Hartmann 1985, Knaflewski 1994]. The next year yield may also be limited by any conditions during the growing season which limit fern growth (insects, diseases, drought, nutrient deficiency, low temperature after harvest). Little is known about the relationship between the age of an asparagus plant and fern growth. Thus, the objective of the study was to determine the effect of asparagus plant age and crown size on fern growth. Additionally, soluble sugar contents before and after the assimilation season were investigated.

MATERIALS AND METHODS

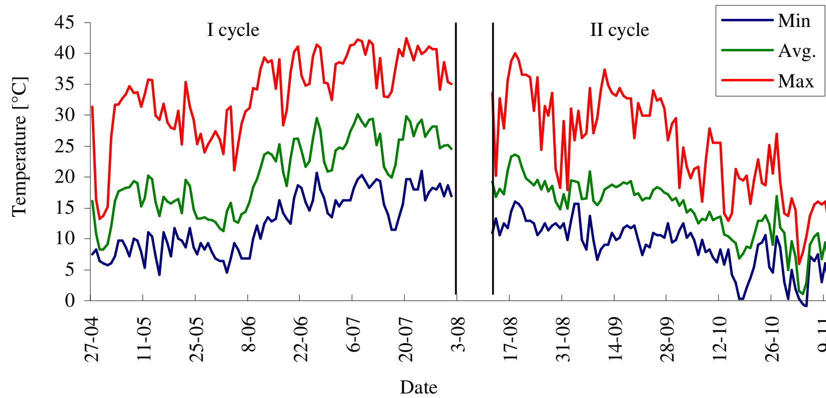
The project was started in April 2006 in a plastic tunnel. Treatments were carried out in a randomized block design with three replications. Eighteen asparagus plants cv. "Epos" were planted in the aeroponic system with recirculation. Plants were planted in two cycles – the first started on the 27th April 2006 and the other one started on the 11th August 2006. The end of harvest was 97 and 98 days after planting, respectively. The experimental factor was plant age. The weight of two-year-old crowns was 1.97 kg ± 0.91 kg, while that of five-year-old crowns was 2.07 ± 0.54 kg and that of eight-year-old crowns 3.34 ± 1.10 kg, respectively. Nutrient composition in the asparagus aeroponic system is given in table 1.

Table 1. Nutrient composition in asparagus aeroponic system
Tabela 1. Skład pożywki w uprawie aeroponicznej szparaga

Nutrient composition – Skład pożywki mg·dm^{-3}									EC mS·cm^{-1}	pH
N	N-NO_3	N-NH_4	P	K	Ca	Mg	Cl	S		
220	200	20	40	250	110	40	60	100	2.5	5.5

Temperature was recorded hourly by Hobo H08-007-02 data loggers (Onset Computer Corporation, USA) (accuracy -0.5°C, range from -40°C to +100°C). During the first week after planting air temperature were low (maximum 14–16°C, average 10°C). During the first cycle minimum temperature was 4°C, maximum 42°C, average 20.6°C. During the second till October minimum temperature was above 5°C and then decreased nearly to 0°C. Minimum temperature during the second cycle was -0,7°C, maximum 40°C and average 14,4°C (fig. 1).

PAR was recorded by Smart Sensor S-LIA-M003 worked with HOBO Weather Station logger. During the first week after planting it was cloudy and rather cold, so that PAR was low. During the first cycle max PAR was 55 mol m^{-2} per day (PAR during all I cycle was 3779 mol m^{-2}), while during the other PAR was 40 mol m^{-2} per day (PAR during all II cycle was 1669 mol m^{-2}) – figure 1.



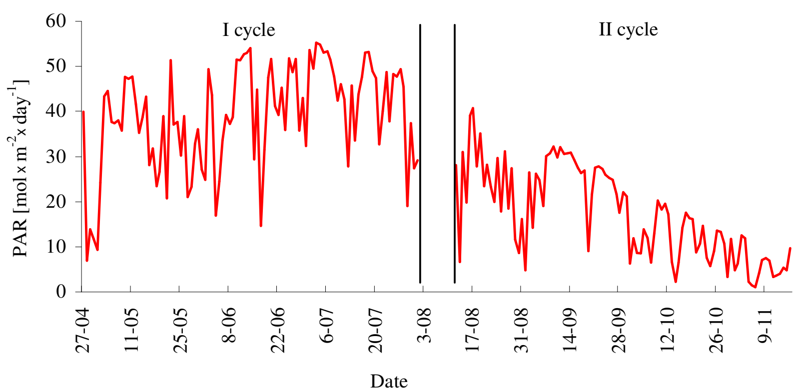


Fig. 1. Temperature and PAR in a plastic tunnel during the first and the second cycle in 2006
Rys. 1. Temperatura i PAR w tunelu podczas pierwszego i drugiego cyklu w roku 2006

Extraction and carbohydrate analysis

Carbohydrates were extracted from fleshy root samples (2 g) for 60 min with 10 ml of 80% ethanol at 80°C [Johansen et al. 1996]. Soluble sugars were analysed by HPLC (Waters Alliance 2695) using a Sugar-Pak I column (Waters). The mobile phase (filtered water with 0.1 mM Ca EDTA) was pumped through the column at a flow rate of 0.4 ml min^{-1}. The temperature of the column was 70°C, while that of the detector 40°C. An RI detector (Waters 2414) was used. Sucrose, glucose and fructose were identified by their retention times (14.4; 12.0 and 9.8 min, respectively) and were quantified according to standards.

Total sugars were determined in the same extracts after hydrolysis with 18% HCl for 24 h at room temperature [Siomos and Pontikidou 2000]. Fructan content was calculated based on the difference between total carbohydrates content and GFS.

Statistical analysis

The yield and content of soluble sugars were analysed statistically by ANOVA and the means were separated by the Newman-Keuls' test at a $\alpha = 0.05$ level. Regression equations and its coefficients were estimated by computer programs: Excel '97 Microsoft Corp., Table Curve 2D SPSS Inc. and Statistica for Windows ver. 5.1G (edition '97) by Statsoft Inc. The equations were fitted by standard least-squares minimisation.

RESULTS AND DISCUSSION

Variation analysis confirmed that the age of asparagus plants affected the number of ferns (tab. 2). Two-year-old plants formed the lowest number of assimilation shoots, while eight-year-old plants formed the highest number. Their diameter, length and one shoot weight were not crown age dependent (tab. 2).

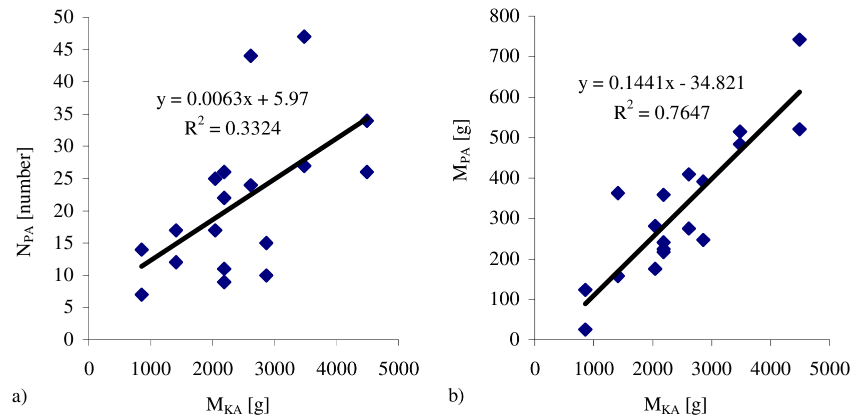
Table 2. Characteristics of assimilation shoots collected from two experiments in a plastic tunnel in 2006

Tabela 2. Charakterystyka pędów asymilacyjnych zbieranych w dwóch cyklach w tunelu foliowym w 2006

Plant age Wiek rośliny	Assimilation shoots – Pędy asymilacyjne						
	number ilość szt.	diameter średnica mm	length długość cm	one shoot weight masa pojed. pędu g	total shoot weight masa wszystkich pędów g	after covariance – po kowariancji: number ilość szt.	after covariance – po kowariancji: total shoot weight masa wszystkich pędów g
2	11.0	5.2	80	21.0	231	14.1	302
5	24.2	3.8	63	11.4	274	26.6	330
8	29.3	4.1	62	15.4	453	23.8	326
$LSD_{\alpha = 0.05}$ $NIR_{\alpha = 0.05}$	11.99	n.s. n.i.	n.s. n.i.	n.s. n.i.	n.s. n.i.	n.s. n.i.	n.s. n.i.

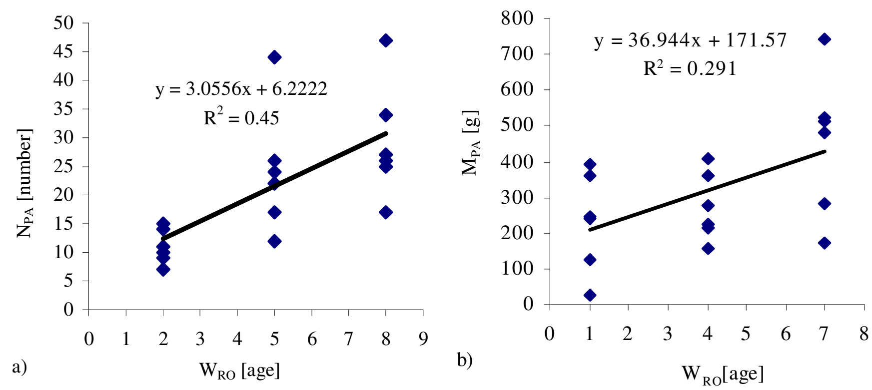
However, the number of shoots (N_{PA}) and their weight (M_{PA}) were confirmed to be dependent on the weight and age of asparagus crowns (M_{KA}) – figures 2 and 3. An increase in crown weight by about 1000 g caused shoot number to increase by about 6, while one shoot weight was by 144 g higher (fig. 2). Each year the number and weight of shoots increased by approx. 3 ferns and by 37 g per plant, respectively (fig. 3). Multiple regression analysis confirmed that the number of assimilation shoots (N_{PA}) was dependent on plant age (W_{RO}) and crown weight (M_{KA}) (equation 1). It was found that Equation 1 explained 51% variation in the number of ferns (shoots).

$$N_{PA} = 2.31 \cdot W_{RO} + 0.0033 \cdot M_{KA} + 4.228, \quad R^2 = 0.51 \tag{1}$$



*significant at $\alpha = 0.05$
* istotne na poziomie $\alpha = 0,05$

Fig. 2. The effect of crown weight (M_{KA}) on a) the number of assimilation shoots (N_{PA}), b) their weight (M_{PA})
Rys. 2. Wpływ masy karpy (M_{KA}) na a) liczbę pędów asymilacyjnych (N_{PA}), b) ich masę (M_{PA})



*significant at $\alpha = 0.05$
*istotne na poziomie $\alpha = 0,05$

Fig. 3. The effect of plant age (W_{RO}) on a) the number of assimilation shoots (N_{PA}) b) their weight (M_{PA})
Rys. 3. Wpływ wieku rośliny (W_{RO}) na a) liczbę pędów asymilacyjnych (N_{PA}), b) ich masę (M_{PA})

Table 3. Mean contents of dry matter, % Brix abd saccharides in asparagus roots after planting in aeroponic cultivation tanks and after the completion of assimilation season in a plastic tunnel in 2005

Tabela 3. Średnia zawartość suchej masy, ekstraktu oraz zawartość i ilość cukrów w korzeniach szparaga po posadzeniu roślin w zbiorniki do uprawy aeroponicznej oraz po zakończeniu okresu asymilacji w tunelu foliowym, średnio w dwóch cyklach uprawowych w roku 2005

Term Termin	Crown age Wiek karpy	d.w. ś.m. %	Brix %	Glucose Glukoza (G)	Fructose Fruktoza (F)	Sucrose Sacharoza (S)	GFS	Fructan Fruktany	Total sugars Cukry ogółem	Total sugars Cukry ogólem $g \cdot plant^{-1}$ $g \cdot roślina^{-1}$
				mg · g^{-1} f.w. – mg · g^{-1} ś.m..						
Before Przed (A)	2	20.2	16.1	7.4	2.4	37.4	47.3	382	429	181
	5	22.3	19.8	5.1	5.6	50.4	61.1	457	519	253
	8	21.9	19.1	6.5	4.7	39.1	50.3	450	500	356
	$LSD_{\alpha=0.05}$ $NIR_{\alpha=0.05}$	0.79	2.95	n.s. n.i.	n.s. n.i.	n.s. n.i.	n.s. n.i.	n.s. n.i.	71.4	n.s. n.i.
After Po (B)	2	16.5	10.0	6.2	2.8	18.5	27.5	252	280	104
	5	19.2	14.5	13.8	13.2	38.5	65.4	336	390	159
	8	18.6	13.5	36.5	38.7	60.8	135.9	276	367	218
	$LSD_{\alpha=0.05}$ $NIR_{\alpha=0.05}$	n.s. n.i.	n.s. n.i.	9.11	14.88	23.5	32.1	n.s. n.i.	n.s. n.i.	87.9
B-A	2	-3.7	-6.2	-1.3	+0.3	-18.9	-19.8	-130	-150	-77
	5	-3.1	-5.3	+8.7	+7.6	-11.9	+4.4	-122	-128	-94
	8	-3.3	-5.5	+30.0	+34.0	+21.6	+85.7	-174	-134	-138
	$LSD_{\alpha = 0.05}$ $NIR_{\alpha = 0,05}$	n.s. n.i.	n.s. n.i.	n.s. n.i.	n.s. n.i.	n.s. n.i	n.s. n.i.	n.s. n.i.	n.s. n.i.	n.s. n.i.

*significant at $\alpha = 0.05$ – istotne na poziomie $\alpha = 0,05$

A – after planting in aeroponic cultivation tanks (before assimilation) – po posadzeniu roślin w zbiorniki do uprawy aeroponicznej, (przed okresem asymilacji)

B – after the completion of assimilation season – po zakończeniu okresu asymilacji

As a result of the elimination of non-significant effects in multiple regression analysis it was found that the weight of assimilation shoots depended only on crown weight. Variation analysis confirmed that plant age was a significant factor for dry weight, % Brix and total carbohydrate content before the assimilation season (tab. 3). Two-year-old plants had the lowest dry weight, % Brix and sugar contents. After the assimilation season glucose, fructose, sucrose, GFS and total carbohydrate contents per plant in storage roots of asparagus were also plant age dependent. The highest amount of these sugars was confirmed in eight-year-old plant. The difference (the mathematical result) between all analyzed parameters after and before the assimilation season was not plant age dependent. Although during the assimilation season dry weight, % Brix, fructan and total carbohydrate content were observed to decrease, glucose (besides at two years old planta) and fructose contents increased. Sucrose content was higher only in eight-year-old plants, while GFS content increased both in five- and eight-year-old plants. As the asparagus fern grows, more dry weight is partitioned to the crown and less to the ferns; a large crown produces greater fern biomass, stores more carbohydrates and initiates more buds, which are a very important factor affecting asparagus yield [Haynes 1987, Hughes et al.1990, Wilcox-Lee and Drost 1990, Wilson et al. 1999, 2002]. The size of assimilation shoots depends also on temperature. Although assimilation shoots grow fast at high temperatures, they are finally smaller in size than shoots of plants growing at moderate temperatures [Yen et al. 1996].

Table 4. Correlation coefficients between crown age/weight and dry weight, glucose, fructose, sucrose, GFS, fructan and total sugar contents before assimilation season
Tabela 4. Współczynniki korelacji pomiędzy wiekiem karpy/masą a suchą masą, zawartością glukozy, fruktozy, sacharozy, GFS, fruktanów oraz ogólna zawartością cukrów przed okresem asymilacji

Parametr Parametr	Unit Jednostka	Crown age – Wiek karpy		Crown weight – Masa karpy kg	
		r	regression equation równanie regresji	r	regression equation równanie regresji
d.w. s.m.	%	0.233	n.s. n.i	-0.009	n.s. n.i.
Glucose (G) Glukoza	$mg \cdot g^{-1}$ f.w. $mg \cdot g^{-1}$ ś.m.	-0.043	n.s. n.i.	-0.329	n.s. n.i.
Fructose (F) Fruktoza		0.218	n.s. n.i	-0.178	n.s. n.i.
Sucrose (S) Sacharoza		0.024	n.s. n.i.	-0.261	n.s. n.i.
GFS GFS		0.034	n.s. n.i.	-0.315	n.s. n.i.
Fructan Fruktany		0.244	n.s. n.i.	0.089	n.s. n.i.
Total sugars Cukry ogółem		0.233	n.s. n.i.	-0.009	n.s. n.i.
Total sugars Cukry ogółem	$g \cdot plant^{-1}$ $g \cdot roślina^{-1}$	0.496*	y = 29.237x + 146.45	0.662*	y = 0.094x + 32.537

*significant at $\alpha = 0.05$
*istotne na poziomie $\alpha = 0,05$.

Table 5. Correlation coefficients between crown age/weight and dry weight, glucose, fructose, sucrose, GFS, fructan and total sugar after assimilation season

Tabela 5. Współczynniki korelacji pomiędzy wiekiem karpy/masą a suchą masą, zawartością glukozy, fruktozy, sacharozy, GFS, fruktanów oraz ogólna zawartością cukrów po okresie asymilacji

Parametr Parametr	Unit Jednostka	Crown age – Wiek karpy		Crown weight – Masa karpy kg	
		r	regression equation równanie regresji	r	regression equation równanie regresji
d.m. s.m.	%	0.332	n.s. n.i	0.032	n.s. n.i.
Glucose (G) Glukoza	$mg \cdot g^{-1}$ f.w. $mg \cdot g^{-1}$ ś.m.	0.745*	y = 4.8795x - 0.7777	0.368	n.s. n.i.
Fructose (F) Fruktoza		0.699*	y = 5.8144x - 5.1044	0.563*	y = 0.0126x - 13.434
Sucrose (S) Sacharoza		0.594*	y = 7.0098x + 11.214	0.329	n.s. n.i.
GFS GFS		0.695*	y = 17.704x + 5.3315	0.431	n.s. n.i.
Fructan Fruktany		0.076	n.s. n.i.	-0.068	n.s. n.i.
Total sugars Cukry ogółem		0.332	n.s. n.i.	0.032	n.s. n.i.
Total sugars Cukry ogółem	g $plant^{-1}$ g $roślina^{-1}$	0.55*	y = 19.001x + 84.447	0.638*	y = 0.053x + 30.15

*significant at α = 0.05
*istotne na poziomie α = 0,05.

Many authors reported [Shelton and Lacy 1980, McGrady and Tilt 1990, Wilcox-Lee and Drost 1991, Pressman et al. 1993], that after fern senesce both the quantity and polymerization rate increased in asparagus storage roots starting from the moment when the amount of formed assimilates exceeded actual requirement of plants. As it was confirmed, after assimilation season carbohydrates contents increase [McGrady and Tilt 1990, Wilcox-Lee and Drost 1991, Pressman et al. 1993]. The opposite relation was observed during the study (tab. 3). In our experiment in the plastic tunnel after the assimilation season, when ferns senesced, losses in fructan content were reported, while content of soluble sugars increased. The first reason of that was probably lower PAR in comparison with field conditions (about 20%). Next reason, especially during I cycle, was probably higher than in field conditions temperature. During II cycle the temperature in the tunnel was nearly the same as in field, but PAR was lower than in I cycle. So that observed losses of sugars contents after assimilation season could be the result of their used for roots respiration. Temperature was supposed to be a stressful factor causing increased respiration and carbohydrates requirement. For this reason fructans were constantly hydrolyzed and not stored. This weather conditions caused also limited formation of buds.

During the experiment the relationships between crown age/weight and sugars contents before and after assimilation season were analyzed (tabs. 4 and 5). Significant correlation were confirmed between:

– total sugars content per plant (both before and after assimilation season) and crown age and weight,

– glucose, fructose, sucrose and GFS content in roots after assimilation season and crown age,

– fructose content in roots after assimilation and crown weight.

Each year before assimilation, plant age caused increase of total sugars content per plant 29 g, and 1 kg increase of crown weight caused 94 g their increase, while after assimilation the sugar content was higher only about 19 g and 53 g, respectively.

CONCLUSIONS

1. The number of assimilation shoots (ferns) of asparagus and total shoot weight were dependent on both plant age and crown weight – successive years of culture and thus also an increase of crown weight caused their number to grow.

2. Asparagus plant age was the factor, which differentiated also other analyzed parameters: contents of dry matter, sugars and % Brix either before or after the assimilation season.

3. Temperature was a reason of high requirement for fructan hydrolysis product, probably because of increasing respiration.

4. Before assimilation season both crown age and weight effected on total sugar content per plant.

5. After assimilation season crown age effected on glucose, fructose, sucrose, GFS and total sugar content per plant, while crown weight only on fructose and total sugar content per plant.

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WPŁYW WIEKU ROŚLINY ORAZ WIELKOŚCI KARPY SZPARAGA NA WZROST PĘDÓW ASYMILACYJNYCH Z UWZGLĘDNIENIEM BILANSU CUKRÓW

Streszczenie. Rośliny szparaga odmiany „Epos" uprawiane były w systemie aeroponicznym z recyrkulacją w dwóch cyklach. Przedmiotem badań był wpływ wieku roślin szparaga i wielkości karpy na wzrost pędów asymilacyjnych. Badania wykazały, że wiek roślin wpływał na ilość pędów asymilacyjnych – ilość pędów wzrastała wraz z wiekiem – natomiast masa karpy wpływała na ilość oraz masę wszystkich pędów ogółem. Wzrost masy karpy o 1000 g powodował wzrost liczby pędów asymilacyjnych o 6 sztuk i wzrost masy pojedynczego pędu o 144 g. Wiek roślin szparaga był istotnym czynnikiem wpływającym na suchą masę, % Brix i ogólna zawartość cukrów w korzeniach przed okresem asymilacji, jak również na zawartość glukozy, fruktozy, sacharozy, GFS i cukrów ogółem w korzeniach spichrzowych po okresie asymilacji.

Słowa kluczowe: szparag, pędy asymilacyjne, wielkość karpy, zawartość cukrów

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