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FACTORS INFLUENCING GROWTH OF MATURE SYCAMORE TREES (*Acer pseudoplatanus* L.) ON CARBONATE BEDROCK

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Abstract
This paper presents the growth potential of sycamore (*Acer pseudoplatanus* L.) on four types of forest sites located on carbonate bedrock. The research covers sycamore sites (*Aceri-Fraxinetum ill.*), beech sites (*Lamio orvalae-Fagetum*), beech sites planted with Norway spruce, and silver fir-beech sites (*Omphalodo-Fagetum aceretosum*). The analyses for each forest type were carried out on five plots. Our aim was to determine the effect of site factors and stand parameters on sycamore growth. Site productivity (SP) is positively correlated with soil depth, coarse silt percentage in the cambic horizon, the content of phosphorus in leaves and, partly, with potassium. The effect of nitrogen supply on height growth or SP was not confirmed. Furthermore, height growth on sites with a higher rate of nutrient cycling, higher macronutrient supply and higher sand percentage in the cambic horizon is significantly faster. As to the growth of basal area, in addition to positive dependences of crown size, many other correlations with site factors were confirmed.

Key words: *Acer pseudoplatanus*, site productivity, height increment, basal area increment, site factor, carbonate bedrock

RASTNI DEJAVNIKI PRI ODRASLEM GORSKEM JAVORJU (Acer pseudoplatanus L.) NA KARBONATNI MATIČNI PODLAGI

Izvleček
V prispevku je obravnavan rastni potencial gorskega javorja (Acer pseudoplatanus L.*) na štirih tipih gozdnih rastišč na karbonatni matični podlagi. V raziskavo so zajeta javorovja (Aceri-Fraxinetum ill.), bukova rastišča (Lamio orvalae-Fagetum), zasmrečena bukova rastišča v isti gozdni združbi in jelovo bukova rastišča (Omphalodo-Fagetum acereretosum). Za vsak rastiščni tip smo napravili analize na petih ploskvah. Namen raziskave je ugotoviti rastiščne faktorje oziroma sestojne parametre, ki vplivajo na rast pri odraslem gorskem javorju. Proizvodna sposobnost je v pozitivni povezavi z globino tal, deležem grobega melja v kambičnem horizontu, s koncentracijo fosforja v listih in deloma tudi s kalijem v listih. Vpliv preskrbe z dušikom na višinsko rast oziroma proizvodno sposobnost ni potrjen. Višinska rast je bila hitrejša na rastiščih z hitrejšim kroženjem snovi, boljšo preskrbljenostjo z makrohranili in višjim deležem peska v kambičnem horizontu. Glede temeljnične rasti smo poleg pozitivne odvisnosti od velikosti krošnje potrdili še številne povezave z rastiščnimi dejavniki.*

Key words: Acer pseudoplatanus, proizvodna sposobnost rastišča, višinski prirastek, temeljnični prirastek, rastiščni faktor, karbonatna matična podlaga

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VSEBINA
CONTENTS

1 INTRODUCTION
UVOD

The importance of minority tree species in Central Europe has been increasing recently, which especially holds true for valuable broadleaves (THIES / HEIN 2000). Sycamore (*Acer pseudoplatanus* L.), the species treated in this paper, undoubtedly belongs to this group (ibidem.). High attractiveness of sycamore is a result of its broad ecological range (SPETHMANN / NAMVAR 1985), its presence in various forest site types, vast reproductive potential (HEGI 1927), solid growth (NAGEL 1985) and the attainability assortments of high value (THOROE / OLLMANN 2001). What is more, the influence of sycamore litterfall on soil processes and soil properties is quite favourable (HOFFMANN 1960; NEIRYNCK *et al*. 2000), especially in coniferous plantations. Frequent and abundant fructifications resulting in dense regeneration are also an important source of food for many animal species, particularly deer (EIBERLE 1985).

Sycamore as an admixed tree species is a valuable indicator of special (micro) conditions or/and events in forest stands (disturbances).

A prerequisite for successful preservation or promotion of any species is sufficient knowledge of its ecological demands. The establishment of a tree species is indicated by its growth, which has not been - in the case of sycamore - sufficiently studied (KJÖLBY / SABROE / MOLTESEN 1958; FAUST 1963; AREND 1982; NAGEL 1985; JÖRNS 2000). Even less is known about the factors influencing sycamore growth (e.g. RÖHRIG 1967; HENNECKE 1977; FELIKSIK / NIEDZIELSKA / WILCZYNSKI 2000), since the majority of researches study young individuals, particularly sycamore seedlings, often growing in artificial conditions (HELLIWELL 1965; LYR / DREYER / AUSSENAC 1996; CORNELLISEN / CARNELLI / CALLAGHAN 1999; WEBER 1999; WEBER / BAHR 2000a; WEBER-BLASCHKE / CLAUS / REHFÜSS 2002). In mature stands, the interspecific competition was mostly researched (e.g. NÜSSLEIN 1995), taking the impact of site conditions into consideration only exceptionally (HEIN 2004).

In addition to growth studies, some fundamental ecological research work has also been carried out (GADOW v. 1975; OKALI 1966a, b; BRAUN 1976; MILLARD / PROE 1991).

This paper aims to determine the factors influencing sycamore growth in the mature phase. We are interested in the influence of stand and site conditions. Our purpose is to confirm the following hypotheses:

1. Site productivity (hereafter: SP) of sycamore is influenced by nitrogen concentration in soil and by plant available water. Furthermore, SP is dependent on soil conditions only.
2. Height increment depends solely on soil conditions.
3. Basal area increment is only influenced by crown dimensions (HEIN 2004), site factors are not important.

The first hypothesis is based on common quotes (e.g. GADOW v. 1975; HENNECKE 1977; FRANC / RUCHAUD 1996; WEBER / BAHR 2000b) on the optimal conditions for sycamore growth: fresh, airy soil rich in nutrients, nitrogen in particular, and well-supplied with water.

This research was carried out on carbonate bedrock. Recent findings on the importance of sufficient base saturation for the growth and development of sycamore, known for having a particular sensitivity to magnesium and calcium deficiencies (WEBER 1999; WEBER / BAHR 2000a; WEBER / BAHR 2000b), supported by some older observations (e.g. KJÖLBY / SABROE / MOLTESEN 1958), led us to the reflection that the effects of other factors might be better expressed excluding bigger variations in base saturation. One way of controlling that is to restrict the study area to carbonate bedrock sites.

2 MATERIALS AND METHODS
OBMOČJE RAZISKAVE IN METODE

2.1 SITE CHARACTERISTICS
ZNAČILNOSTI LOKACIJ

The study was carried out in the central and southern parts of Slovenia, in four stand-site conditions. The first forest type presents a beech stand with admixed sycamore on a site phytosociologically defined as *Lamio orvalae – Fagetum* (the location of Brezova reber). The second type appears in the same site unit, but is occupied by a spruce stand (plantation) with naturally admixed sycamore (the location of Jauhe). The third type is to be found on the site defined as *Aceri-Fraxinetum illyricum*, where sycamore is the dominant tree species (the location of Konjice). The latter type presents mixed stands of beech, silver fir, spruce and sycamore in the site unit *Omphalodo-Fagetum aceretosum* (the location of Strmec).

Table 1: General characteristics of research sites

Preglednica 1: Spošne značilnosti analiziranih lokacij

Site descriptor / *Rastni deskriptor*	Site / *Lokacija*			
	Brezova reber	Jauhe	Konjice	Strmec
Exposition / *Ekspozicija*	All directions / *Vse smeri*	East / *Vzhod*	Mainly North / *Pretežno sever*	Mainly North / *Pretežno sever*
Altitude (m) / *Nadm. višina*	400-450	570-670	800-950	600-800
Inclination (°) / *Naklon*	5	3	12	14
Precipitation (mmyear^{-1}) / *Padavine*	1300	1280	1150	1600
Stoniness (%) / *Kamnitost*	14	27	11	21
Soil type / *Talni tip*	Luvisol on limestone / *Izprana rjava pokarbonatna tla*	Luvisol on limestone / *Izprana rjava pokarbonatna tla*	Brown soil on limestone / *Rjava po-karbonatna* tla	Luvisol and brown soil on limestone / *Izprana in neizprana rjava pokarbonatna tla*
Soil parameters / *Talni parametri*	Mean/Min/Max *Povp./min./max.*	Mean/Min/Max *Povp./min./max.*	Mean/Min/Max *Povp./min./max.*	Mean/Min/Max *Povp./min./max.*
Soil depth / *Globina*	0.47/0.42/0.52	0.27/0.21/0.34	0.52/0.41/0.67	0.29/0.23/0.40
Forest floor (tha^{-1})/ *Organski talni horizonti*	13.8/10.0/16.5	16.3/11.4/26.0	14.4/10.9/16.4	21.7/11.1/47.5
Volume of A horizon (m^{3}ha^{-1}) (A_{hor}) / *Volumen A horizonta*	985/498/1376	893/549/1600	2008/1296/3300	1019/474/1404
pH (A_{hor})	4.7/4.1/5.0	4.7/4.1/5.8	5.7/4.7/6.5	5.0/4.3/6.5
C/N (A_{hor})	13.2/11.5/14.2	16.3/9.7/19.9	12.5/11.3/14.1	13.2/10.0/18.1
V (%) (A_{hor})	29.8/15.3/40.7	40.7/26.9/63.1	55.9/34.8/74.0	38.2/15.6/72.9

For each forest type, five research plots measuring 30 × 30 m (0.09 ha) were established (Table 1). On bigger plots, the homogeneity of site conditions would in most cases deteriorate. The plots included in the research were sampled by the principles of quota sampling, since the correct random sampling would be very expensive and time-consuming work. On the appropriate macrolocation for a particular forest type, only those five plots which best fulfilled the conditions (mature stand, appropriate tree species composition, at least four dominant sycamore trees per plot, expressiveness of site conditions and absence of severe injuries on trees and soil) were included into the research.

The analysed forest types differ importantly in the past management or silvicultural treatments. The most intensively managed location was Brezova reber, followed by the locations of Strmec and Jauhe. On the location Konjice, only salvage fellings were carried out. The actual intensity of management actions is impossible to reconstruct due to small surfaces of the analysed plots.

2.2 METHODS
METODE

This study is based on several methodological complexes.
The stand structure was analysed by means of measurements on 20 sample plots (30 × 30 m). Diameter at breast height (hereafter: DBH), tree height, crown base height (from the lowest primary branch with a diameter of at least 3 cm) and eight radii of the crown projection area were measured for each tree (with a DBH above 10 cm) on each plot.

The density of crown cover was calculated as a sum of crown projections of all the trees on each plot. This parameter is expressed as a ratio between the sum of crown projections and plot surface in percentages.

For each tree crown on every plot, the mean diameter, surface and volume were calculated. When calculating the last two parameters, we relied on the procedure and species specific coefficients, as proposed by PRETZSCH (2002, p. 207).

We dug out a soil profile on each plot, determined the soil horizons and examined them by means of pedological analysis. In the laboratory the following parameters were examined: pH ($CaCl_2$), P_2O_5, K_2O, organic matter, C %, N %, texture, exchangeable cations, exchangeable hydrogen, the sum of cations, cation exchange capacity (CEC) and base saturation.

The gathered soil data enabled us to model the values of air capacity (expressed in % of soil volume), plant available water and field capacity for each soil horizon on all the plots. The model was based on the procedure developed by FINNERN *et al.* (1994). The water-soil characteristics were modelled for cambic horizons (hereafter: B_{hor}). These horizons are most appropriate for the comparison of the plots, since they are highly objective with regard to water-soil characteristics.

Furthermore, the soil depth on each plot was measured by means of 25 systematically scattered points. The maximum depth of penetration was 80 cm. If stones or rocks stopped the probing before reaching a depth of 80 cm, we recorded the maximum depth that had been reached. In this research, variable depth is defined as the share of soil without rocks to a depth of 80 cm. Moreover, the surface stoniness of plots was determined through estimations of stoniness in percentages on 25 subplots - measuring 1 square meter each - arranged systematically on each plot.

Additionally, the quantity of soil organic layers (hereafter: forest floor) on each plot was systematically sampled (26 points per plot; at each point the material was sampled within the square of 25 x 25 cm). The material was dried at 105 ºC and weighed.

Four litter traps were put out on each plot in order to perform litter sampling. The inner surface of litter traps totalled 0.5 m^2. The litter from the four traps on one plot was put together and then dried at 105 ºC and weighed.

At the end of November we put bags with cellulose (bleached cellulose of beech) systematically under the forest floor in order to specify the speed of decomposition on two plots of each location (8 plots altogether). Nine bags per plot were sampled after 12 months. By weighing the cellulose before putting it on plots and after picking it up, we were able to determine the share of non-decomposed cellulose.

For foliar analyses the procedure was based on methods proposed by UN ECE-ICP (1994). In the second half of August and in the first days of September (before yellowing of sycamore leaves), the leaves of five thickest sycamore trees from each plot were sampled. The share of an individual tree in the composite sample of each plot was in proportion to its share in the total crown surface. The crown surface of each tree was calculated with the formula for the surface of a quadratic paraboloid, using mean crown diameter and crown length in calculations.

The concentrations of C, N, Ca, Mg, K and P in leaves were determined in the laboratory using the methods proposed by ECE-ICP (1993).

To indicate the nutrient cycling rate, Olson's formula, which represents the ratio between the annual litter and the quantity of forest floor, was used. The inverse ratio is called the turnover time.

For growth analyses, four thickest sycamore trees were cut down on each plot. A stem analysis was made for each analysed tree. Moreover, stem discs taken at breast height were also dendrochronologically analysed. Dendrochronological analyses were performed with digital positiometer (produced by L. Kutschenreiter) in four directions on each stem disc.

For regression analyses of height and diameter growth, the function of Chapman-Richard (ZEIDE 1993) was used.

The statistical analyses were carried out in an SPSS program (version 12.0.1 for Windows). The level of statistical significance is 5 % (P = 0.05).

Before making any correlation analysis between growth and stand-site factors, the influence of different ages and different past management actions should be eliminated (i.e. using partial correlation).

2.3 GROWTH DESCRIPTORS
RASTNI DESKRIPTORJI

The average height of four thickest sycamore trees on each plot at 80 years of age (site index at 80 years of age; hereafter: SI_{80}) was used as a growth descriptor for the collective of trees, which indicate SP. 80 years was the highest age achieved (rounded off) by the analysed trees on all the plots. As additional descriptors (growth descriptors) we used the height and basal area increment for trees (mean value of four individuals per plot) in the last 10 years (hereafter: HI_{10} and BAI_{10}).

As to obvious differences in the age of sycamore on the plots (Table 2), we tested the statistical significance in growth descriptors between the locations by using the covariance analysis (hereafter: Covar; age is the covariate). All the descriptors significantly differ between locations (SI_{80}, P = 0.003; HI_{10}, P = 0.000 and BAI_{10}, P = 0.001). Furthermore, after the exclusion of stand density influence (Nha^{-1}; this variable and the age were covariates), we again ascertained significant differences between locations for all growth descriptors (SI_{80}, P = 0.006; HI_{10}, P = 0.001 and BAI_{10}, P = 0.003).

Table 2: Basic parameters of growth descriptors and age of sycamore by analysed location

Preglednica 2: Osnovni parametri rastnih deskriptorjev in starosti po lokacijah

Growth descriptor / *Rastni deskriptor*	Parameter	Brezova reber	Jauhe	Konjice	Strmec
SI_{80} (m)	Mean / *Povprečje*	26.21	24.23	25.64	22.66
	Std. Dev. / *St. odklon*	3.9720	0.7170	1.3328	3.4752
	Std. Error / *St. napaka*	1.7763	0.3207	0.5960	1.5542
	Min / Max	22.60/30.61	23.41/25.34	23.67/27.15	18.98/26.72
HI_{10} (m/10year)	Mean / *Povprečje*	2.11	1.67	1.80	1.33
	Std. Dev. / *St. odklon*	0.2528	0.1861	0.3943	0.2615
	Std. Error / *St. napaka*	0.1131	0.0832	0.1763	0.1169
	Min / Max	1.79/2.36	1.53/1.99	1.32/2.28	1.11/1.66
BAI_{10} (dm^2/10year)	Mean / *Povprečje*	1.71	1.55	3.17	1.43
	Std. Dev. / *St. odklon*	0.4532	0.2771	0.8220	0.5526
	Std. Error / *St. napaka*	0.2027	0.1239	0.3676	0.2471
	Min / Max	1.05/2.18	1.18/1.89	2.34/4.08	0.87/2.17
Age / *Starost* (year)	Mean / *Povprečje*	95.7	90.0	130.7	129.5
	Std. Dev. / *St. odklon*	13.471	1.961	6.093	42.152
	Std. Error / *St. napaka*	6.0246	0.8768	2.7249	18.8509
	Min / Max	80.3/107.0	88.0/93.3	122.5/137.5	90.7/193.3

3 RESULTS
REZULTATI

3.1 INFLUENCE OF STAND PARAMETERS ON GROWTH POTENTIAL
VPLIV SESTOJNIH PARAMETROV NA RASTNI POTENCIAL

In order to establish which stand parameter influences growth descriptors most strongly, we tested the relations (partial correlations; age is the covariate) between growing stock (m^3ha^{-1}), basal area (m^2ha^{-1}), stand density (Nha^{-1}), crown projection area (%) and growth descriptors. Only two significant correlations were confirmed. The relationship between BAI_{10} and stand density (r = -0.587; P = 0.008) is quite logical (fewer trees means larger crowns, larger crowns provide for higher increment), while the correlation between SI_{80} and stand density (r = -0.622; P = 0.004) is probably a result of certain favourable site conditions on the plots with low density (despite the lowest felling intensities, which were found on valuable-broadleaved tree-species sites). Otherwise, low stand density destimulates height growth, which is reflected in lower site indices.

Furthermore, the correlation between growth descriptors and age was tested. Only one significant relationship was confirmed by the exclusion of stand density influence (partial correlation). The negative connection between age and SI_{80} (r = -0.758; P = 0.000; locations with low or high mean site index are equally distributed among younger and older collectives) signifies that younger collectives of dominant sycamore trees achieved higher site indices.

Before testing the correlations between growth descriptors and crown parameters, the influence of age and different stand densities on the plots was eliminated (Table 3). The last column on the right includes information about (non)significant differences of crown parameters between locations.

Table 3: Partial correlation coefficients between growth descriptors and crown parameters

Preglednica 3: Parcialni korelacijski koeficienti med rastnimi deskriptorji in parametri krošnje

Crown parameter / *Parameter krošnje*	Growth descriptor / *Rastni deskriptor*			Covar (age and stand density are covariates) / *Kovarianca (starost in gostota sestoja sta kovariati)*
	SI_{80}	HI_{10}	BAI_{10}	
Mean diameter (m) / *Povp. premer*	0.392	0.022	0.743***	0.010**
Surface (m^2) / *Površina*	0.306	0.059	0.782***	0.010**
Volume (m^3) / *Volumen*	0.317	0.054	0.787***	0.026*
Length (m) / *Dolžina*	0.181	0.112	0.722***	0.024*
Ratio surface/volume (m^2m^{-3}) / *Razmerje površina/volumen*	-0.242	-0.186	-0.572*	0.114

Obviously, only basal area increment correlates with each and every crown parameter (Table 3). The conclusion from the results is that the influence of different past management actions - reflected in different stand densities - should only be eliminated in further correlations with basal area increment, since only this descriptor significantly correlates with crown parameters. Therefore, in the following analyses the age factor will be excluded in correlations to all growth descriptors, while the stand density factor will be eliminated only in correlations with basal area increment.

In addition, the differences between locations with regard to crown dimensions considering the eliminated age and density are quite astonishing. Evidently, the crown dimensions of sycamore are at least partly dependent on site characteristics.

3.2 INFLUENCE OF NUTRIENT SUPPLY AND RATE OF NUTRIENT CYCLING ON GROWTH POTENTIAL

VPLIV PRESKRBE S HRANILI IN HITROSTI KROŽENJA SNOVI NA RASTNI POTENCIAL

Evidently, only phosphorus concentration indicates higher SP (SI_{80}) and even higher recent basal area increment (Table 4). Interestingly enough, in spite of similar soil types there are significant differences in calcium supplies between locations.

Moreover, the higher rate of nutrient cycling (higher values of ratio annual litter/forest floor) and higher values of annual litter per growing stock (in some way representing the dynamics of nutrient cycling as well) indicate faster height growth.

Table 4: Partial correlation coefficients between growth descriptors and macronutrient concentrations in leaves or indicators of nutrient cycling rate

Preglednica 4: Parcialni korelacijski koeficienti med rastnimi deskriptorji in koncentracijami makrohranil v listih oziroma indikatorji hitrosti kroženja hranil

Macronutrient or indicator of nutrient cycling rate / *Makrohranilo oziroma indikator hitrosti kroženja snovi*	Growth descriptor / *Rastni deskriptor*			Covar (age = covariate) / *Kovarianca (starost je kovariata)*
	SI_{80}	HI_{10}	BAI_{10}	
N %	0.047	0.278	0.040	0.003**
P %	0.494*	0.231	0.601**	0.002**
K %	0.446	0.111	0.130	0.313
Ca %	-0.056	0.431	0.123	0.024*
Mg %	0.040	0.014	0.127	0.456
% of non-decomposed cellulose after 12 months / *% nerazgrajene celuloze po 12 mesecih*	-0.014	-0.298	-0.664	0.961[a]
Annual litter per growing stock (tm^{-3}) / *Letni opad glede na lesno zalogo*	0.055	0.462*	0.156	0.172
Ratio annual litter/forest floor (%) / *Razmerje letni opad/organski talni horizonti*	0.048	0.482*	-0.066	0.051

[a] – Kruskal-Wallis test

Furthermore, we tested the existence of correlations between growth descriptors and the following nutrient relations or ratios: C/N, N/P, N/K, N/Mg, N/Ca, P/Mg, Ca/K, Ca/Mg, Ca+Mg, K+P, N+P, N+K, Mg+Ca+K, N+P+K, Mg+Ca+K+P, Mg+Ca+K+P+N. Due to the extensive list of correlated pairs of variables, only the significant ones are given below:

- SI_{80} and N/P (r = -0.550; P = 0.015),
- SI_{80} and K+P (r = 0.505; P = 0.028),
- HI_{10} and Mg+Ca+K+P+N (r = 0.463; P = 0.046),
- BAI_{10} and N/P (r = -0.520; P = 0.027).

A great importance of nitrogen/phosphorus ratio is detected from the results. Lower values of this ratio are reflected in higher basal area growth, as well as in higher site indices. Moreover, the positive importance of potassium for SI_{80} is indicated. The most unclear connections concern height growth. It is quite likely that the analysed stands are too old for a sensitive reaction of height increment to nutrient supply.

3.3 INFLUENCE OF SOIL PROPERTIES ON GROWTH POTENTIAL
VPLIV LASTNOSTI TAL NA RASTNI POTENCIAL

The relation between growth descriptors and the most important parameters of the A horizon (hereafter: A_{hor}) was tested. The influence of A_{hor} parameters on the growth process of mature sycamore trees in the analysed locations is small (Table 5). The positive influence of calcium or base saturation on recent basal area increment, however, is an exception.

Table 5: Partial correlation coefficients between growth descriptors and parameters of A_{hor}

Preglednica 5: Parcialni korelacijski koeficienti med rastnimi deskriptorji in parametri A horizonta

Soil parameter (A_{hor}) / *Talni parameter (A_{hor})*	Growth descriptor / *Rastni deskriptor* SI_{80}	HI_{10}	BAI_{10}	ANOVA between locations / *ANOVA med lokacijami*
Volume (m^3ha^{-1}) / *Volumen*	0.362	0.081	0.199	0.013*
pH	0.409	-0.043	0.436	0.109
C/N ratio / *C/N razmerje*	-0.337	-0.243	0.225	0.139
N (%)	0.122	0.139	0.365	0.286
P_2O_5 (mgg^{-1})	-0.234	0.077	-0.010	0.710
K_2O (mgg^{-1})	0.188	-0.031	0.415	0.807
Ca (eq mmol H/100g)	0.193	-0.063	0.491*	0.125
Mg (eq mmol H/100g)	0.341	0.176	0.381	0.434
K (eq mmol H/100g)	0.331	-0.097	0.420	0.466
Na (eq mmol H/100g)	0.159	0.099	0.167	0.367
V (%)	0.352	-0.071	0.474*	0.132

Furthermore, we tried to ascertain the influences of soil depth, surface stoniness and the most important parameters of B_{hor}. Except for three texture classes, soil depth is the only parameter that significantly differs between locations (Table 6). This parameter strongly influences SP (SI_{80}). Surprisingly enough, surface stoniness does not influence growth, in spite of its correlation with soil depth (r = -0.514; P = 0.020). Basal area increment is dependent on the ratio between air capacity and plant available water in B_{hor}. The share of sand positively correlates with recent height increment, and the share of coarse silt is in positive connection with SI_{80}, while the share of fine silt negatively influences recent basal area increment.

Table 6: Partial correlation coefficients between growth descriptors and soil depth, surface stoniness and parameters of B_{hor}

Preglednica 6: Parcialni korelacijski koeficienti med rastnimi deskriptorji in globino tal, površinsko skalovitostjo in parametri B horizonta

Soil parameter / *Talni parameter*	Growth descriptor / *Rastni deskriptor* SI_{80}	HI_{10}	BAI_{10}	ANOVA between locations / *ANOVA med lokacijami*
Soil depth / *Globina tal*	0.642**	0.363	0.436	0.000***
Surface stoniness (%) / *Površinska skalovitost*	-0.303	-0.256	0.414	0.139
Air capacity (%); B_{hor} / *Kapaciteta tal za zrak*	-0.103	-0.040	-0.458	0.133
Plant available water (%); B_{hor} / *Rastlinam dostopna voda*	0.096	-0.116	-0.009	0.076
Ratio air capacity of soil/plant available water; B_{hor} / *Razmerje med kapaciteto tal za zrak in rastlinam dostopno vodo*	-0.217	0.010	-0.532*	0.678
V (%); B_{hor}	0.004	-0.118	0.304	0.141
Sand (%); B_{hor} / *Pesek*	-0.125	0.573*	-0.104	0.306
Coarse silt (%); B_{hor} / *Grobi melj*	0.572*	0.066	0.428	0.001***
Fine silt (%); B_{hor} / *Fini melj*	-0.026	-0.040	-0.568*	0.022*
Clay (%); B_{hor} / *Glina*	-0.223	-0.288	0.354	0.002**

4 DISCUSSION
RAZPRAVA

4.1 ESTIMATION OF SITE PRODUCTIVITY
OCENJEVANJE PROIZVODNE SPOSOBNOSTI

SP is basically defined as timber production potential on a particular site type for a particular tree species or forest type in one rotation period (SPIECKER *et al.* 1994). There are two problems that make this research approach to establish SP regarding sycamore rather impossible. First, unmanaged (virgin) forests, particularly on better sites, are an exceptional rarity in Central Europe, where destructive analyses are forbidden for understandable reasons. Second, sycamore is mostly an admixed tree species, its pure stands are rather small and restricted to special (micro)sites, therefore it is hard to study SP indicators at the stand level.

SP can be estimated by using different methods or approaches (KIMMINS 1997; SPIECKER *et al.* 1994). Total volume production of woody mass at the culmination point of mean volume increment of a stand, whose structure was not influenced by man, is theoretically an optimal indicator. Other indicators of SP are as follows: top height at definite age (usually 100 years), estimations based on maximum densities, soil properties (often in combination with topographic and climatic factors), tree nutrient supply, (quantified) ground vegetation, and fertilization trials in combination with visual symptoms estimation (KIMMINS 1997; SPIECKER *et al.* 1994). Along with these methods, the growth characteristics (trends, correlations with stand or site parameters etc.) can be analysed by means of permanent plots, dendroecological analyses (single tree data) and inventory data (SPIECKER *et al.* 1996). A very promising approach to understanding the (dynamic) relationships between growth and site is to relate changes in nutrient availability and uptake with growth variables (REHFUESS *et al.* 1999). Unfortunately, the majority of these options were not available to us.

In order to study the relationship between growth and stand or site characteristics, the top height of dominant sycamore trees seemed to be the best available method to estimate SP. Another promising and available method is the evaluation of ground vegetation as a bioindicator of productivity, but unfortunately it is not improved enough at present (KADUNC 2003). It turned out that on the plots with admixed sycamore only four trees of the studied species per plot (they were also the thickest sycamores) belonged to the collective of dominant trees in stand canopies.

Top height or height development patterns of dominant trees in even-aged stands are little affected by silvicultural interventions, except by thinning from above (SPIECKER *et al.* 1994). This type of thinning was applied on some locations included in the present research, but sycamore trees were preserved. Consequently, it can be claimed with high probability that the analysed trees were the thickest during all their lifetime. Moreover, thinning from above destimulates height growth of the released trees, because they are allowed to increase their crown growth in width. Our results show, however, that stands with lower density achieved higher values of SI_{80}, which could be explained by naturally lower initial stand density on high productive valuable-broadleaved sites (DIACI 1997). A detailed analysis at a single tree level reveals that correlations between crown diameter and height at 80 years of age by location (influence of age was statistically eliminated) are not significant in any location. On that basis the effects of crown release on top height development of dominant trees can be rejected, at least within this research.

In the last decade, SP changes have been discussed quite intensively (e.g. SPIECKER *et al.* 1996). For Central Europe it has prevailed that in the majority of sites SP has increased (SPIECKER *et al.* 1996; DITTMAR / ZECH / ELLING 2003). Our results indicate positive growth trends (younger collectives had higher values of SI_{80}), which is in accordance with the above-mentioned researches in European and Slovenian studies as well (KOTAR 2002).

4.2 INFLUENCING FACTORS
RASTNI FAKTORJI

Obvious importance of phosphorus regarding SP is in agreement with the findings proposed by WEBER / BAHR (2000a), which pointed out the deficiency problem with phosphorus on carbonate rock (due to Ca-phosphates). Our results are, however, in contradiction with the statements made by FRANC / RUCHAUD (1996), who detected sycamore tolerance to phosphorus deficiency (except in forest nurseries). Furthermore, they stressed the importance of a good supply of potassium, which is in accordance with our results, and the importance of nitrates. Our research, however, did not confirm the explicit role of nitrogen in sycamore growth. The undetected relationship between growth and nitrogen could be due to methodological reasons. BAUER *et al.* (2000) establish that the net above-ground primary production of spruce and beech stands correlates with nitrogen content in crowns (g Nm^{-2}), but not with nitrogen concentration in leaves.

As to the first hypothesis, it is obvious that optimal nitrogen concentration depends mostly on available phosphorus, while the importance of sufficient water supply could be indirectly linked to soil depth. Deeper soil means larger water supplies and slower outflow of water. Nevertheless, the first hypothesis about nitrogen soil concentration and plant available water as the key factors for SP could not be accepted within the frames of this research. The analysed site conditions are very likely to provide a sufficient supply of nitrogen. An excess nitrogen supply of trees may also be associated with a reduction in growth (KENNEL / WEHRMANN 1967). Moreover, no direct influence of plant available water was detected, despite frequent dry conditions on karst soils during summers.

With regard to height increments, extremely few correlations were confirmed. HENNECKE (1977) mentions that water supply or favourable microsite conditions have an extremely strong influence on sycamore height growth. Similar conclusions were drawn by HÖLSCHER / SCHMITT / KUPFER (2002). According to them, water supply results in decreasing height growth of sycamore seedlings along slope gradient (upper parts of the slope had the poorest water supply). In addition, insufficient water supply restricted the uptake of soil nutrients, despite their sufficient concentrations (ibidem.). Our results, however, did not confirm the connection between height growth and water conditions in soil. The research done by WEBER / BAHR (2000a) states the importance of base saturation for favourable height growth of sycamore trees, which is not in accordance with our results. We studied growth of mature sycamore trees on a limited range of soil types, while the research done by WEBER / BAHR (2000a) was carried out on a wider range of soils and with young trees (5-10 years). Moreover, the positive relationship between nitrogen supply in leaves and height growth was confirmed in WEBER / BAHR's research (2000a) as well. Our research, however, did not confirm the role of nitrogen in sycamore growth. A possible explanation might be the higher age of analysed trees compared to the age of analysed trees included in WEBER / BAHR's research (2000a), despite the similarity of nitrogen concentration in leaves (1.3 – 2.6 %). In contrast to WEBER / BAHR (2000a), our research did not establish the role of magnesium in height growth, possibly due to the fact that there was no lack of magnesium on any of the research plots.

From the results it can be concluded that the response of the height growth of mature sycamore trees to site factors and stand conditions is extraordinarily modest. Evidently, growth is in decline and it is strongly dependent on age. To conclude, the second hypothesis can not be accepted.

With regard to the growth of basal area, many significant connections were confirmed. Basal area increment is positively dependent on diameter, surface, volume and crown length. The established negative relationship between basal area increment and ratio of crown surface to crown volume does not correspond to the findings made by PRETZSCH (1992). He cites that a higher ratio of crown surface to volume positively influences the increment due to a better ratio between photosynthesis (surface) and respiration (volume). Our results could be explained by a less advantageous ratio between sunny and shady leaves as a response to a bigger amount of foliage. Mature sycamore is more light demanding and this ratio could be crucial for its growth potential. It is also well known that yield starts to decrease if the leaf area index (LAI) is too large (e.g. KIMMINS 1997; KOZLOWSKY / PALLARDY 1997; MARSCHNER 1998).

It is logical that stands with lower density provided higher basal area increments in the last 10 years. Our results, however, do not accord well with the conclusions of a Danish experiment, which points out a very restricted response of radial growth to stand density reductions of 40-year stands (PLAUBORG 2004). Thinning from below could be an explanation for the poor response of relatively young stands.

The importance of base saturation and calcium concentration for recent basal area increment is slightly surprising due to a very narrow range of soil types included in the research. The role of base saturation was already stressed in WEBER's research (1999), but for substantially younger individuals.

Evidently, basal area increment responds quite intensively to site factors and stand conditions. Diameter growth dies away much later than height growth does. The hypothesis that basal area increment depends only on crown dimensions is rejected. In contrast to that, HEIN (2004) does not confirm the dependence between ring width and site quality, which might be due to uneliminated factors (e.g. stand density).

Furthermore, it also turned out that the role of soil parameters was much less evident on the limited range of analysed soil types than it could be on a wider group of included soils. In our case some other factors can be more strongly expressed. The weakness of SP or growth potential estimation based on soil properties is that analytical methods of soil research only give a static picture. In addition, these methods do not include downslope seepage, which importantly increases SP of lower situated sites (KLINKA 1976).

Finally, it must be stressed that our research was carried out in real forest conditions, where the great complexity of interactions is impossible to control. Consequently, the interpretations of results demand the highest degree of caution. The maturity of analysed trees and the fact that the research was restricted to carbonate bedrock sites allow only partial comparisons with the majority of other researches dealing with sycamore.

5 POVZETEK

Namen prispevka je ugotoviti vpliv rastiščnih dejavnikov oziroma sestojnih parametrov na rast odraslega gorskega javorja (*Acer pseudoplatanus* L.). Raziskavo smo izpeljali na štirih tipih gozdnih rastišč. Omejili smo se na karbonatno matično podlago. Za vsak rastiščni tip smo napravili pet ponovitev, z drugimi besedami, analizirali smo po pet ploskev za posamezen rastiščni tip. Prvi tip leži na rastišču združbe *Aceri-Fraxinetum ill.* (lokacija Konjice), kjer v sestoju prevladuje gorski javor. Naslednji rastiščni tip smo analizirali v fitocenozah, ki jih uvrščamo v okvir združbe *Lamio orvalae-Fagetum*, v teh sestojih je prevladovala bukev (lokacija Brezova reber). Tudi tretji tip leži v okviru iste združbe, vendar v sestoju prevladuje (umetno vnešena) smreka (lokacija Jauhe). Zadnji tip smo analizirali na rastiščih združbe *Omphalodo-Fagetum aceretosum* (lokacija Strmec). Skupno smo torej zajeli 20 ploskev v velikosti 30 x 30 m.

Na vseh ploskvah smo analizirali strukturo sestoja, vsem nadmerskim drevesom (prsni premer nad 10 cm) smo izmerili prsni premer, višino, višino pričetka krošnje in osem polmerov projekcije krošnje. Na podlagi teh meritev smo izračunali površino in volumen ter srednji premer krošnje. Nadalje smo na vsaki ploskvi izkopali talni profil in napravili klasično pedološko analizo po talnih horizontih. V laboratoriju smo določili: pH ($CaCl_2$), P_2O_5, K_2O, organsko snov, % ogljika, % dušika, teksturo, izmenljive katione, izmenljiv vodik, KIK in stopnjo nasičenosti z bazami. Na podlagi teh podatkov smo s pomočjo nemškega modela (FINNERN *et al.* 1994) zmodelirali vrednosti za kapaciteto tal za zrak in rastlinam dostopno vodo po horizontih in ploskvah. Na vseh ploskvah smo s sistematičnim vzorčenjem ugotovili tudi globino tal, površinsko skalovitost, količino organskih talnih horizontov in količino nadzemnega opada. S pomočjo položenih vzorčnih enot celuloze smo ocenili hitrost razgradnje v tleh. Nadalje smo pri dominantnih gorskih javorjih s foliarnimi analizami ugotovili preskrbljenost le-teh z makrohranili. Na koncu smo na vsaki ploskvi podrli po štiri najdebelejše javorje in na njih opravili debelne analize. Tako smo ugotovili višinsko in debelinsko rast. Na podlagi doseženih višin gorskih javorjev pri 80 letih smo definirali proizvodno sposobnost rastišč za obravnavano drevesno vrsto. Kot indikator rasti pri odraslem javorju smo izbrali višinski prirastek v zadnjih 10 letih (HI_{10}), temeljnični prirastek v zadnjih 10 letih (BAI_{10}) in povprečno višino analiziranih štirih osebkov na ploskvi pri 80 letih (rastiščni indeks; SI_{80}).

Ker se je starost dreves razlikovala med ploskvami in lokacijami in ker se lokacije razlikujejo glede preteklega gospodarjenja (jakost poseganj), smo vpliv teh spremenljivk (starost in gostota sestoja) odstranili, kjer je bilo to primerno.

Po pričakovanju smo potrdili pozitivni vpliv premera, površine, volumna in dolžine krošnje na temeljnični prirastek. Razmerje med površino in volumnom krošnje pa vpliva negativno na velikost temeljničnega prirastka. To je najverjetneje posledica neugodnega razmerja med sončnimi in senčnimi listi, saj gorski javor v zrelem obdobju postaja vse bolj zahteven glede svetlobe.

Vpliva preskrbljenosti z dušikom na rast presenetljivo nismo ugotovili, izkazal pa se je velik pomen fosforja, ki ga na karbonatni matični podlagi praviloma primanjkuje in zato povečuje tako proizvodno sposobnost rastišča kot tudi temeljnično rast pri gorskem javorju. Na tleh s hitrejšo razgradnjo oziroma hitrejšim kroženjem hranil je višji višinski prirastek.

Vpliv karakteristik A horizonta na rast odraslih javorjev je relativno skromen, nekoliko presenetljivo smo potrdili le pozitivni vpliv nasičenosti z bazami oziroma koncentracije kalcija na temeljnično rast. Pač pa je proizvodna sposobnost močno povezana z globino tal, kjer globlja tla nakazujejo boljšo produktivnost. Ta je večja tudi pri višjih deležih grobega melja v kambičnem horizontu. Z višjimi deleži peščene frakcije v taistem horizontu pa se dosega večji višinski prirastek. Temeljnični prirastek je v negativni povezavi z deležem finega melja v kambičnem horizontu in z razmerjem med kapaciteto tal za zrak ter rastlinam dostopno vodo.

Izkazalo se je, da pri odraslem javorju temeljnični prirastek še (močno) reagira na parametre sestoja (gostota, katere posledica so večje ali manjše krošnje) in dejavnike rastišča. V nasprotju s tem pa je rast v višino pod močnejšim nadzorom starosti in le šibko odseva razmere.

Raziskava je pokazala tudi na razmeroma šibko vlogo talnih parametrov, kar je v največji meri posledica ozkega ekološkega intervala analize.

Dodati je treba, da je raziskava potekala v realnih gozdnih razmerah in pri odraslem drevju, kjer je nemogoče izločiti vpliv kompleksa interakcij. Omejenost prispevka na karbonatno matično podlago narekuje tudi veliko previdnost pri prenosu rezultatov oziroma zaključkov.

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