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Leaf area index (LAI), climatic conditions and aboveground biomass production in stands of red oak (*Quercus rubra* L.) and black walnut (*Juglans nigra* L.)

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Abstract

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In this paper we present evaluation of development of leaf area index (LAI) and aboveground biomass production in connection to climatic contitions in the stands of red oak (*Quercus rubra* L.) and black walnut (*Juglans nigra* L.) growing on the PRP series in Ivanka pri Nitre (Forestry administration Nitra, Forest enterprise Palárikovo). Over the whole developmental cycle, the highest LAI values were observed in the mixed stand consisting of black walnut and small-leaved linden. As for the aboveground biomass production, the best results were obtained in red oak monoculture, and at advanced age also in mixed stand of red oak and black walnut not subjected to tending (control PRP). In connection to climatic conditions, the highest values of mean periodical increment per leaf unit area (g dm^{-2} $year^{-1}$) were reached in 1994–1998 and in 1999–2003, in all types of the stands. The absolute maximum (42.90 g dm^{-2} $year^{-1}$1) was reached in 1994–1998 in the improved mixed stand of red oak (20%) and black walnut (80%).

Key words

aboveground biomass, LAI, climatic conditions, *Quercus rubra* L., *Juglans nigra* L.

Introduction

The cultivation of red oak (*Quercus rubra* L.) and black walnut (*Juglans nigra* L.) in Slovakia is based on sound grounds: the distribution of this woody plant in the land (Benčať, 1982), approved high growth and production abilities (Holubčík, 1968; Réh J., 1967, 1989, 1995; TOKÁR, 1979, 1987, 1994, 1998), approved resistance against airborne pollutants and tracheomycoses (Juhásová and Hrubík, 1984) range of application in making furniture (Réh R., 1992; Réh J. and Réh R., 1997), cultivation in orchards and forest management.

In this paper we evaluate the production of aboveground biomass in dry state in connection to leaf area index and climatic conditions in several stand types of red oak and black walnut improved through moderate thinning from above with positive selection. The research ran from 1978 to 2003 on plots in Ivanka pri Nitre (10 km south from the town of Nitra).

Material and methods

The concerned series of permanent research plots (PRP) was established in 1978 in point of a thinning programme (Tokár, 1987), and it was situated within forest stands 131 k (PRP I, II, III, VI), 131 h (PRP IV) and 131 d (PRP V). The stands were established in years 1954–1956 on alluvial deposits of the Nitra River. The one-year seedlings of red oak (ro) and seeds of black walnut (bw, provenance Sereď) were planted in triangular grid with spacing 1 x 1 m. The stands belong to the group of forest types Ulmeto-Fraxinetum Carpineum. The soil type is fluvisol, altitude is 150 m asl. The PRP series is situated in the warm climate district A. The forest stands are managed by the Forest enterprise Palárikovo, Forest administration Nitra.

All trees on the PRP series have been provided with numbers. The evaluations were performed in 1978, 1983, 1988, 1993, 1998 and 2003, following the methods by TOKÁR (1987, 1998). The aboveground biomass was determined using the destructive method. The number of sample trees to be analysed was determined using the method of stratified selection according to the individual tree classes and basal area values. The admissible error was set to 10% (ŠMELKO and WOLF, 1977). For each sample tree we determined the weight of stem, branches, current year shoots and leaves. The weighing was performed using a scale KAMOR. From 4 sample trees representing the tree classes, we sampled material from each stem third, branches, current year shoots and leaves. The material was dried in the laboratory at a temperature of 105 °C up to a constant weight. The converted values of dry mass (at 105 °C) of the aboveground biomass components (stem, branches, current year shoots) and the values of leaf area index in green state were put in correlation with the values of diameter $d_{1,3}$. The relation was best fitted with a 2-nd degree parabola (TOKÁR, 1987, 1998). The fitted values of dendromass were converted according to the proportion of trees in stand diameter structure converted per one hectare.

The leaf area index was determined for each woody plant in each stand type, separately. The value was determined using 3 representative samples (3 x 100 leaves) examined with a photoplanimeter EJKELKAMP. The calculated conversion coefficient (weight of fresh leaves/leaf area in m^2) was subsequently used to obtain the converted values for all sample trees.

The thinning method applied on PRP I–V is moderate thinning from above with positive selection and a 5-year interval of repetition. The aim is to direct the development of various stand types of red oak and black walnut in such a way as to reach maximum production in terms of amount and quantity. The thinning method is based on tending of promising trees (TOKÁR, 1987, 1998) selected from trees with appropriate quantitative and qualitative signs (1-st and 2-nd tree classes, 1-st and 2-nd degree of stem and crown quality) dimensions (with the diameter larger than the average stand diameter $d_{1,3}$ and the height higher than the average stand height) and appropriate spacing.

The values of climate variables for years 1979–2003 were obtained from the climate yearbooks edited by the Slovak Agricultural University in Nitra (ŠPÁNIK et al., 1995, 2002). The stands developing on the PRP were subjected to six thinning interventions. Each five years, there were performed biometrical evaluations of the following parameters: leaf area index (ha ha^{-1}), aboveground biomass stock (t ha^{-1}), mean annual increment per unit growth area (t ha^{-1} $year^{-1}$) and leaf area (g dm^{-2} $year^{-1}$).

Results

Leaf area index (LAI)

Beginning with the first thinning intervention (in 1978), the influence of thinning on development of aboveground biomass production was also evaluated through the development of LAI (TOKÁR, 1999, Table 1). Over the whole period of study, the largest LAI was found in the mixed stand of black walnut (*Juglans nigra* L.) with small-leaved linden (*Tilia cordata* Mill.). The relation between the LAI and age can be fitted by a negative exponential function $y = e^{(a+bx)}$ (Fig. 1). The highest values of LAI (5.21–11.90 ha ha^{-1}) were found in all stand types in 1978 at establishment of the experiment. During the thinning period (1978–2003) LAI decreased after each thinning intervention. This decrease could not have been compensated by the remaining trees over the further stand development. Surprising is, however, the drop in LAI on the control plot PRP VI (natural development).

Aboveground biomass stock

Until the stand age of 34 years (1988) was the highest growing stock found (Table 2) in the homogeneous tended stand of red oak (PRP II). In the following period, was the highest growing stock in the unimproved mixed stand of red oak (80%) and black walnut (20%). From the tended stands had the highest stock of aboveground biomass the mixed stand of black walnut (80%) and red oak (20%) on PRP I. The tending interventions promoted the growth and production of black walnut trees belonging to the 1-st and 2-nd tree classes according to their biosociological status, and red oak trees belonging to the 3-rd and the 4-th tree classes. Such a vertical structure promotes in black walnut intensive growth, high production and high quality of stems. In 2003, at the age of 49 years, reached the stock of aboveground biomass in this stand a value of 367.16 t ha (Table 2).

Mean periodic increment in aboveground biomass

Over the period 1978–2003 were the PRP subjected to six thinning interventions. Forest inventories performed after five year periods provided the data for determining the mean periodic increments per growth area (t ha^{-1} $year^{-1}$) and leaf area (g dm^{-2} $year^{-1}$). The increment creation in individual phases is influenced by the stand type and species composition (Table 3). From homogeneous stands, at the beginning of improvement (1979–1988) were better values obtained in the red oak stand. In 1989–2003 were better values obtained for the black walnut stand (in 1999–2003 it was a maximum of 16.94 t ha^{-1} $year^{-1}$).

Table 1. Leaf area index (LAI) in different stand types of red oak (*Quercus rubra* L.) and black walnut (*Juglans nigra* L.) on six permanent research plots (PRP-s) at Ivanka pri Nitre in years 1978–2003

PRP	Stand type	Proportion of species (%)	1978		1983		1988		1993		1998		2003	
			Age (years)	LAI (ha ha^{-1})	Age (years)	LAI (ha ha^{-1})	Age (years)	LAI (ha ha^{-1})	Age (years)	LAI (ha ha^{-1})	Age (years)	LAI (ha ha^{-1})	Age (years)	LAI (ha ha^{-1})
I.	*Quercus rubra* L.	20	24	0.96	29	0.84	34	0.54	39	0.83	44	0.20	49	0.24
	Juglans nigra L.	80	23	4.25	28	3.72	33	3.26	38	0.51	43	0.45	48	0.49
	Total	100		5.21		4.56		3.80		1.34		0.65		0.73
II.	*Quercus rubra* L.	100	24	6.80	29	6.02	34	4.04	39	2.55	44	2.31	49	2.84
III.	*Quercus rubra* L.	20	24	5.63	29	4.95	34	3.04	39	2.26	44	2.08	49	2.39
	Juglans nigra L.	80	23	1.47	28	1.35	33	1.31	38	0.24	43	0.20	48	0.26
	Total	100		7.10		6.30		4.35		2.50		2.28		2.65
IV.	*Juglans nigra* L.	100	22	5.5	27	4.91	32	4.58	37	1.73	42	0.60	47	0.58
V.	*Juglans nigra* L.	20	21	3.44	26	3.60	31	3.84	36	1.02	41	0.98	46	1.08
	Tilia cordata Mill.	80	17	8.46	22	7.89	27	6.14	32	3.03	37	2.21	42	3.42
	Total	100		11.90		11.49		9.98		4.05		3.19		4.50
VI. (control)	*Quercus rubra* L.	80	24	3.58	29	3.11	34	2.86	39	2.66	44	2.87	49	3.46
	Juglans nigra L.	20	23	2.02	28	1.92	33	1.61	38	0.58	43	0.43	48	0.44
	Total	100		5.60		5.03		4.47		3.24		3.30		3.90

Table 2. Aboveground biomass stock in different stand types of *Quercus rubra* L. and *Juglans nigra* L. on six permanent research plots (PRP) at Ivanka pri Nitre in years 1978–2003

PRP	Stand type	1978		1983		1988		1993		1998		2003	
		Age (years)	Dendro-mass (t ha^{-1})	Age (years)	Dendro-mass (t ha^{-1})	Age (years)	Dendro-mass (t ha^{-1})	Age (years)	Dendro-mass (t ha^{-1})	Age (years)	Dendro-mass (t ha^{-1})	Age (years)	Dendro-mass (t ha^{-1})
I.	*Quercus rubra* L.	24	13.04	29	20.62	34	22.94	39	17.41	44	16.69	49	24.39
	Juglans nigra L.	23	72.13	28	86.92	33	95.54	38	173.55	43	268.52	48	342.77
	Total		88.17		107.54		118.48		190.96		285.21		367.16
II.	*Quercus rubra* L.	24	144.02	29	175.49	34	199.93	39	188.85	44	215.94	49	263.40
III.	*Quercus rubra* L.	24	112.64	29	134.63	34	144.26	39	160.13	44	178.96	49	215.75
	Juglans nigra L.	23	30.38	28	33.01	33	37.70	38	49.47	43	80.41	48	125.36
	Total		143.02		167.64		181.96		209.60		259.37		341.11
IV.	*Juglans nigra* L.	22	100.24	27	117.44	32	134.52	37	183.69	42	235.05	47	319.73
V.	*Juglans nigra* L.	21	72.10	26	88.31	31	107.53	36	148.81	41	190.12	46	257.86
	Tilia cordata Mill.	17	23.89	22	33.85	17	52.22	32	32.07	37	35.58	42	55.92
	Total		96.08		122.16		159.75		180.88		225.70		313.78
VI. (control)	*Quercus rubra* L.	24	108.17	29	124.12	34	133.77	39	165.79	44	195.89	49	292.89
	Juglans nigra L.	23	23.87	28	35.96	33	46.21	38	67.97	43	139.04	48	193.61
	Total		132.04		160.08		179.98		233.76		334.93		486.50

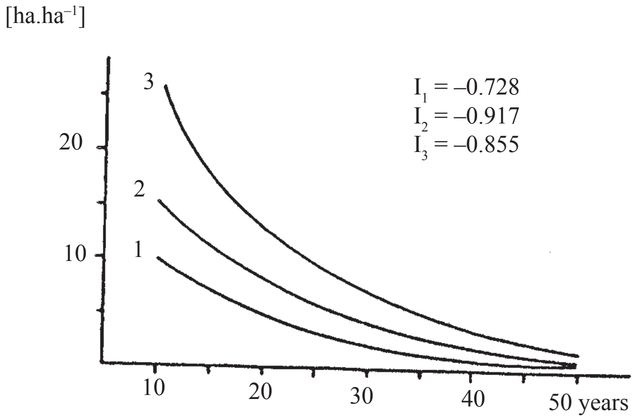

Fig. 1. LAI for the tended mixed stand (PRP V). 1 – *Juglans nigra* L., 2 – *Tilia cordata* Mill., 3 – total

Table 3. Mean periodical increment of aboveground biomass per unit growth area in different stand types of *Quercus rubra* L. with *Juglans nigra* L. on six permanent research plots (PRP-s) at Ivanka pri Nitre in years 1979–2003

PRP	Stand type	Mean periodical increment ($t\ ha^{-1}\ year^{-1}$) over years				
		1979–1983	1984–1988	1989–1993	1994–1998	1999–2003
I.	*Quercus rubra* L.	0.92	0.46	1.11	0.14	1.54
	Juglans nigra L.	2.96	1.72	4.11	18.99	14.85
	Total	3.88	2.18	5.22	19.13	16.39
II.	*Quercus rubra* L.	6.29	4.89	2.22	5.42	9.49
III.	*Quercus rubra* L.	4.40	1.93	3.17	3.77	7.36
	Juglans nigra L.	0.53	0.94	2.35	6.19	8.99
	Total	4.93	2.87	5.52	9.96	16.35
IV.	*Juglans nigra* L.	3.44	3.42	9.83	10.27	16.94
V.	*Juglans nigra* L.	3.24	3.84	8.26	8.26	13.55
	Tilia cordata Mill.	1.99	3.67	4.03	0.70	4.07
	Total	5.23	7.51	12.29	8.96	17.62
VI. (control)	*Quercus rubra* L.	3.19	1.93	6.40	6.02	19.40
	Juglans nigra L.	2.42	2.05	4.35	14.21	10.91
	Total	5.61	3.98	10.75	20.23	30.31

As for the tended mixed stands, over the whole tending period were the best results obtained in the black walnut stand mixed with small-leaved linden. The small-leaved linden is a shade-loving woody plant, and it builds up the second layer of the stand. The status and litterfall of this tree have favourable influence on growth, production and wood quality of black walnut present in the 1-st and 2-nd tree classes.

Over the whole period of study, the highest mean annual periodical increment per unit growth area (in 1999–2003 up to 30.31 t ha^{-1} $year^{-1}$) was observed on the control plot (PRP VI), in consequence of the higher number of trees.

In the case of LAI, higher values of mean periodical increment per leaf area were observed in the black walnut monoculture than in the red oak monoculture. From the mixed stands, mainly in the recent 10 years of improvement (1994–2003), the highest production was reached in the stands consisting of black walnut (80%) and red oak (20%) as well as in the stands consisting of red oak (80%) and black walnut (20%). The maximum increment (42.90 g dm^{-2} $year^{-1}$) was observed on PRP I in 1994–1998.

Climatic conditions and aboveground biomass production

The mean periodical increment per leaf area (g dm^{-2} $year^{-1}$) is a characteristic trait of the productivity of the individual stand types of red oak and black walnut in dependence on leaf area index (LAI) and climatic conditions.

In the period of stand improvement, the most favourable climatic conditions for maximum production in all the stand types of red oak and black walnut were found in years 1994–1998 and 1999–2003. The highest values of mean periodical increment per unit leaf area (Table 4) were reached in the mixed stand of black walnut (80%) and red oak (20%) in 1994–1998 (42.90 g dm^{-2} $year^{-1}$) and in the mixed stand of red oak (80%) with black walnut (20%) in 1999–2003 (37.21 g dm^{-2} $year^{-1}$).

The climatic conditions were favourable for development of stands of red oak and black walnut in both 5-year periods (Table 5). The mean annual temperature was higher in 1999–2003 (10.7 °C) than in 1994–1998 (10.1 °C), on the other hand, the annual precipitation totals were higher in 1994–1998 (586.3 mm) than in 1993–2003 (490.9 mm). Photosynthetically active radiation was higher in 1999–2003 (643 kWh m^{-2}) than in 1994–1998 (607 kWh m^{-2}). The values of mean annual temperature of 10 °C, mean annual precipitation total of 500 mm and photosynthetically active radiation of 600 kWh m^{-2} are favourable for reaching maximum increment production in stands of red oak and black walnut in floodplain forests of south-western Slovakia.

Table 4. Mean periodical increment of aboveground biomass per unit leaf area in different stand types of *Quercus rubra* L. with *Juglans nigra* L. on six permanent research plots (PRP-s) at Ivanka pri Nitre in years 1979–2003

PRP	Stand type	Mean periodical increment (g dm^{-2} $year^{-1}$) over years				
		1979–1983	1984–1988	1989–1993	1994–1998	1999–2003
I.	*Quercus rubra* L.	1.09	0.85	1.34	0.70	6.41
	Juglans nigra L.	0.79	0.53	8.06	42.20	30.31
	Total	1.88	1.38	9.40	42.90	36.72
II.	*Quercus rubra* L.	0.92	1.21	0.87	2.35	3.34
III.	*Quercus rubra* L.	0.89	0.63	1.40	1.81	2.64
	Juglans nigra L.	0.39	0.72	9.79	30.95	34.57
	Total	1.28	1.35	11.19	32.76	37.21
IV.	*Juglans nigra* L.	0.70	0.75	5.68	17.12	29.20
V.	*Juglans nigra* L.	0.90	1.00	8.10	8.43	12.55
	Tilia cordata Mill.	0.25	0.60	1.33	0.32	1.19
	Total	1.15	1.60	9.43	8.75	13.74
VI. (control)	*Quercus rubra* L.	1.02	0.67	2.41	2.10	5.61
	Juglans nigra L.	1.26	1.27	7.50	33.04	24.79
	Total	2.28	1.94	9.91	35.14	30.40

Table 5. Average annual temperature, precipitation and photosynthetically active radiation (GPAR)

Year	Average temperature (°C)	Average precipitation (mm)	GPAR (kWh m^{-2})
1979	9.8	701.6	555
1980	8.4	570.7	516
1981	10.1	538.2	581
1982	10.2	483.6	592
1983	10.5	510.3	615
Total	49.0	2,804.4	2,859
Average	9.8	560.8	572
1984	9.5	598.3	571
1985	8.9	597.8	597
1986	9.7	440.7	591
1987	9.3	540.6	600
1988	10.0	581.8	611
Total	47.4	2,759.2	2,870
Average	9.5	551.8	574
1989	10.5	438.9	585
1990	10.8	480.2	616
1991	9.6	436.1	596
1992	10.8	438.9	664
1993	9.6	564.4	619
Total	51.3	2,358.5	3,080
Average	10.3	471.9	616
1994	11.1	676.8	615
1995	10.1	580.4	595
1996	9.0	680.8	591
1997	9.7	494.9	632
1998	10.4	498.8	600
Total	50.3	2,931.7	3,033
Average	10.1	586.3	607
1999	10.2	549.5	592
2000	11.1	489.1	645
2001	10.5	435.2	608
2002	10.9	612.5	609
2003	10.6	368.2	671
Total	53.3	2,454.5	3,215
Average	10.7	490.9	643

Discussion

The production of dry biomass in plants is dependent on their leaf area index (LAI) expressed as leaf blade surface per ground area unit and on the net assimilation rate. LAI and net assimilation rate are dependent on the environment and also on the developmental stage and spacing between the trees in the population (Tokár, 1998, 1999). To reach a high production, it is necessary to reach the maximum leaf area index in the most favourable vegetation phase (Oszlányi, 1992, 1995; Walter, 1964, sec. Vyskot et al. 1971).

According to Tokár (1991, 1994, 1998), who studied the influence of phytotechnics (thinning) applied to stands of red oak and black walnut, the production of aboveground biomass is, apart from the tending, also influenced by ecological conditions (soil fertility, stand composition, climatic conditions), and by genetic and physiological properties of the taxons. The hitherto knowledge about ecology and production of these woody plants points out their high production capacity and the fact that accompanying species have a considerably favourable influence on growth, production and quality of stems, primarily in case of black walnut. However, up to these days, there has not been discovered the connection between the aboveground biomass production per unit leaf area (g dm^{-2} $year^{-1}$) and climatic conditions. Our long-term, 25-year observations revealed that the maximum mean periodical increment of aboveground biomass in stands of red oak and black walnut are reached at a mean annual temperature of 10 °C, mean annual precipitation total of 500 mm and mean photosynthetically active radiation of 600 kWh m^{-2}. The natural environment characterised with such values, in connection with favourable soils (fluvisols) and silvicultural measures (primarily thinnings), provide optimum conditions for cultivation of red oak and even more fore black walnut. Such ecological conditions are in groups of forest types set „C" in floodplain forests bordering the lower reaches of Slovak rivers.

Conclusions

The work provides evaluation of the development of leaf area index (LAI) and aboveground biomass production in connection to the climatic conditions in a range of stand types of red oak (*Quercus rubra* L.) and black walnut (*Juglans nigra* L.) in Ivanka pri Nitre improved by appplying moderate thinning from above, over the period of 1978–2003.

The highest mean periodical increments per unit leaf area were found in mixed stands of black walnut with red oak in years 1994–1998 (42.90 g dm^{-2} $year^{-1}$) and in years 1999–2003 (37.21 g dm^{-2} $year^{-1}$) when the mean annual temperature was 10 °C, mean annual precipitation toal was 500 mm and mean photosynthetically active radiation was 600 kWh m^{-2}.

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Index listovej plochy (LAI) a klimatické podmienky vo vzťahu k produkcii nadzemnej dendromasy porastov duba červeného (*Quercus rubra* L.) a orecha čierneho (*Juglans nigra* L.)

Súhrn

Práca zhodnocuje vývoj indexu listovej plochy (LAI) a produkcie nadzemnej dendromasy a ich vzťah ku klimatickým podmienkam u rôznych porastových typov duba červeného (*Quercus rubra* L.) a orecha čierneho (*Juglans nigra* L.) vychovávaných miernymi úrovňovými prebierkami za r. 1978–2003 na lokalite Ivanka pri Nitre.

Najvyššie priemerné periodické prírastky na jednotku listovej plochy sme zistili v zmiešaných porastoch orecha čierneho s dubom červeným v období r. 1994–1998 (42,90 g dm^{-2} rok^{-1}) a r. 1999–2003 (37,21 g dm^{-2} rok^{-1}), kedy boli klimatické podmienky charakterizované priemernými ročnými teplotami 10 °C, priemernými úhrnmi ročných zrážok 500 mm a priemerným fotosyntetickým aktívnym žiarením 600 kWh m^{-2}.