Ekológia (Bratislava) Vol. 28, No. 3, p. 234–241, 2009
doi:10.4149/ekol_2009_03_234

ABOVEGROUND BIOMASS PRODUCTION IN BLACK WALNUT (*Juglans nigra* L.) MONOCULTURES IN DEPENDENCE ON LEAF AREA INDEX (LAI) AND CLIMATIC CONDITIONS

FERDINAND TOKÁR

Institute of Forest Ecology of SAS, Branch of Woody Plants Biology, Akademická 2, 949 01 Nitra, Slovak Republic; e-mail: ferdinand.tokar@savzv.sk

Abstract

Tokár, F.: Aboveground biomass production in black walnut (*Juglans nigra* L.) monocultures in dependence on leaf area index (LAI) and climatic conditions. Ekológia (Bratislava), Vol. 28, No. 3, p. 234–241, 2009.

The work evaluates the development of mass production of aboveground biomass in dependence on leaf area index and climatic conditions in homogeneous monocultures of black walnut (*Juglans nigra* L.) tended by thinning from above. The experiment was carried out in 1978–2003, in the locality Sikenica (Forest Enterprise Levice, Forest District Levice) on three permanent research plots (PRP) at age of 64 years (2003) with growing stock of 173.61–207.56 $t.ha^{-1}$ and LAI 6.54–7.82 $ha.ha^{-1}$. Maximum mean periodical increments per LAI were reached in 1979–1983 (1.28–1.67 $g.dm^{-2}.year^{-1}$) and in 1984–1988 (1.66–2.11 $g.dm^{-2}.year^{-1}$), with mean annual temperature 9.5–10.0 ^{o}C, total annual precipitation 505 mm and mean annual photosynthetically active radiation 545–572 $kWh.m^{-2}$. These conditions represented an optimum forest environment for reaching maximum production of aboveground biomass in homogeneous stands of black walnut in floodplain forests of the Hron river.

Key words: aboveground biomass, LAI, climatic conditions, *Juglans nigra* L.

Introduction

Black walnut (*Juglans nigra* L.) belongs to the introduced woody plants recommended for cultivation in forests of central, south and southeast Europe. The hitherto experience has revealed that its commercial importance is in precious wood production (Réh, 1996; Šindelářová, 1973), high-quality fruits (Šika, 1957) and fast growth in favourable localities (Benčať, 1982; Beran, Šindelář, 1996; Frýdl, Šindelář, 2004; Holubčík, 1968; Šika, 1958; Hríb et al., 2003; Prudič, 1991; Tokár, 1987, 1998).

In Slovakia is black walnut cultivated on an area of approximately 500 ha, most frequently in floodplain forests of the rivers Hron, Nitra and Žitava in the group of forest types *Ulmeto-Fraxinetum*. We evaluated the structure, development, quality, volume and mass production of homogeneous black walnut stands and stands of this species mixed with red oak (*Quercus rubra* L.) and small-leaved linden (*Tilia cordata* M i l l.) over the territory of its most intensive cultivation (Forest Districts Nitra and Levice (Tokár, 1987, 1998; Tokár, Krekulová, 2005).

In this contribution we summarise the development of aboveground biomass in dependence on leaf area index (LAI) and climatic conditions in homogeneous stands of black walnut tended by thinning from above. The experiment was carried out in 1978–2003 in the locality Sikenica.

Material and methods

The series of permanent research plots (PRP) Sikenica, consisting of three PRP (each 50x50 m in size), was established in 1978 following the points of the thinning programme (Tokár, 1998) focussed on evaluation of changes in structure, development of quality and aboveground biomass (mass and volume) under influence of thinning from above: moderate (PRP III) and heavy (PRP IV) with positive selection, repeated at 5-year intervals (PRP V has been left without intervention) in black walnut in small pole stage. The PRP series is situated in the warm climatic region A, with the mean annual temperature of 9.6 °C and mean annual precipitation sum 580 mm (Petrovič, et al., 1968). The altitude is 150 m a.s.l., the soil type is black soil (Šály et al., 2000). The PRP´s were established in the stand 9b by seeding black walnut seed of domestic provenance (1000 $kg.ha^{-1}$) over the floodplain of the Hron river. The PRP series Sikenica belongs to the group of forest types *Ulmeto-Fraxinetum carpineum*, forest type 954 Dry elm-ash forest with hornbeam (Hančinský, 1972; Tokár, Krekulová, 2005; Tokár, Kukla, 2009). The stands are managed by the Forest Enterprise Levice, Forest District Levice. The stand age in 1978 was 39 years.

All the trees on the PRP series have been numbered. The PRP´s were evaluated in 1978, 1983, 1988, 1993, 1998 and 2003, using the methods of Tokár (1987, 1992, 1998). The aboveground biomass was estimated using the destructive method. The number of analysed sample trees was determined by means of the method of stratified selection according to the tree classes and their basal area values, with an accuracy of 10% (Šmelko, Wolf, 1977). On the sample trees we measured the following parameters: weight of stem, weight of branches, weight of annual shoots, weight of leaves. We used a KAMOR scale. From four sample trees representing the tree classes, we sampled material from each stem third, annual shoots and leaves. The material was dried in the laboratory at 105 °C to a constant weight. The converted values of components of dry aboveground biomass (stem, branches, annual shoots) and leaf area in fresh state were examined in correlation to the diameter $d_{1,3}$. The most appropriate fitting was found with a 2nd degree parabola (Tokár, 1987, 1998). The smoothed biomass values were adjusted according to the stand diameter structure and converted per one hectare.

The leaf area was determined on each plot with three representative samples (3x100 leaves), using a photoplanimeter EJKELKAMP. We calculated the conversion coefficient (weight of leaves in fresh state in kg:leaf area in m^2), which was used for the conversion in all sample trees.

The thinning method applied on the PRP III is the moderate thinning from above (intensity up to 1 %), on PRP IV, it is heavy thinning from above (intensity up to 20%) with positive selection repeated at 5-year intervals. The purpose is to control the development of the black walnut monocultures, focussing on maximum production and quality. The used thinning method is based on tending of promising trees (Tokár, 1987, 1992, 1996, 1998, 2000; Tokár, Krekulová, 2005; Tokár, Kukla, 2009) selected from trees with appropriate quantitative and qualitative parameters (1st and 2nd tree class, 1st and 2nd degree of stem and crown quality) as well as dimensional characteristics (with the diameter bigger than the average stand diameter $d_{1,3}$ and higher than the mean stand height) and appropriate spacing.

The climatic characteristics of the years 1979–2003 were compiled from the meteorological record of the Slovak Hydrometeorological Institute Bratislava and meteorological yearbooks of the Slovak Agricultural University in

Nitra (Špánik et al., 1995, 2002). During the stand development, the PRP´s were subjected to 6 thinnings. The biometric measurements were carried out at 5-year intervals, and they were focussed on the estimation of leaf area index, (ha.ha^{-1}), aboveground biomass stock (t.ha^{-1}), mean periodical increments in growth area (t.ha^{-1}.and $^{-1}$) and leaf area (g.dm^{-2}.year^{-1}).

Results

Leaf area index (LAI)

The experiment was launched in 1978 when the stands on PRP were old 39 years and their leaf area index reached the values from 4.90 ha.ha^{-1} (PRP V) to 5.80 ha.ha^{-1} (PRP III). In 2003, at stand age 64 years, was the highest leaf area index found on PRP V (7.82 ha.ha^{-1}) as a result of higher number of trees (656 ts.ha^{-1}). From the two thinned plots, the higher leaf area index (7.27 ha.ha^{-1}) was on PRP IV tended using heavy thinning from above (Table 1).

T a b l e 1. Leaf area index (LAI) in black walnut (*Juglans nigra* L.) monocultures on permanent research plots (PRP) Sikenica in years 1978–2003.

PRP	1978		1983		1988		1993		1998		2003	
	age	LAI	age	LAI	age	LAI	age	LAI	age	LAI	age	LAI
	years	ha.ha^{-1}	years	ha.ha^{-1}	years	ha.ha^{-1}	years	ha.ha^{-1}	years	ha.ha^{-1}	years	ha.ha^{-1}
III	39	5.80	44	5.90	49	6.00	54	6.15	59	6.30	64	6.54
IV	39	5.65	44	5.90	49	6.19	54	6.50	59	6.71	64	7.27
V	39	4.90	44	5.60	49	6.19	54	6.80	59	7.41	64	7.82

Aboveground biomass stock

The development of the aboveground biomass stock is summarised in Table 2. The plot PRP IV tended by heavy thinning from above has higher stock values than PRP III tended using moderate thinning from above. At the stand age of 64 years, the aboveground biomass stock on PRP III was 173.61 t.ha^{-1}, on PRP IV it was 194.68 t.ha^{-1}. However, thank to the higher tree number, the highest stock value was reached on the control plot PRP V (207.56 t.ha^{-1}).

Mean periodical increment in aboveground biomass

During the stand development in 1978–2003 we carried out 6 thinning interventions on plots PRP III and IV. Mensurational evaluations performed at 5-year intervals enabled us to estimate the values of mean periodical increments per growth area (t.ha^{-1}.year^{-1}) and leaf area (g.dm^{-2}.year^{-1}).

The highest mean periodical increments per growth area (Table 3) were on all the plots reached in 1984–1989 (10.37–13.07 t.ha^{-1}.year^{-1}) and in 1979–1983 (7.24–7.54 t.ha^{-1}.year^{-1}).

T a b l e 2. Aboveground biomass stock in black walnut (*Juglans nigra* L.) monocultures on permanent research plots (PRPs) Sikenica in years 1978–2003.

PRP	1978		1983		1988		1993		1998		2003	
	age	biomass	age	biomass	age	biomass	age	biomass	age	biomass	age	biomass
	years	$t.ha^{-1}$	years	$t.ha^{-1}$	years	$t.ha^{-1}$	years	$t.ha^{-1}$	years	$t.ha^{-1}$	years	$t.ha^{-1}$
III	39	68.42	44	106.12	49	162.01	54	165.20	59	169.19	64	173.61
IV	39	70.36	44	116.82	49	168.18	54	173.40	59	179.39	64	194.98
V	39	64.40	44	100.61	49	165.98	54	170.21	59	196.47	64	207.56

T a b l e 3. Mean periodical increment in the aboveground biomass per unit growth area in black walnut (*Juglans nigra* L.) monocultures n permanent research plots (PRPs) Sikenica.

PRP	Mean periodical increment ($t.ha^{-1}.year^{-1}$) over the years				
	1979–1983	1984–1988	1989–1993	1994–1998	1999–2003
III	7.54	11.18	0.64	0.80	0.88
IV	9.29	10.27	1.04	1.20	3.12
V	7.24	13.07	0.85	5.25	2.22

Also in case of mean periodical increment per leaf area (Table 4) were the highest values on all the PRPs reached in 1984–1988 (1.66–2.11 $g.dm^{-2}.year^{-1}$) and in 1979–1983 (1.28–1.67 $g.dm^{-2}.year^{-1}$). The values in the other 5-year periods were considerably lower.

Following the t-test, the means significantly differed from the means of 1979–1983 period at $P = 0.05$ and from the means of 1984–1988 at $P = 0.01$.

Also mean values of growth increment on PRP with crown thinning of high intensity differed significantly (at $P = 0.01$) from the respective values on the control PRP in the period 1979–1983. In the other thinning periods and in other PRPs significant differences between studied characteristics were not observed.

Climatic conditions and aboveground biomass production

As we have just reported, the highest periodical increments per leaf area unit were on all the plots reached in the periods 1984–1988 and 1979–1983.

T a b l e 4. Mean periodical increment in the aboveground biomass per unit leaf area in black walnut (*Juglans nigra* L.) monocultures on permanent research plots (PRPs) Sikenica .

PRP	Mean periodical increment ver ($g.gm^{-2}.year^{-1}$) the years				
	1979–1983	1984–1988	1989–1993	1994–1998	1999–2003
III	1.28	1.86	0.10	0.13	0.13
IV	1.57	1.66	0.16	0.18	0.43
V	1.29	2.11	0.12	0.71	0.28

T a b l e 5. Mean annual temperature, precipitation and photosynthetically active radiation (G_{PAR}).

Year	Mean temperature °C	Average precipitation mm	G_{PAR} kWh.m^{-2}
1979	10.1	524	555
1980	8.7	643	516
1981	10.1	526	581
1982	10.3	399	592
1983	10.7	433	615
Total	49.9	2525	2859
Average	10.0	505.0	572
1984	9.8	559	571
1985	8,9	496	597
1986	9.5	415	539
1987	9.3	510	506
1988	10,0	541	512
Total	47.5	2521	2725
Average	9.5	504.2	545
1989	10.5	370	453
1990	10.5	440	503
1991	9.3	441	472
1992	10.9	389	500
1993	10.5	483	502
Total	51.7	2123	2430
Average	10.3	424.6	486
1994	11.8	551	488
1995	10.2	570	467
1996	9.1	576	474
1997	9.7	442	490
1998	10.4	643	418
Total	51.2	2782	2337
Average	10.2	556.4	467
1999	10.5	708	446
2000	11.5	406	491
2001	10.1	562	453
2002	10.9	664	448
2003	10.4	362	510
Total	53.4	2702	2348
Average	10.7	540.4	470

The climate in these two 5-year periods was very favourable for the development of black walnut monocultures (Table 5). The main climatic characteristics (mean annual temperature, annual precipitation totals and photosynthetically active radiation) reached almost the same values (period 1979–1983: 10.0 °C, 505.0 mm, 572 kWh.m^{-2}, period 1984–1988: 9.5 °C, 504.2 mm, 545 kWh.m^{-2}). These conditions provided optimum for reaching maximum mean periodical increment in aboveground biomass per leaf area in black walnut monocultures in floodplain forests in south part of the Hron river.

Discussion

The hitherto knowledge in the research on ecology and production on stands of introduced woody plants (Tokár, 1984, 1987, 1998; Tokár, Krekulová, 2005) suggests that the aboveground biomass production is, apart from tending interventions (thinning) also influenced by a number of other ecological variables (soil fertility, stand composition, climatic conditions), genetic and physiological properties of the taxons. The dry biomass production is also dependent on the leaf area index (LAI) and net assimilation yield. LAI and assimilation yield are influenced by the environment, and they also depend on the developmental phase and density (spacing) of trees in the population (Tokár, 1998). For high production, it is necessary to reach maximum leaf area in the optimum vegetation phase (Oszlányi, 1992, 1995; Vyskot et al, 1971).

Up to these days, the research on aboveground biomass production in stands of introduced woody plants has not explained yet the connection between the aboveground biomass production per leaf area unit (g.dm^{-2}.year^{-1}) and climatic conditions. The first results were published by Tokár (2004, 2005). The author found that the limiting factor for reaching maximum aboveground biomass production in European chestnut stands over the study period was mean annual precipitation (at least 500 mm per year).

Our long-term, 25-year observations on phytotechnics of homogeneous stands of black walnut showed that the production of aboveground biomass in these stands is controlled by intensity of thinning intervention (Tokár, 1984, 1986, 1987, 1992, 1996, 1998, 2000). Examining the dendrochronology, there was also found a significant correlation with the climate history (Tokár, Krekulová, 2005). Maximum mean periodical increments in aboveground biomass (g.dm^{-2}.year^{-1}) in black walnut monocultures corresponded to the following conditions: mean annual temperature 9.5 °C, annual precipitation total 550 mm and photosynthetically active radiation 570 kWh.m^{-2}. Such a natural environment, together with favourable soils and phytotechnics (thinning), provide optimum conditions for cultivation of black walnut trees in forests of south-western Slovakia.

Good results for growth and production were also obtained for black walnut in forest stands in South Moravia (Hríb et al., 2003; Prudič, 1991). Beran and Šindelář (1996) as well as Frýdl and Šindelář (2004) also support the introduction of this woody plant in forest stands.

Conclusion

This work evaluates the development of weight production of aboveground biomass in black walnut (*Juglans nigra* L.) monocultures in dependence on leaf area index (LAI) and climatic conditions. The research ran in 1978–2003 in the locality Sikenica, in homogeneous black walnut stands subjected to thinning from above.

The highest mean annual periodical increments per unit leaf area were found for the period 1984–1988 (1.66–2.11 $g.dm^{-2}.year^{-1}$) and 1979–1983 (1.28–1.67 $g.dm^{-2}.year^{-1}$), with the following climatic characteristics: mean annual temperature 9.5–10.0 ^{o}C, mean annual precipitation total 505 mm and mean annual photosynthetically active radiation 545–572 $kWh.m^{-2}$. These conditions provided an optimum forest environment of reaching of maximum aboveground biomass production in tended homogeneous stands of black walnut in floodplain forests situated in the south stream of the Hron river.

Translated by D. Kúdelová

References

Benčať, F., 1982: Atlas of the distribution of exotic woody plants in Slovakia and zoning of their cultivation (in Slovak). Veda, Bratislava, 368 pp.

Beran, F., Šindelář, J., 1996: Perspectives of the selected introduced woody plant species in the forestry of Czech Republic (in Czech). Lesnictví-Forestry, *42*: 337–355.

Frýdl, J., Šindelář, J., 2004: Breeding and introduction of woody plant species in the ecologically directed forestry (in Czech). Lesnická Práce, *83*: 20–21.

Hančinský, L., 1972: Forest types of Slovakia (in Slovak). Príroda, Bratislava, 307 pp.

Holubčík, M., 1968: Introduced woody plants in forest management (in Slovak). SVPL, Bratislava, 371 pp.

Hríb, M., Kneifl, M., Kadavý, J., 2003: Growth of black walnut (*Juglans nigra* L.) in the floodplain forests of the Židlochovice Forest Enterprise. Ekológia (Bratislava), *22*: 162–176.

Oszlányi, J., 1992: Biomass production per leaf area unit in three Scotch pine (*Pinus sylvestris* L.) forest stands. Ekológia (ČSFR), *11*: 133–137.

Oszlányi, J., 1995: Dynamics of leaf area index in an adult floodplain forest ecosystem during one vegetation period. Ekológia (Bratislava), *14*: 35–41.

Petrovič, Š. et al., 1968: Climatic and phenological conditions of West-Slovakia region (in Slovak). Hydrometeorologický ústav, Praha, 326 pp.

Prudič, Z., 1991: The growth of black walnut (*Juglans nigra* L.) in the Stražnice forest establishment (in Czech). Lesnictví, *37*: 359–369.

Réh, R., 1996: A perspective species for central European woodworking Industry-black walnut (*Juglans nigra* L.). In Proceedings of the 2nd International symposium Wood Structure and Properties 94, Zvolen, Technical University, p. 235–246.

Šály, R. et al., 2000: Morphogenetic soil classification system of Slovakia. Base referential taxonomy. VÚPOP, Bratislava, Societas Pedologica Slovaca, 76 pp.

Šika, A., 1957: On prospects of cultivation of black walnut in CSSR (in Czech). Lesnická Práce, *36*: 9–14.

Šika, A., 1958: Growth characteristics of black walnut in young age (in Czech). Vědecké Práce VÚLM, *2*: 61–79.

Šindelářová, J., 1973: Wood properties in introduced woody plants (in Czech). Studijní Informace, *4*, 64 p.

Šmelko, Š., Wolf, J., 1977: Statistical methods in forestry (in Slovak and Czech). Príroda, Bratislava, 330 pp.

Špánik, F. et al., 1995: The agrometeorological and phenological characteristics for 1961–1990 years in Nitra (in Slovak). SPU, Nitra, 101 pp.

Špánik, F. et al., 2002: The agrometeorogical and phenological characteristics for 1991–2000 years in Nitra (in Slovak). SPU, Nitra, 40 pp.
Tokár, F., 1984: Structure and production of pure stands of black walnut (*Juglans nigra* L.) in riverine forests along the Hron river (in Slovak). Lesnictví, *30*, 11: 993–1000.
Tokár, F., 1986: Aboveground biomass of a pure stand of black walnut (*Juglans nigra* L.) (in Slovak). Lesnictví, *32*, 8: 717–722.
Tokár, F., 1987: Biomass of selected exotic woody plants in forest stands of southwest Slovakia (in Slovak). Acta dendrobiologica, Veda, Vyd. SAV, Bratislava, 116 pp.
Tokár, F., 1992: The influence of thinnings on the development of volume and weight production in pure stands of black walnut (*Juglans nigra* L.) (in Slovak). Lesnícky Časopis-Forestry Journal, *38,* 3: 189–203.
Tokár, F., 1996: The production of biomass in pure stands of black walnut (*Juglans nigra* L.) in Slovakia. Zborník vedeckých prác, Lesnícka fakulta, Lesotechnická univerzita, Ľvov, p. 187–192.
Tokár, F., 1998: Phytotechnique and dendromass production in selected exotic species stands in Slovakia (in Slovak). Veda, Vyd. SAV Bratislava, 157 pp.
Tokár, F., 2000: The effect of thinnings on the development of unmixed stands of black walnut (*Juglans nigra* L.). Folia Oecologica, *27*: 39–46.
Tokár, F., 2004: Leaf area index (LAI), production and silvicultural practice in European chestnut (*Castanea sativa* Mill.) monocultures. Folia Oecologica, *31*, 2: 111–121.
Tokár, F., 2005: Production of the aboveground dendromass of European chestnut (*Castanea sativa* Mill.) in relation to leaf area index and climatic conditions. Folia Oecologica, *32*, 2: 116–124.
Tokár, F., Krekulová, E. 2005: Influence of phytotechnology on growth, production and leaf area index of black walnut (*Juglans nigra* L.) monocultures in Slovakia. Journal of Forest Science, *51*, 5: 213–224.
Tokár, F., Kukla, J., 2009: Ecology phytotechnics and production of black walnut (*Juglans nigra* L.) plantations. Ekológia (Bratislava), (in press).
Vyskot, M., et al., 1971: Bases of growth and production of forests (in Czech and Slovak). SZN, Praha, 440 pp.