© *Acta hydrotechnica* **22/36 (2004)**, Ljubljana
ISSN 1581–0267

UDK/*UDC:* 556.52:630*1
Izvirni znanstveni članek – *Original scientific paper*

Prejeto/*Received:* 21. 9. 2004
Sprejeto/*Accepted:* 23. 6. 2005

DOLOČANJE INDEKSA LISTNE POVRŠINE LISTNATEGA GOZDA NA POVODJU DRAGONJE – 2. DEL: REZULTATI IN DISKUSIJA
ESTIMATING LEAF AREA INDEX OF THE DECIDUOUS FOREST IN THE DRAGONJA WATERSHED – PART II: RESULTS AND DISCUSSION

Mojca ŠRAJ

Meritve in določanje indeksa listne površine (LAI) so se izvajale v listnatem gozdu na eksperimentalnem povodju Dragonje. Poleg teh meritev so bile sočasno narejene natančne meritve in analize posameznih komponent hidrološkega kroga gozda in drugih parametrov vegetacije s sodobno mersko opremo. V prvem delu članka (Šraj, 2003b) so bile predstavljene metode določanja indeksa listne površine in meritve LAI. Prav tako so v prvem delu članka natančno opisane lastnosti dreves na obeh izbranih raziskovalnih ploskvah. V tem delu članka so predstavljeni rezultati meritev in določanja indeksa listne površine ter njihova analiza. Meritve so se začele v jeseni 2000. Najpogostejšim drevesnim vrstam (hrast, jesen, gaber, javor, dren) je bila določena specifična površina listov SLA. Indeks listne površine LAI se je določal po treh metodah: neposredni metodi zbiranja odpadlega listja, metodi hemisferičnega fotografiranja in metodi merjenja fotosintetskega aktivnega sevanja (PAR). Z analizami je bilo ugotovljeno, da metodi hemisferičnega fotografiranja in merjenja fotosintetskega aktivnega sevanja PAR v obdobju z listjem podcenjujeta vrednosti LAI. Dobljeni vrednosti za LAI po metodi zbiranja listja sta 6,7 za južno pobočje in 7,3 za severno. Manjša vrednost LAI na južnem pobočju je bila pričakovana, saj ima gozd na tem pobočju bolj odprt značaj kot na severni strani.
Ključne besede: *indeks listne površine (LAI), specifična listna površina (SLA), Dragonja, gozdna hidrologija, raziskovalno polje*

Measurements and estimation of leaf area index (LAI) were carried out in the deciduous forest in the experimental watershed of the Dragonja River. At the same time precise measurements and analysis relevant to single elements of the forest hydrological cycle and other vegetational parameters with modern measuring equipment were made. In Part 1 of the paper (Šraj, 2003b) the methods of delineation of the leaf area index and measurements of LAI were discussed. An accurate description of characteristical features of trees on both chosen plots was also given. In this part of the paper, results of measurements, LAI estimation and analysis are given. The measurements commenced in autumn 2000. The specific leaf area (SLA) was estimated for the most abundant tree species (for example oak, ash, hornbeam, maple, cornelian cherry dogwood). Leaf area index was estimated according to three methods: direct method of litterfall collection, method of hemispherical photography, and method of measuring photosynthetically active radiation (PAR). The analyses revealed that the methods of hemispherical photography and of photosynthetically active radiation (PAR) underestimated the value of LAI in the full-leaf period. LAI estimated according to the litterfall collection method was 6.7 on the south plot and 7.3 on the north plot. The lower value of LAI on the south plot was expected, since the forest on the south plot has a more open character than the one on the north plot.
Key words: *leaf area index (LAI), specific leaf area (SLA), Dragonja, forest hydrology, experimental plot*

1. REZULTATI MERITEV IN RAZPRAVA

1.1 SPECIFIČNA POVRŠINA LISTOV *SLA*

Za izračun indeksa listne površine po neposredni metodi je potrebno najprej določiti specifično površino listov *SLA* (Šraj, 2003b). *SLA* se je določila za pet najbolj tipičnih drevesnih vrst na vsaki ploskvi posebej (hrast, gaber, jesen, javor, rumeni dren), poleg tega pa tudi za kategorijo "ostali listi" ter za droben listni material. Dobljene vrednosti *SLA* so prikazane v preglednici 1. Kot je razvidno iz dobljenih rezultatov, so specifične površine listov posameznih drevesnih vrst na severnem pobočju večje kot na južnem, z izjemo gabra. Razlike v *SLA* med obema pobočjema se gibljejo od 2 % (hrast) do 30 % (rumeni dren).

Vrednosti specifičnih površin za listopadne vrste dreves je v literaturi malo. Eden od razlogov je tudi vedno večje število raziskav, kjer se uporablja posredne metode določanja *LAI*, kjer specifična površina listov ni potrebna. Drug razlog pa je gotovo zamudnost metode. Za približno primerjavo so bile najdene le vrednosti Chasona in sodelavcev (1991), ki so za hrast v ZDA dobili vrednosti *SLA* 10–12 m^2/kg, za rdeči javor pa 16,5 m^2/kg.

1. RESULTS OF MEASUREMENTS AND DISCUSSION

1.1 SPECIFIC LEAF AREA *SLA*

For calculation of the leaf area index according to the direct method one first has to estimate the specific leaf area *SLA* (Šraj, 2003b). *SLA* was estimated for the five most typical tree species on each plot separately (oak, hornbeam, maple, ash, cornelian cherry dogwood), and also for the "other leaves" category and for fine foliage material. *SLA* values are shown in Table 1. As is apparent from the results obtained, the specific leaf area of single tree species on the north plot is higher than that on the south plot, with the exception of hornbeam. Differences in SLA between both slopes are from 2 % (oak) to 30 % (cornelian cherry dogwood).

SLA values for deciduous tree species are not often found in the literature. One of the reasons is that a growing number of studies use the indirect methods of *LAI* estimation, where the estimation of specific leaf area is not needed. Another reason is that the direct method tends to be time-consuming. For an approximate comparison only the values by Chason *et al.* (1991) were available, who acquired for oak (in USA) the *SLA* values of 10–12 m^2/kg, and for red maple 16.5 m^2/kg.

Preglednica 1. Specifična površina listov *SLA* za posamezne drevesne vrste na južni in severni raziskovalni ploskvi.
Table 1. Specific leaf area SLA for each tree species on the south and north research plots.

DREVESNA VRSTA/ ***TREE SPECIES***	**JUŽNA PLOSKEV/** ***SOUTH PLOT*** **[m^2kg^{-1}]**	**SEVERNA PLOSKEV/** ***NORTH PLOT*** **[m^2kg^{-1}]**
Hrast/*oak*	15.95*	16.25*
Gaber/*hornbeam*	30.60*	26.27*
Javor/*maple*	32.41	37.61
Jesen/*ash*	36.61	48.90
Rumeni dren/*cornelian cherry dogwood*	30.63	43.47
Ostali listi/*other leaves*	26.55	27.68
Droben listni material/*fine foliage material*	5.35*	5.01*

* te Linde (2001)

Preglednica 2. Povprečne količine zbranega odpadlega listja [kg/m^2] po posameznih drevesnih vrstah v sezoni 2001/02 na severni raziskovalni ploskvi.

Table 2. Average quantity of collected litterfall [kg/m^2] of single trees species in the season 2001/2002 on the north research plot.

Datum/*date*	**HRAST/ *OAK***	**GABER/ *HORNBEAM***	**JAVOR/ *MAPLE***	**JESEN/ *ASH***	**DREN/ *DOGWOOD***	**OSTALI LISTI/ *OTHER LEAVES***	**DROBEN LISTNI MATERIAL/ *FINE LEAF MATERIAL***	**SKUPAJ LISTJE/ *TOTAL LITTERFALL***
7.9.01	0.006	0.028	0.005	0.000	0.000	0.003	0.003	0.046
23.10.01	0.011	0.007	0.001	0.000	0.001	0.001	0.003	0.023
8.11.01	0.006	0.004	0.001	0.000	0.001	0.001	0.003	0.016
30.11.01	0.037	0.026	0.014	0.004	0.003	0.003	0.012	0.099
11.12.01	0.081	0.020	0.011	0.005	0.003	0.002	0.003	0.125
19.12.01	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.004
9.1.02	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.002
30.1.02	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
8.3.02	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.002
22.5.02	0.001	0.000	0.000	0.000	0.000	0.005	0.001	0.008
SKUPAJ/ *TOTAL*	**0.145**	**0.088**	**0.033**	**0.010**	**0.008**	**0.017**	**0.026**	**0.326**
%	**44.52**	**26.96**	**10.01**	**3.01**	**2.35**	**5.16**	**7.99**	**100.00**

Preglednica 3. Povprečne količine zbranega odpadlega listja [kg/m^2] po posameznih drevesnih vrstah v sezoni 2001/02 na južni raziskovalni ploskvi.

Table 3. Average quantity of collected litterfall [kg/m^2] of single trees species in the season 2001/2002 on the south research plot.

Datum/*date*	**HRAST/ *OAK***	**GABER/ *HORNBEAM***	**JAVOR/ *MAPLE***	**JESEN/ *ASH***	**DREN/ *DOGWOOD***	**OSTALI LISTI/ *OTHER LEAVES***	**DROBEN LISTNI MATER./ *FINE LEAF MATERIAL***	**SKUPAJ LISTJE/ *TOTAL LITTERFALL***
7.9.01	0.004	0.001	0.000	0.000	0.000	0.001	0.001	0.007
23.10.01	0.005	0.002	0.000	0.002	0.007	0.001	0.003	0.021
8.11.01	0.001	0.002	0.000	0.003	0.003	0.000	0.001	0.010
30.11.01	0.009	0.010	0.000	0.047	0.008	0.004	0.004	0.082
11.12.01	0.061	0.001	0.000	0.014	0.004	0.005	0.003	0.088
19.12.01	0.036	0.000	0.000	0.004	0.000	0.003	0.001	0.044
9.1.02	0.006	0.000	0.000	0.001	0.000	0.001	0.000	0.008
30.1.02	0.002	0.000	0.000	0.000	0.000	0.001	0.000	0.004
8.3.02	0.009	0.000	0.000	0.001	0.000	0.002	0.000	0.012
22.5.02	0.007	0.000	0.000	0.000	0.000	0.001	0.000	0.008
SKUPAJ/ *TOTAL*	**0.140**	**0.016**	**0.000**	**0.071**	**0.023**	**0.021**	**0.013**	**0.284**
%	**49.24**	**5.80**	**0.10**	**25.10**	**7.97**	**7.23**	**4.56**	**100.00**

1.2 LAI PO METODI ZBIRANJA ODPADLEGA LISTJA

Iz rezultatov tehtanja odpadlega listja je razvidno (preglednica 2; slika 1), da skoraj polovico zbranega listja [kg/m^2] na severni strani predstavljajo hrastovi listi. Dobra četrina je gabrovih listov, 10 % javorjevih, medtem ko je vseh ostalih vrst manj kot 10 %. To se na videz ne ujema popolnoma z deležem zastopanosti posameznih dreves na severnem pobočju, kjer gabrova drevesa predstavljajo 47 %, hrastova pa 34 % vseh dreves. To lahko razložimo z večjo specifično površino listov gabrovih dreves (preglednica 1), kar pomeni, da so gabrovi listi lažji od hrastovih, to pa rezultira k večji masi zbranih hrastovih listov. Drug razlog pa bi lahko bil v naključnosti razporeditve desetih zbiralnih košar.

Tudi na južni strani približno polovico zbranega listja [kg/m^2] predstavljajo hrastovi listi (preglednica 3; slika 2). Četrtina je jesenovih listov, vse ostale vrste pa predstavljajo manj kot deset odstotkov. Tudi na južnem pobočju prihaja do navideznih neujemanj z deležem zastopanosti posameznih drevesnih vrst, kjer imamo 54 % jesena ter 26 % hrasta. Razlog je enak. Specifična površina jesenovih listov je več kot enkrat večja od specifične površine hrastovih listov (preglednica 1), kar nam da precej večjo maso zbranih hrastovih listov.

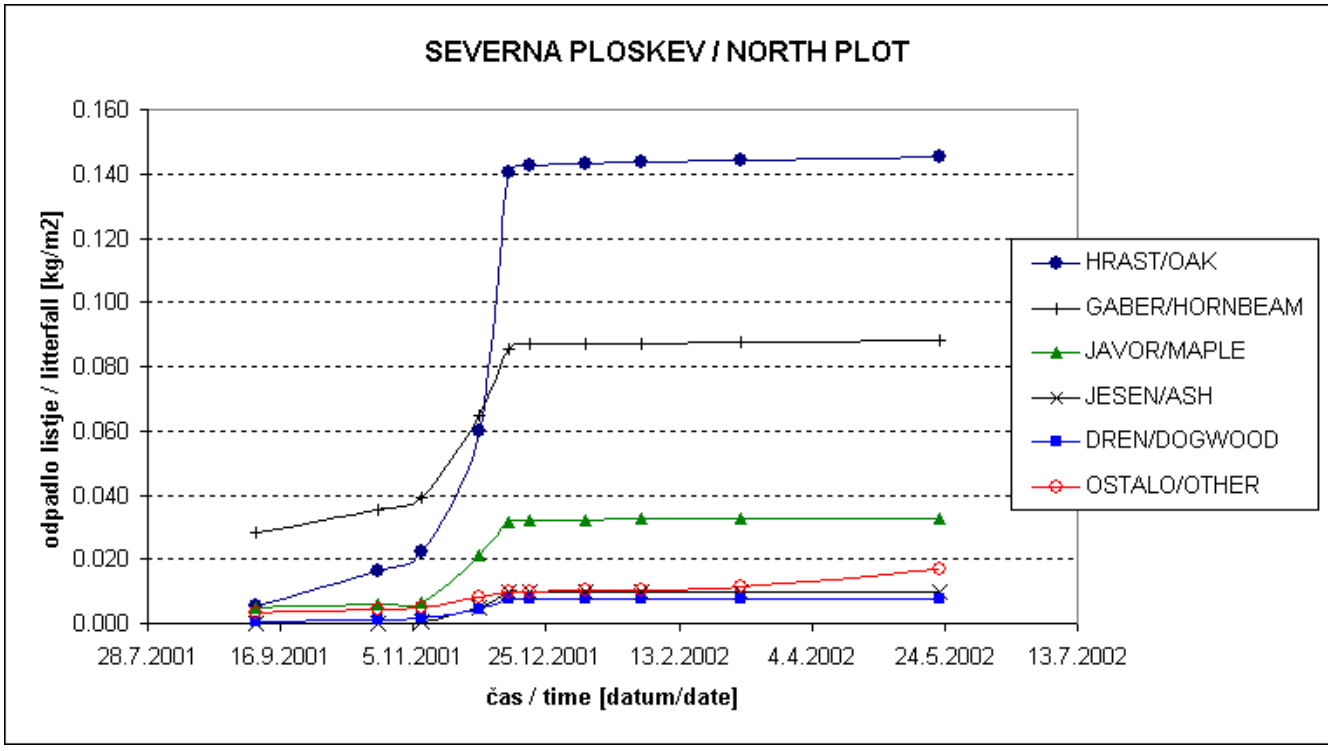
Če pogledamo količine odpadlega listja v odvisnosti od časa, ugotovimo, da večina listja odpade v obdobju od začetka novembra do konca decembra, torej v dveh mesecih (sliki 1 in 2; preglednici 2 in 3). Primerjava obeh ploskev kaže na nekoliko večje količine listja na severnem pobočju (~ 0,04 kg/m^2). Na severnem pobočju imajo vse drevesne vrste višek odpadanja listja v prvi tretjini decembra (slika 1). Na južnem pobočju pa listi jesena in gabra dosežejo višek odpadanja približno 14 dni prej, torej v drugi polovici novembra, listi ostalih drevesnih vrst pa tako kot na severnem pobočju v začetku meseca decembra (slika 2).

1.2 LAI ESTIMATED WITH DIRECT LITTERFALL COLLECTION METHOD

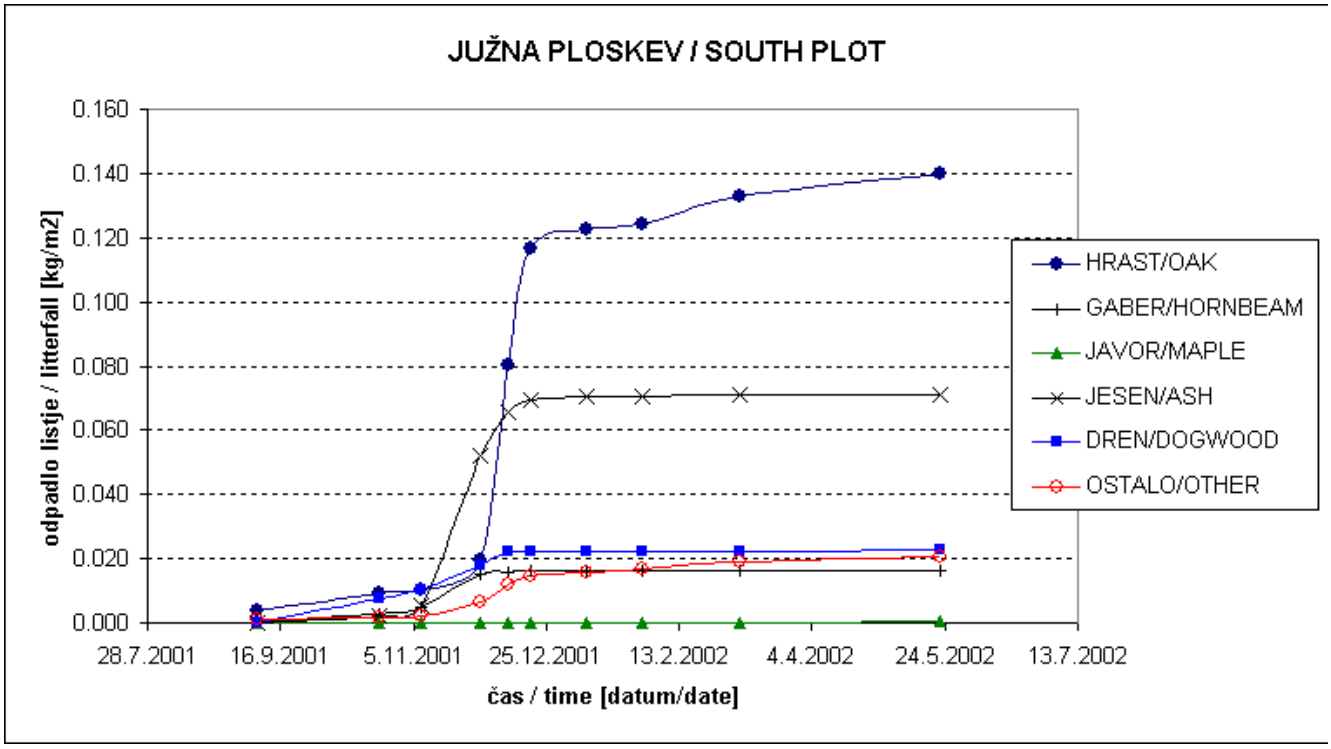
The results of weighing the leaf litterfall show (Table 2, Figure 1) that almost half of the leaves collected [kg/m^2] on the north plot consists of oak leaves. Over a quarter of leaves are represented by hornbeam, 10 % by maple, while all other species make up less than 10 %. Apparently, this does not completely coincide with the representation of single species on the north plot, where hornbeam trees represent 47 %, and oak 34 % of all trees. This can be explained by larger specific leaf area of hornbeam (Table 1), meaning that hornbeam leaves are lighter than oak leaves, which results in bigger mass of collected oak leaves. The other reason could be the randomness of distribution of 10 collection baskets.

Oak leaves represent approximately a half of collected leaves [kg/m^2] on the south plot as well (Table 3, Figure 2). A quarter is composed of ash leaves, all other tree species represent less than 10 percent. There are apparent discrepancies in the share of representation of single species on the south plot as well, where ash is represented by 54 % and oak by 26 %. The reason remains the same. Specific leaf area of ash is more than one time the size of specific leaf area of oak leaves (Table 1), which results in a greater mass of collected oak leaves.

By considering the litterfall quantity in dependence of time, it can be established that most of the leaves falls off in the period from the beginning of November to the end of December, that is in two months (Figures 1 and 2; Tables 2 and 3). Comparison of both plots shows somewhat higher litterfall volume on the north plot (by approx. 0.04 kg/m^2). On the north plot all tree species reach their peak in litterfall in the first third of December (Figure 1). On the south plot, however, ash and hornbeam leaves reach their peak in litterfall approx. 14 days earlier, that is in the second half of November, whereas leaves of other tree species reach their peak in the beginning of December (Figure 2), as is the case on the north plot.



Slika 1. Kumulativna vsota odpadlega listja za posamezne drevesne vrste v odvisnosti od časa na severni raziskovalni ploskvi v sezoni 2001/02 (Šraj, 2003a).
Figure 1. Cumulative total of litterfall for single tree species as a function of time on the north research plot in the 2001/02 season (Šraj, 2003a).



Slika 2. Kumulativna vsota odpadlega listja za posamezne drevesne vrste v odvisnosti od časa na južni raziskovalni ploskvi v sezoni 2001/02 (Šraj, 2003a).
Figure 2. Cumulative total of litterfall for single tree species as a function of time on the south research plot in the 2001/02 season (Šraj, 2003a).

Preglednica 4. Indeks listne površine, dobljen z metodo zbiranja odpadlega listja v sezoni 2001/02 za vsako posamezno raziskovalno ploskev po posameznih datumih zbiranja.
Table 4. Leaf area index acquired by the method of litterfall collection in season 2001/02 for each research plot and different collection dates.

	SEVERNA PLOSKEV/ *NORTH PLOT*		**JUŽNA PLOSKEV/ *SOUTH PLOT***	
Datum/*date*	**SKUPAJ LISTJE/ *TOTAL LITTERFALL* [kg/m^2]**	**LAI**	**SKUPAJ LISTJE/ *TOTAL LITTERFALL* [kg/m^2]**	**LAI**
7.9.01	0.046	1.150	0.007	0.121
23.10.01	0.023	0.462	0.021	0.490
8.11.01	0.016	0.306	0.010	0.291
30.11.01	0.099	2.306	0.082	2.541
11.12.01	0.125	2.691	0.088	1.802
19.12.01	0.004	0.096	0.044	0.797
9.1.02	0.002	0.045	0.008	0.154
30.1.02	0.001	0.029	0.004	0.084
8.3.02	0.002	0.043	0.012	0.228
22.5.02	0.008	0.185	0.008	0.151
SKUPAJ/ *TOTAL*	**0.326 (± 0.045)**	**7.312 (± 0.99)**	**0.284 (± 0.032)**	**6.658 (± 0.84)**

Preglednica 5. Indeks listne površine, dobljen z metodo zbiranja odpadlega listja v sezoni 2001/02 za vsako posamezno raziskovalno ploskev po posameznih drevesnih vrstah (Šraj, 2003a).
Table 5. Leaf area index determined with the method of litterfall collection in the season 2001/02 for each research plot and for single tree species (Šraj, 2003a).

	SEVERNA PLOSKEV/ *NORTH PLOT*		**JUŽNA PLOSKEV/ *SOUTH PLOT***	
VRSTA/ *SPECIES*	**SKUPAJ LISTJE/ *TOTAL LITTERFALL* [kg/m^2]**	**LAI**	**SKUPAJ LISTJE/ *TOTAL LITTERFALL* [kg/m^2]**	**LAI**
HRAST/*OAK*	0.145	2.362	0.140	2.230
GABER/ *HORNBEAM*	0.088	2.311	0.016	0.504
JAVOR/*MAPLE*	0.033	1.229	0.000	0.009
JESEN/*ASH*	0.010	0.480	0.071	2.608
DREN/ *DOGWOOD*	0.008	0.333	0.023	0.693
OSTALI LISTI/ *OTHER LEAVES*	0.017	0.466	0.021	0.545
DROBEN LISTNI MATERIAL/ *FINE LEAF MATERIAL*	0.026	0.131	0.013	0.069
SKUPAJ/ *TOTAL*	**0.326 (± 0.051)**	**7.312 (± 0.95)**	**0.284 (± 0.049)**	**6.658 (± 1.04)**

Zgodnejše odpadanje listja na južnem pobočju je bilo zaznati v obeh letih merjenja. Po vsej verjetnosti je to posledica pomanjkanja vode v zemljini na južnem pobočju, kar izhaja tudi iz večje evapotranspiracije na tej ploskvi.

Primerjava obeh sezon merjenja daje zelo podobno sliko, tako po času kot v količinah. Časovna primerjava sicer v ozkem časovnem obdobju kaže manjša odstopanja, ki so po vsej verjetnosti posledica vpliva burje, kažejo pa se tako na severni kot južni strani.

Z množenjem specifične površine listov posameznih drevesnih vrst s količino zbranega listja dobimo indeks listne površine *LAI*. Dobljeni vrednosti za največji indeks listne površine sta 6,66 za južno pobočje in 7,31 za severno pobočje (na višku rastne dobe) (preglednici 4 in 5). Manjša vrednost *LAI* na južnem pobočju (za približno 10 %) je bila pričakovana, saj ima gozd na tem pobočju bolj odprt značaj. Podobno se tudi skupna količina zbranega listja na obeh ploskvah razlikuje za približno enako vrednost.

1.3 METODA HEMISFERIČNEGA FOTOGRAFIRANJA

Izračunane vrednosti *LAI* za posamezna časovna obdobja po metodi hemisferičnega fotografiranja so zbrane v preglednicah 6 in 7. Dobljeni vrednosti največjega indeksa listne površine v sezoni 2000/01 sta 5,24 za južno pobočje in 4,81 za severno pobočje, v naslednji sezoni pa 3,50 oziroma 3,22.

1.4 MERJENJE FOTOSINTETSKEGA AKTIVNEGA SEVANJA (*PAR*)

Za merjenje fotosintetskega aktivnega sevanja *PAR* je bil uporabljen Sunflect Ceptometer (Vrije Universiteit Amsterdam). *LAI* se je izračunal iz razmerja med izmerjenim *PAR* pod krošnjami (prepuščeno sevanje) in nad krošnjami (vpadlo sevanje), koeficienta pojemanja posamezne vegetacije (angl. org. extinction coefficient) in Beer-Lambertovega zakona. Uporabljeni koeficient pojemanja svetlobe skozi krošnje κ je bil privzet 0,70 (po Campbell, 1986; Ross, 1975). Meritve so bile izvedene le na južnem pobočju, saj na severnem pobočju v času meritev skozi krošnje ni prehajalo nič

Earlier falling off of leaves on the south plot was recorded in both years of measurements. In all likelihood, this resulted from water shortage in the soil on the south plot, which is also the consequence of bigger evapotranspiration on the plot.

Comparison of both seasons of measurements gives a very similar picture in terms of time and quantity. Comparison in terms of time shows minor deviations, which are probably the result of the north-east *burja* wind, and they occur on north and south plots alike.

The specific leaf area of single tree species multiplied by the quantity of collected litterfall gives the leaf area index *LAI*. The highest values of leaf area index were 6.66 for the south plot and 7.31 for the north plot (at the peak of growth) (Tables 4 and 5). Smaller *LAI* value on the south plot (by approx. 10 %) was expected, because the forest in the area is of more open character. Similarly, the total quantity of collected litterfall on both plots differentiates for approximately the same value.

1.3 HEMISPHERICAL PHOTOGRAPHY

The values of *LAI* for each time period according to the method of hemispherical photography are given in Tables 6 and 7. The highest values of the leaf area index in the season 2000/01 were estimated at 5.24 for the south plot and 4.81 for the north plot, and during the next season 3.50 and 3.22, respectively.

1.4 PHOTOSYNTHETICALLY ACTIVE RADIATION (*PAR*)

The Sunflect Ceptometer (Vrije Universiteit Amsterdam) was used for measuring the photosynthetically active radiation *PAR*. *LAI* was calculated from the relationship between *PAR* measured below canopy (transmitted solar radiation) and above canopy (incoming solar radiation), extinction coefficient and the Beer-Lambert Law. The extinction coefficient κ was set at the default value of 0.70 (according to Campbell, 1986; Ross, 1975). The measurements were carried out on the south plot only, since on the north plot there was no direct solar radiation transmitted

neposrednega sončnega sevanja. Izračunana povprečna vrednost *LAI* po tej metodi znaša 3,86 (± 0,24) (te Linde, 2001).

during the time of measurements. The calculated average value of *LAI* according to the method was 3.86 (± 0.24) (te Linde, 2001).

Preglednica 6. Izračunane vrednosti *LAI* s pomočjo hemisferičnega fotografiranja za sezono 2000/01 (te Linde, 2001).
Table 6. LAI values calculated by the method of hemispherical photography for the season 2000/01 (te Linde, 2001).

DATUM/ ***DATE***	**SEVERNA PLOSKEV/** ***NORTH PLOT***	**JUŽNA PLOSKEV/** ***SOUTH PLOT***
27.9.00	4.65 (± 0.48)	5.24 (± 0.78)
4.10.00	4.83 (± 0.71)	4.22 (± 0.35)
13.10.00	4.45 (± 0.21)	3.70 (± 0.26)
20.10.00	4.81 (± 0.17)	4.31 (± 0.35)
26.10.00	4.49 (± 0.23)	-

Preglednica 7. Izračunane vrednosti *LAI* s pomočjo hemisferičnega fotografiranja za sezono 2001/02 (Šraj, 2003a).
*Table 7. LAI values calculated by the method of hemispherical photography for the season 2001/02 (*Šraj, 2003a*).*

DATUM/ ***DATE***	**SEVERNA PLOSKEV/** ***NORTH PLOT***	**JUŽNA PLOSKEV/** ***SOUTH PLOT***
7.9.01	3.22 (± 0.46)	3.50 (± 0.55)
5.12.01	2.19 (± 0.39)	2.07 (± 0.43)
11.12.01	1.20 (± 0.26)	1.56 (± 0.25)
18.12.01	0.89 (± 0.19)	1.34 (± 0.30)
9.1.02	1.06 (± 0.19)	1.52 (± 0.42)

Preglednica 8. Primerjava vrednosti *LAI*, dobljenih po različnih metodah za 20.–23.oktober.
Table 8. Comparison of LAI values obtained by different methods for 20–23 October.

	ZBIRANJE LISTJA/ ***LITTERFALL COLL.***	**HEMISFERIČNO FOTOGRAFIRANJE/** ***HEMISPHERICAL PHOTOGRAPHY***	**MERITVE PAR/** ***PAR MEASUREMENTS***
SEVERNA PLOSKEV/ *NORTH PLOT*	5.70 (± 0.49)	4.81 (± 0.17)	-
JUŽNA PLOSKEV/ *SOUTH PLOT*	6.05 (± 0.26)	4.31 (± 0.35)	3.86 (± 0.24)

1.5 PRIMERJAVA VREDNOSTI *LAI* DOBLJENIH PO RAZLIČNIH METODAH

Primerjava vseh treh metod za kratko obdobje (20.–23. oktober), v katerem so bile izvedene vse tri meritve, kaže, da dobimo

1.5 COMPARATION OF *LAI* OBTAINED WITH DIFFERENT METHODS

Comparation of all three methods during a short period (20–23 October), when all three sets of measurements were carried out, shows that the highest values were obtained by the

najvišje vrednosti po metodi zbiranja odpadlega listja, najmanjše pa z merjenjem fotosintetskega aktivnega sevanja (*PAR*). Meritve *PAR* nam dajo skoraj za polovico manjši *LAI*, hemisferično fotografiranje pa v povprečju okrog 20 % manjši *LAI* od metode zbiranja odpadlega listja (preglednica 8). Torej obe posredni metodi podcenjujeta vrednosti *LAI*. To ni presenetljivo, saj so do podobnih ugotovitev prišli tudi drugi raziskovalci po svetu (Chason in ostali, 1991; Chen in ostali, 1997; Levy in Jarvis, 1999). Chason s sodelavci (1991) je za mešani listnati gozd (hrast, hikori, bukev, javor) v ZDA dobil vrednosti *LAI* po metodi zbiranja odpadlega listja 4,89, z dvema različnima posrednima metodama merjenja prepuščenega sevanja pa 3,79 oziroma 2,91 (Šraj, 2003a).

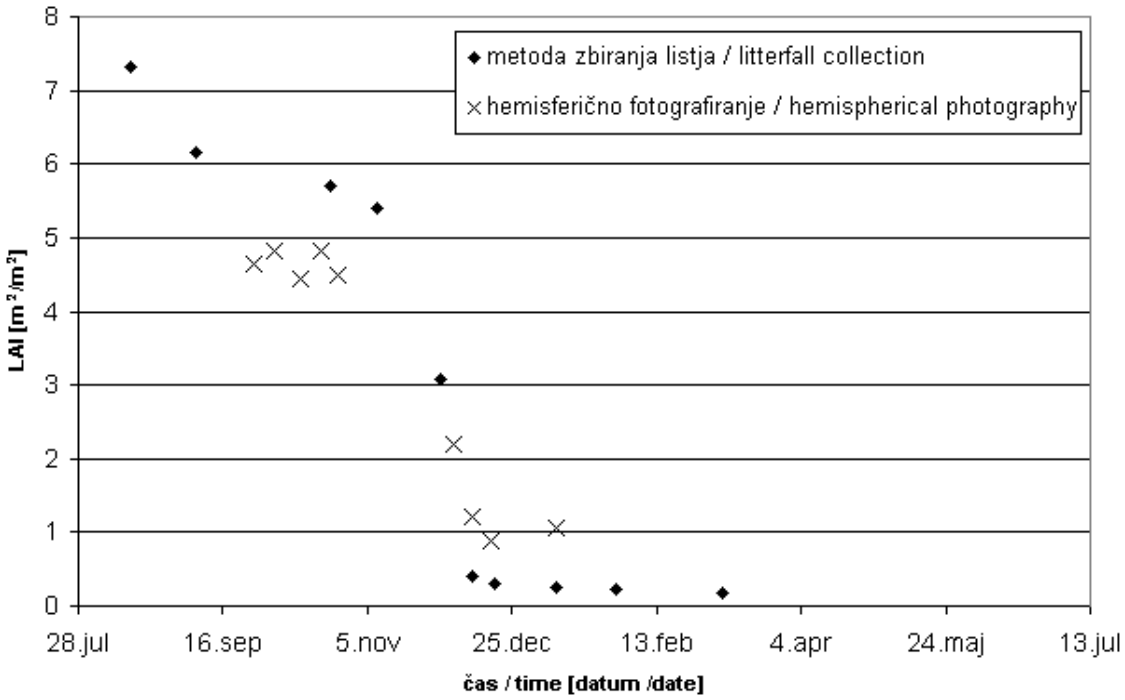
Časovna primerjava meritev skozi celo sezono nam kaže celotno sliko (sliki 3 in 4). V začetnem obdobju odpadanja listja, tj. nekje do sredine novembra, lahko vidimo, da nam metoda hemisferičnega fotografiranja res daje konstantno nižje vrednosti kot metoda zbiranja odpadlega listja, kar smo že ugotovili pri prejšnji primerjavi. Na višku sezone odpadanja listja, tj. v drugi polovici novembra do sredine decembra, pa lahko vidimo, da se vrednosti *LAI* obeh metod ujemajo precej dobro. Po tem obdobju metoda fotografiranja precenjuje vrednosti *LAI*, kar je seveda pričakovano, saj so pri tej metodi v površino krošenj zajeti tudi deblo in veje. Podobno ugotavljata v svoji raziskavi tudi Levy in Jarvis (1999). Ugotovila sta, da posredne metode (hemisferično fotografiranje, Ceptometer) podcenjujejo *LAI* pri velikih vrednostih in precenjujejo pri majhnih.

Dobljene vrednosti so primerljive z rezultati študij, narejenih drugod po svetu v približno podobnih klimatskih razmerah za podobne gozdne združbe listopadnih dreves. Le Dantec s sodelavci (2000) je za hrastove in bukove gozdove v Franciji izmeril vrednosti *LAI* od 0,5 do 8,1, v povprečju pa med 6 in 8. Chason s sodelavci (1991) je za mešani listnati gozd (hrast, bukev, javor) v ZDA dobil vrednosti *LAI* po metodi zbiranja odpadlega listja 4,9. Za listnati gozd na Nizozemskem je bil izmerjen *LAI* 4,9 (Lankreijer in ostali, 1993). Karlik in Mckay (2002) poročata o vrednostih 4–6,75 za hrastov gozd v Sredozemlju (Šraj, 2003b). V študiji, ki je zajela raziskave določanja *LAI* od leta 1932 do 2000 po celem svetu (Scurlock in ostali, 2001), pa so za listopadne gozdove v zmernem podnebju ugotovili povprečno vrednost 5,12 (± 1,84).

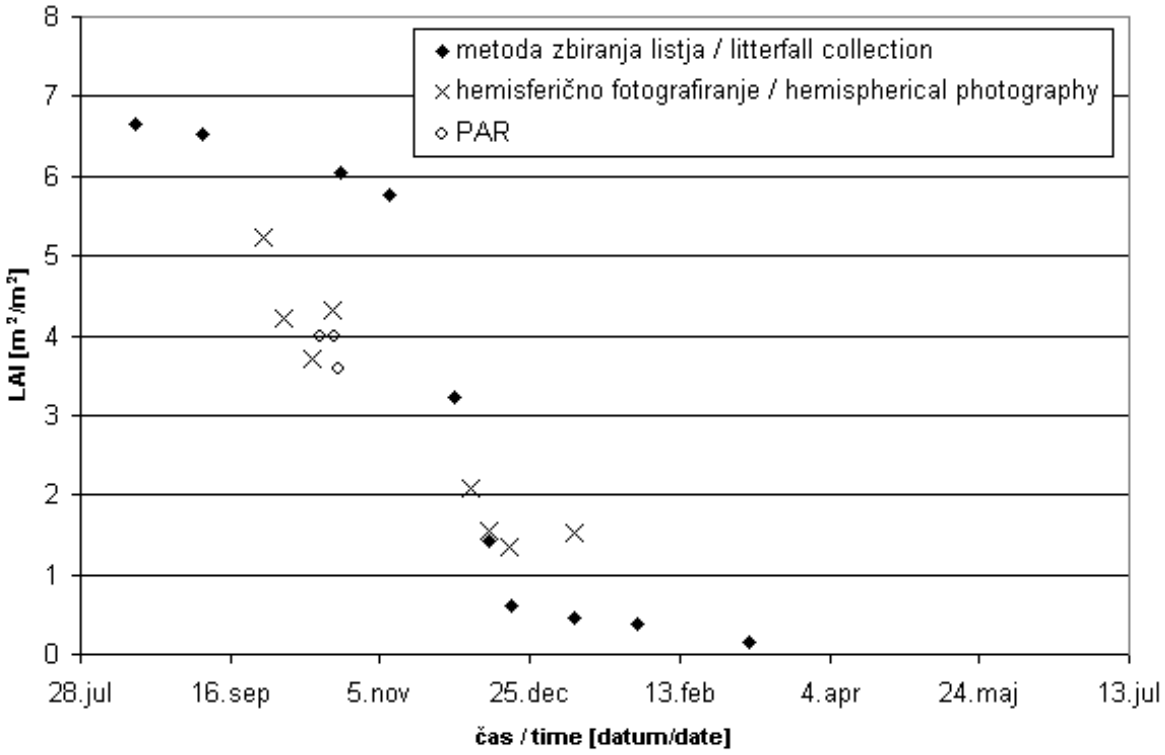
litterfall collection method, and the lowest values with the method of photosynthetically active radiation (*PAR*). *PAR* measurements give *LAI* values smaller almost by half, and hemispherical photography on average 20 % lower *LAI* values from the litterfall collection method (Table 8). This is not surprising, since other scientists worldwide have come to similar conclusions (Chason *et al.,* 1991; Chen *et al.* 1997; Levy & Jarvis, 1999). Chason *et al.* (1991) obtained for the mixed deciduous forest (oak, hickory, beech, maple) in USA according to the litterfall collection method LAI values of 4.89, and with two different indirect methods of transmitted solar radiation 3.79 and 2.91, respectively (Šraj, 2003a).

Temporal comparison of measurements throughout the whole seasons serves as an overview (Figures 3 and 4). In the beginning of the leaves falling-off period, i.e. by mid-November, it can be established that the method of hemispherical photography indeed gives constantly lower values than the litterfall collection method, as established in previous comparison. At the peak of the season of leaves falling off, i.e. in the second half of November to mid-December, there is a good correlation between values of *LAI* acquired by both methods. After that the method of hemispherical photography overestimates the *LAI* values, which is to be expected, because the tree trunks and branches are incorporated into the canopy surface. Levy & Jarvis (1999) have reached a similar conclusion in their study. They concluded that indirect methods (hemispherical photography, Ceptometer) underestimate *LAI* with high values and overestimate with low values.

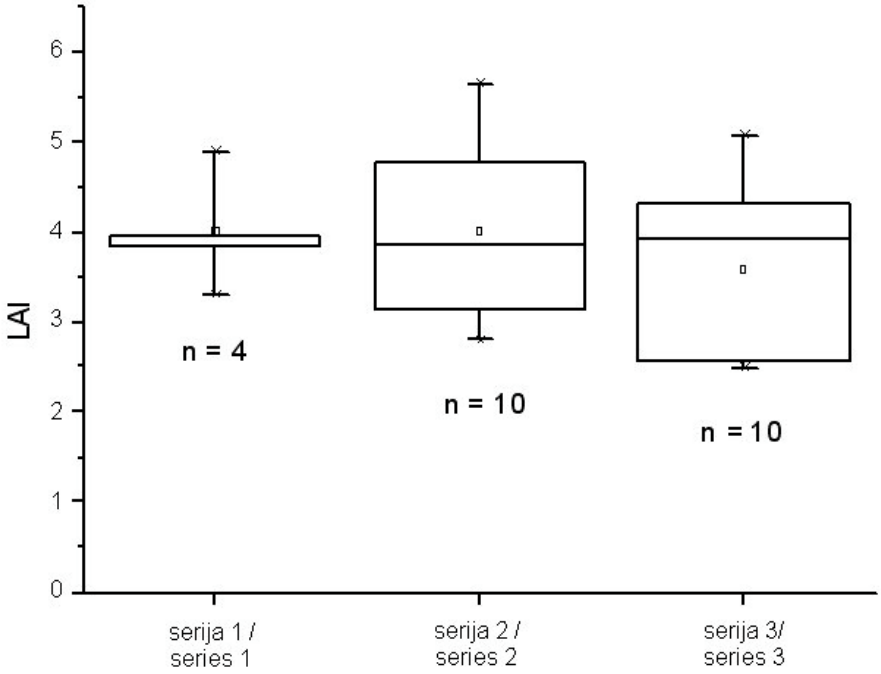
The values obtained are comparable with the results of studies carried out elsewhere in approximately similar climate conditions for similar deciduous forests. However, Le Dantec *et al.* (2000) measured *LAI* values between 0.5 and 8.1 for oak and beech forest in France, and on average between 6 and 8. Chason *et al.* (1991) obtained *LAI* 4.9 for mixed deciduous forest (oak, beech, maple) in USA according to the the litterfall collection method. For the deciduous forest in the Netherlands *LAI* was estimated at 4.9 (Lankreijer *et al.*, 1993). Karlik & Mckay (2002) recorded values between 4–6.75 for an oak forest in the Mediterranean (Šraj, 2003b). In the study that incorporated the *LAI* estimation from 1932 to 2000 worldwide (Scurlock *et al*., 2001) the average value of 5.12 (±1.84) was estimated for deciduous forests in moderate climate.



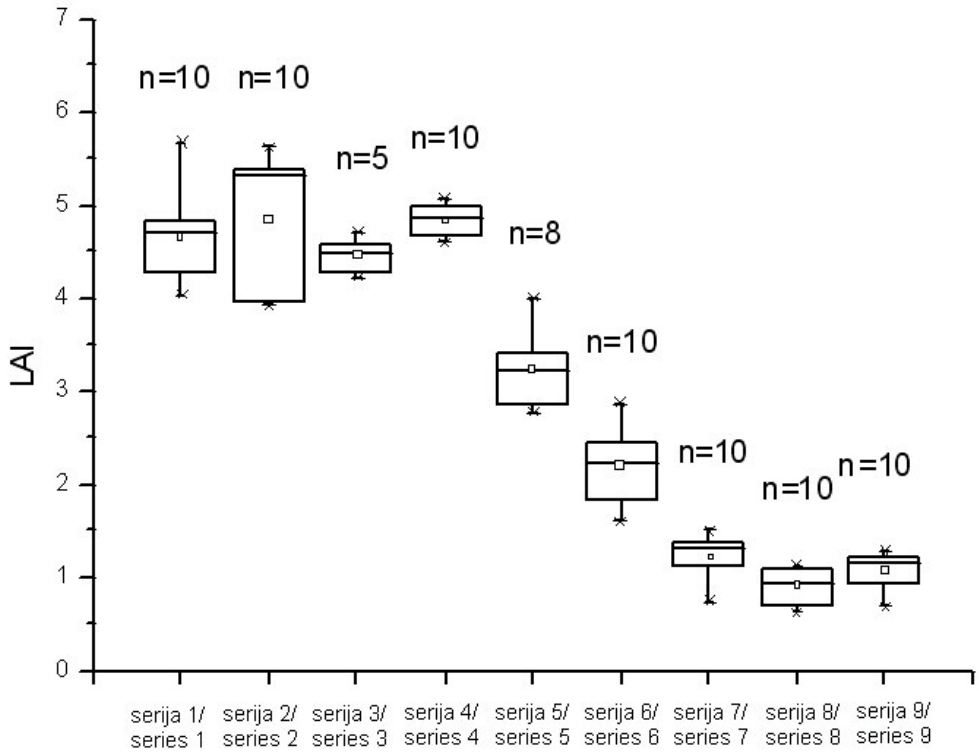
Slika 3. Primerjava meritev *LAI* po obeh metodah za severno raziskovalno ploskev.
Figure 3. Comparation of LAI obtained with different methods on the north plot.



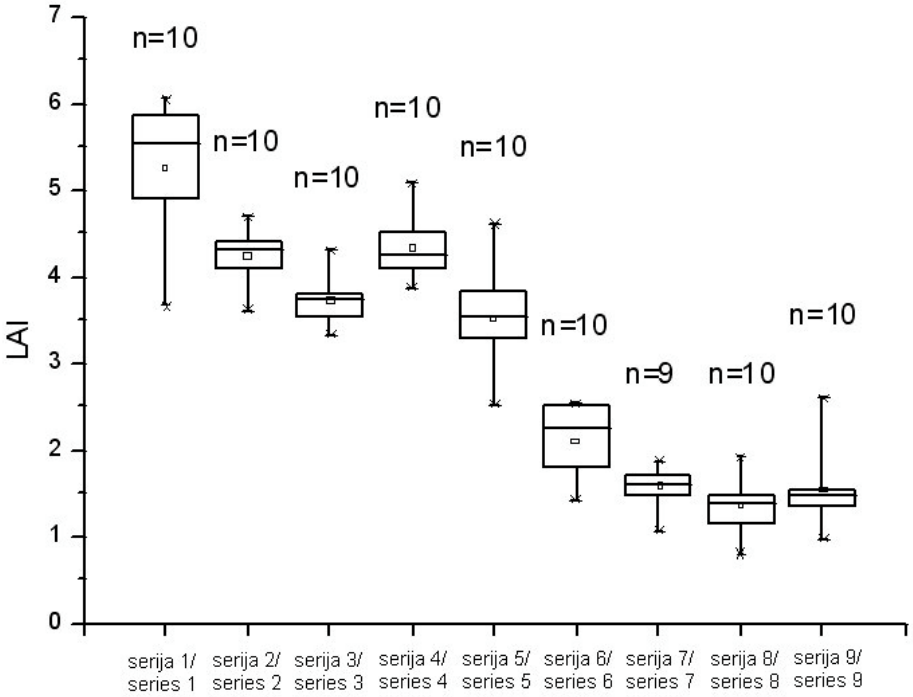
Slika 4. Primerjava meritev *LAI* po vseh treh metodah za južno raziskovalno ploskev.
Figure 4. Comparation of LAI obtained with different methods on the south plot.



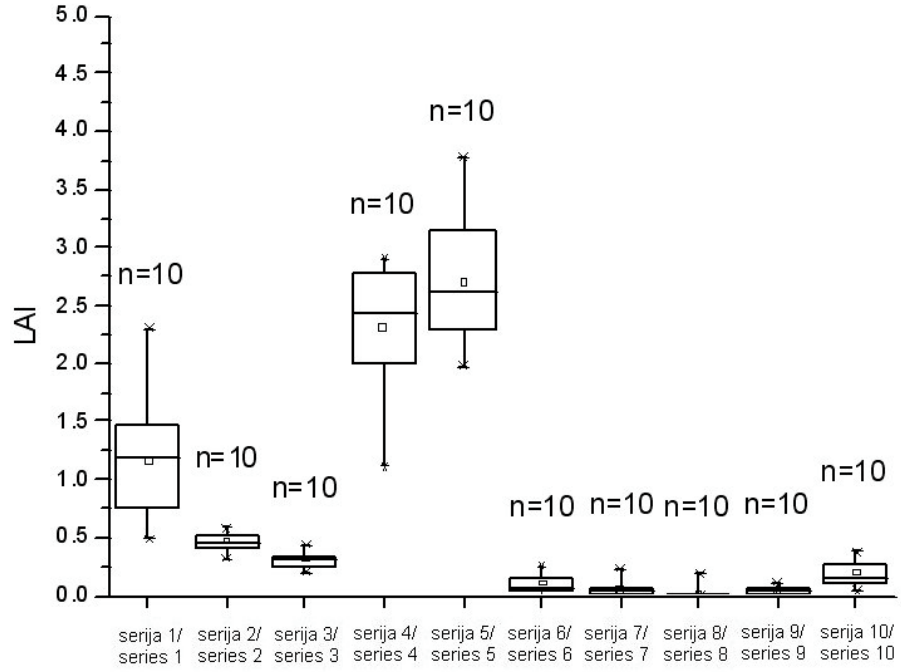
Slika 5. Prostorska spremenljivost *LAI* pri merjenju *PAR* za južno raziskovalno ploskev (serije predstavljajo različne časovne meritve, n je število merskih točk).
Figure 5. Spatial variability of LAI in PAR measurements on the south research plot (series represent different time measurements, n is the number of measuring points).



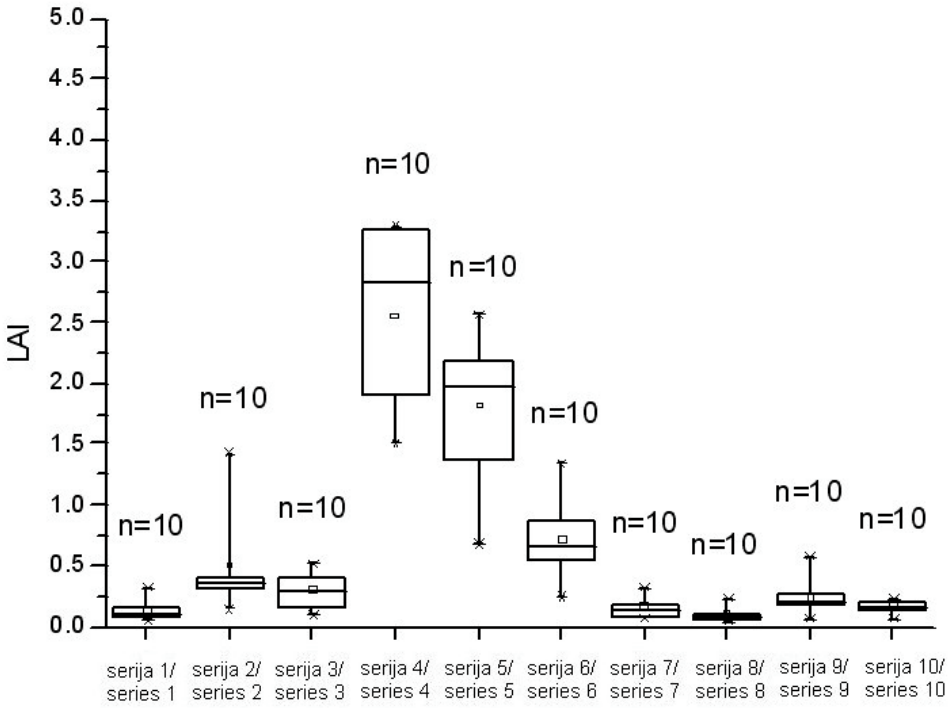
Slika 6. Prostorska spremenljivost *LAI* pri hemisferičnem fotografiranju krošenj na severni raziskovalni ploskvi (serije predstavljajo različne časovne meritve, n je število merskih točk).
Figure 6. Spatial variability of LAI in hemispherical photography of canopy on the north research plot (series represent different time measurements, n is the number of measuring points).



Slika 7. Prostorska spremenljivost *LAI* pri hemisferičnem fotografiranju krošenj na južni raziskovalni ploskvi (serije predstavljajo različne časovne meritve, n je število merskih točk).
Figure 7. Spatial variability of LAI in hemispherical photography of canopy on the south research plot (series represent different time measurements, n is the number of measuring points).



Slika 8. Prostorska spremenljivost *LAI* po metodi zbiranja odpadlega listja v sezoni 2001/02 na severni raziskovalni ploskvi (serije predstavljajo različne časovne meritve, n je število merskih točk).
Figure 8. Spatial variability of LAI according to the method of litterfall collection in season 2001/02 on the north research plot (series represent different time measurements, n is the number of measuring points).



Slika 9. Prostorska spremenljivost *LAI* po metodi zbiranja odpadlega listja v sezoni 2001/02 na južni raziskovalni ploskvi (serije predstavljajo različne časovne meritve, n je število merskih točk).
Figure 9. Spatial variability of LAI according to the method of litterfall collection in season 2001/02 on the south research plot (series represent different time measurements, n is the number of measuring points).

1.6 PROSTORSKA SPREMENLJIVOST *LAI*

Prostorska spremenljivost *LAI* pri merjenju *PAR* na južnem pobočju je razvidna iz slike 5. Serije na sliki 5 predstavljajo različne časovne meritve tekom sezone odpadanja listja. V istem času se *LAI* po prostoru spreminja za približno 2,5 m^2/m^2. Izstopa prva meritev, ki pa je bila izvedena le v štirih točkah, zato verjetno tako majhen raztros.

Precej manjšo prostorsko spremenljivost dobimo pri hemisferičnem fotografiranju krošenj, predvsem na severnem pobočju. Spremenljivost na severnem pobočju se giblje do 1,5 m^2/m^2, v večini serij pa pod 0,5 m^2/m^2 (slika 6). Na južnem pobočju pa je spremenljivost večja, in sicer se giblje od 1–2,5 m^2/m^2 (slika 7). To lahko razložimo z bolj odprtim značajem gozda na južni strani.

Po metodi zbiranja odpadlega listja na severnem pobočju v večini serij dobimo zelo majhno prostorsko spremenljivost, okrog 0,25

1.6 SPATIAL VARIABILITY OF *LAI*

Spatial variability of *LAI* in *PAR* measurements on the south plot is shown in Figure 5. Series on Figure 5 represent different time measurements during the period of leaves falling off. During the same time, *LAI* changes by approximately 2.5 m^2/m^2 in space. The first measurement stands out, it was carried out in only in four points, and thus the small fragmentation.

Fairly less significant spatial variability is achieved with hemispherical photography of canopy, primarily on the north plot. Variability on the north plot is estimated at up to 1.5 m^2/m^2, in majority of sets, however, it is below 0.5 m^2/m^2 (Figure 6). On the south plot the variability is higher, i.e. from 1 to 2.5 m^2/m^2 (Figure 7). This can be explained by the more open character of the forest on the south plot.

According to the litterfall collection method on the north plot in majority of sets a very small spatial variability is achieved, which is about 0.25 m^2/m^2, with the exception of three sets, i.e. the first set in September and two sets

m^2/m^2, z izjemo treh serij, tj. prve septembrske in dveh serij na višku odpadanja listja konec novembra in v sredini decembra, ko je bila spremenljivost malo manj kot 2 m^2/m^2 (slika 8). Nekaj podobnega se pojavlja tudi na južnem pobočju, kjer pa je v povprečju prostorska spremenljivost večja od tiste na severni strani. Podobno je bilo ugotovljeno že pri metodi hemisferičnega fotografiranja. Na južni strani je spremenljivost v večini serij manjša od 0,5 m^2/m^2, z izjemo štirih serij v oktobru, konec novembra in v decembru, ko znaša do 2 m^2/m^2 (slika 9).

2. ZAKLJUČKI

Med gozdoma na severno in južno ležečih pobočjih so bile pričakovane večje razlike, saj se opazno razlikujeta tako v strukturi, gostoti in velikosti dreves kot v sami sestavi. Primerjava rezultatov vseh treh metod določanja indeksa listne površine je pokazala, da obe posredni metodi podcenjujeta *LAI* v obdobju odpadanja listja in precenjujeta v obdobju brez listja. To ni presenetljivo, saj so do podobnih ugotovitev prišli tudi mnogi drugi raziskovalci. Torej se z gotovostjo lahko zanesemo le na neposredno metodo določanja *LAI* z zbiranjem odpadlega listja.

Z meritvami *LAI* in analizami bi bilo potrebno nadaljevati še dve do tri leta, da bi dobili potrditev rezultatov. Predvsem bi bilo potrebno narediti več meritev fotosintetskega aktivnega sevanja *PAR* in povečati število merskih točk na obeh raziskovalnih ploskvah.

ZAHVALA

Za angleški prevod se zahvaljujem g. Mojci Vilfan, za finančno podporo pa Slovenskemu komiteju IHP UNESCO in Ministrstvu za šolstvo, znanost in šport Republike Slovenije. Zahvaljujem se tudi izr. prof. dr. Damjani Drobne iz Biotehniške fakultete Univerze v Ljubljani za prijazno pomoč in uporabo njihovega laboratorija. Prav tako bi se rada zahvalila prof. dr. L.A. Bruijnzeelu in mag. A.H. te Linde iz Vrije University v Amsterdamu za strokovno pomoč.

at the peak of leaves falling off at the end of November and mid-December, when the variability was a little less than 2 m^2/m^2 (Figure 8). Something similar was observed on the south plot, where on average the spatial variability is higher than that on the north side. This was established earlier for the method of hemispherical photography. On the south plot the variability in the majority of sets was lower than 0.5 m^2/m^2, with the exception of four sets in October, at the end of November and in December, when it was estimated up to 2 m^2/m^2 (Figure 9).

2. CONCLUSIONS

Greater differences were expected between the forests on the north and south-facing plots, since there are considerable differences in terms of structure, density, tree size as well as composition. The comparison of results of all three methods of estimating the leaf area index revealed that both indirect methods underestimated *LAI* values in the period of leaves falling off and overestimated *LAI* in the leafless period. This comes as no surprise, since many other experts have come to the same conclusion. It appears that the only highly reliable method of estimating *LAI* is the direct method of litterfall collection.

For verification of results, *LAI* measurements and analyses should be carried out for another two or three years. Further measurements of photosynthetically active radiation *PAR* should be carried out in particular and the number of measuring points on both plots should be increased.

ACKNOWLEDGMENTS

I thank Ms. Mojca Vilfan for the translation into English, and I greatly acknowledge the financial support of the Slovenian National Committee for the IHP UNESCO and the Ministry od Education, Science and Sport of the Republic of Slovenia. Furthermore, I would like to thank Assoc. Prof. Damjana Drobne from the Biotechnical Faculty of the University of Ljubljana for her kind support and access to their laboratory. I would also like to thank Prof. dr. L.A. Bruijnzeel and Msc. A.H. te Linde from Vrije University in Amsterdam for their professional support.

VIRI – REFERENCES

Campbell, G.S. (1986). Extinction coefficient for radiation in plant canopies calculated using an ellipsoidal inclination angle distribution. *Agricultural and Forest Meteorology* **36**, 317–321.

Chason, W.J., Baldocchi, D.D., Huston, M.A. (1991). A comparation of direct and indirect methods for estimating forest canopy leaf area. *Agricultural and Forest Meteorology* **57**, 107–128.

Chen, J.M., Rich, P.M., Gower, R.T., Norman, J.M., Plummer, S. (1997). Leaf area index of boreal forests: Theory, Tehniquesand measurements. *Journal of Geophysical Research* **102**(D24), 29429–29443.

Karlik, J.F., Mckay, A.H. (2002). Leaf area index, leaf mass density, and allometric relationships derived from harvest of blue oaks in a California oak savanna. USDA forest Service Gen. Tech. Report PSW-GTR-184, 719–729 (http://danr.ucop.edu/ihrmp/proceed/karlik.pdf).

Lankreijer, H.J.M., Hendriks, M.J., Klassen, W. (1993). A comparation of models simulating rainfall interception of forests. *Agricultural and Forest Meteorology* **64**, 187–199.

Le Dantec, V. Dufrene, E., Saugier, B. (2000). Interannual and spatial variation in maximum leaf area index of temperate deciduous stands. *Forest Ecology and Management* **134**, 71–81.

Levy, P.E., Jarvis, P.G. (1999). Direct and indirect measurements of LAI in millet and fallow vegetation in HAPEX-Sahel. *Agricultural and Forest Meteorology* **97**, 199–212.

te Linde, A.H. (2001). Modelling rainfall interception by two deciduous forests of contrasting stature in the upper Dragonja catchment, southwestern Slovenia. Dragonja project working paper No. 3, Vrije Universiteit, Amsterdam, 42 p.

Ross, J. (1975). "Radiative transfer in plant communities" in J.L. Monteith, Ed., *Vegetation and the Atmosphere – Vol. 1*. Academic Press, London, 13–15.

Scurlock, J.M.O., Asner, G.P., Gower, S.T. (2001). Worldwide historical estimates of leaf area index, 1932-2000. Oak Ridge National Laboratory, Tennessee, U.S.A. (http://www.daac.ornl.gov – 24. 10. 2002).

Šraj, M. (2003a). *Modeliranje in merjenje prestreženih padavin* (Modeling and measuring of rainfall interception). Unpublished Doctoral Thesis, University of Ljubljana, Faculty of Civil and Geodetic Engineering, 236 p. (in Slovenian)

Šraj, M. (2003b). Določanje indeksa listne površine listnatega gozda na povodju Dragonje – 1. del: Metode in meritve/Estimating Leaf Area Index of the Deciduous Forest in the Dragonja Watershed – Part I: Methods and Measuring, *Acta hydrotechnica* **21**(35), 105–128.

Naslov avtorice – Author's Address

dr. Mojca ŠRAJ
Univerza v Ljubljani – University of Ljubljana
Fakulteta za gradbeništvo in geodezijo – Faculty of Civil and Geodetic Engineering
Katedra za splošno hidrotehniko – Chair of Hydrology and Hydraulic Engineering
Jamova 2, SI-1000 Ljubljana, Slovenia
E-mail: msraj@fgg.uni-lj.si