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VERTICAL PROFILE OF NEEDLE BIOMASS AND PENETRATION OF RADIATION THROUGH THE SPRUCE STAND

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Abstract

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Seven sample trees of Norway spruce of different social position were chosen for analysis of needle biomass distribution in the crown profile in a 19-year-old stand. Vertical needle dry mass distribution was approximated with a one-peak-curve according to equation $Q = A \,.\, \exp\,[- B \,.\, (h^{0.5} - C)^2]$. Crown zone with the maximum of needle dry mass did not exceeded 70% of the tree relative height. In individual groups of subdominant, co-dominant, and dominant sample trees these zones reached 24, 33 and 42% of the tree relative height respectively. The total amount of needle dry mass of the whole stand was 2.624 kg.m^{-2} with a maximum ca 3 m above the soil surface. A spatial stationary network containing 48 sensors in four levels was installed for evaluating the effect of the stand vertical structure to its radiation regime. Parameters of exponential profile of radiation intensity were figured out for the individual sun elevation angles ($h°$) in the range between 20 and 65 degrees. The radiation intensity $I_{6,2\,m}$ in clear days increased proportionally with the Sun elevation angle for $20° < h° < 40°$, and was independent of $h°$ for the angles above 40°. The intensity I increased mostly proportionally with $h°$ up to its maximum (63°) for the level 1.5,3.75 m above the soil surface. The penetration of radiation through the canopy in cloudy days was completely independent on the sun elevation angle. Concerning the biomass distribution, only 3 to 10% of the radiation income reached the level with the minimum of needle dry mass in dependence on the elevation angle. On the other hand, the irradiation dropped to its half at the height corresponding to ca 90% of the total needle dry mass, 50% of solar energy were absorbed by the highest 10% of needle biomass.

Key words: needle dry mass, canopy modeling, light penetration, vertical distribution

Introduction

Crown structure of forest tree species is determined not only by genetic preconditions, but also by environmental conditions of the site, mainly by the quantity of solar radiation and its vertical distribution in forest stands (Janíček, 1990). And vice versa, the penetration of radiation through the stand is significantly influenced by the leaf density and by the shape and dimension of the crown (Kuuluvianen, Pukkala, 1987). Taking into consideration that the photosynthesis per unit leaf area is determined by the quantity and spatial distribution of foliage in tree crown, the understanding of connection between the solar radiation and leaf area would contribute to the optimization of forest management and consequently to the higher wood production.

Several authors describe the spruce needle biomass in forests of Czech Republic (e.g. Vyskot, 1981; Tesař, 1982; Čermák et al., 1990; Chroust, 1993; Barták et al., 1993; Pokorný, Regner, 1998, and others). Campbell, Norman (1987) described the photosynthetic elements in forest stands by the spatial or time averages of the foliage structural parameters. The distribution of the assimilating elements within young stands is discussed by Chroust, Tesařová (1985) and Lokvenc, Chroust (1987). Analysis of the young spruce monocultures (Janíček, 1992) then contribute to the proper approximation of the age-dependant variables of mature stands.

The quantity of radiation reaching the top of a stand is determined by macroclimatic conditions of the given region (Jarvis et al., 1976), solar radiation available for the stand of a given structure depends on the sun elevation angle and on the immediate transmissivity of atmosphere. In forest ecosystems the solar radiation is partially absorbed when passing through the tree crowns and understorey layers and consequently changes its both quantity and quality (Smolen, Matejka, 1982; Tomášková, Rožnovský, 1999, and others). Reflection, transmission, absorption and spectral characteristics of solar radiation into stand are significantly influenced by its structure and optical features (Jarvis, Leverenz, 1983; Baldocchi et al., 1984). Supposing the homogeneous foliage density, the penetration of solar radiation can be simply expressed by the equation (Monsi, Saeki, 1953) $I(L,\mu) = I(0,\mu)\cdot\exp(-k\cdot L)$, where I is the direct beam intensity, L is the leaf area index (LAI), k is the extinction coefficient of the vegetation canopy and μ is the directional cosine of the beam. So the decrease of solar radiation intensity in stand basically depends on the LAI, which characterizes foliage density in a certain volume of crown layer, and on the elevation angle of the Sun (Chen et al., 1997; Johansson, 1989; Smith et al., 1991, and others).

Material and methods

Experimental site and forest stand

Experimental forest site was situated in the Drahanská vrchovina uplands. The locality of the experimental plot is situated 3 km west of the village Němčice. The coordinates of the plot are 49°26′of North latitude and 16°41′ of East longitude, with the altitude of 620 meters. The bedrock is here acid granodiorit, overlapped by deluvial

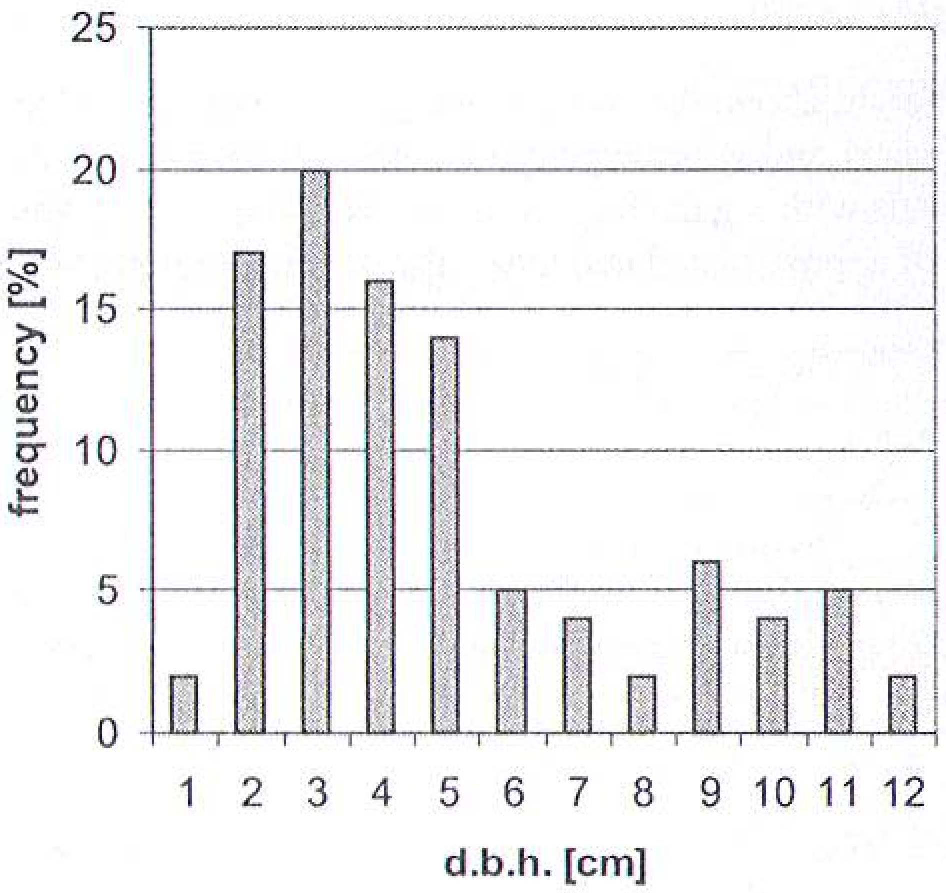

Fig. 1. Tree DBH distribution on the sample plot in 1994.

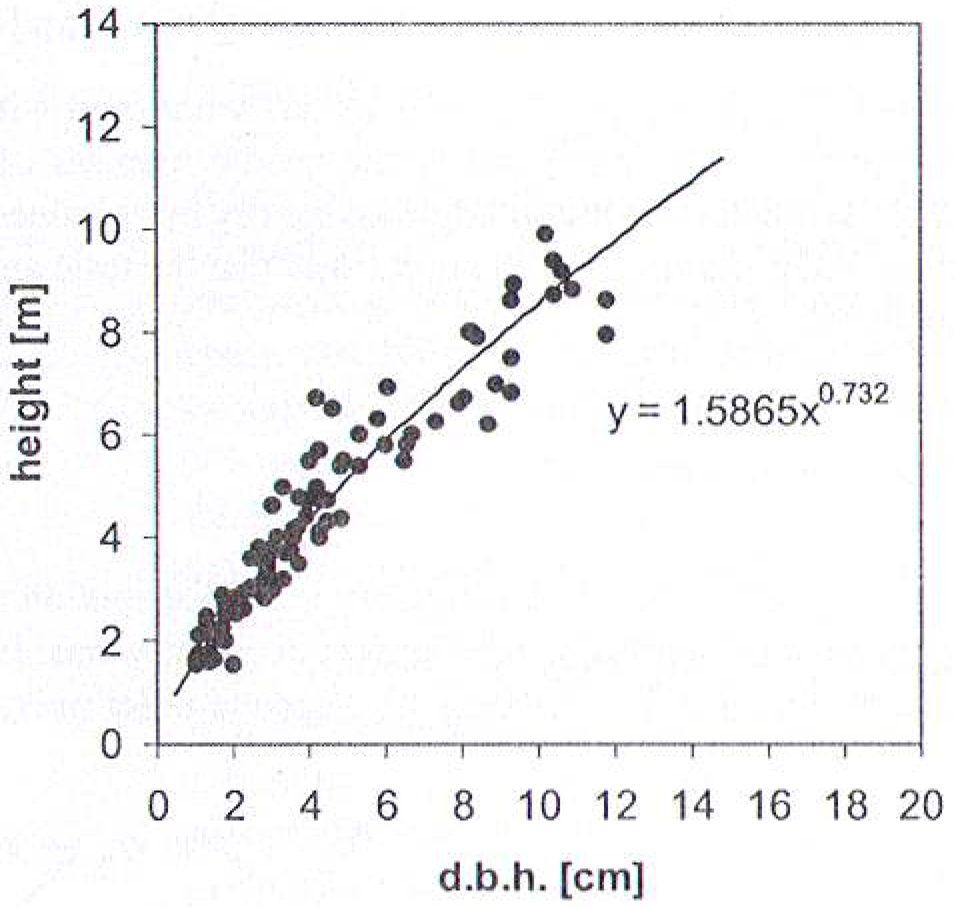

Fig. 2. Dependence of spruce tree height on DBH in 1994 at the age of 19 years.

deposits. According to the climatic classification of weather of the Czech Republic (Quitt, 1971) the experimental plot is situated in the region MT7. Duration of the main vegetation period is 140 to 160 days. Average temperatures are as follows: January -2 to -3°C, April 6 to 7°C, July 16 to 17°C, and October 7 to 8°C. Precipitation sum for the vegetation period equals to values 400 to 450 mm, for the winter period to 250 to 300 mm. Average amount of the overcast days is 120 to 150, of the mostly clear days 40 to 50.

Attention was focused on segment C1 (25x25 m) of the C quadrant (in greater detail Knott, 2001), where three years old seedlings of Norway spruce (*Picea abies* [L.] Karst.) spaced 2.5x2.0 m were planted in 1978. No thinning has been done here since the time of the stands establishment. However, Norway spruce, birch, goat willow, aspen, pine, larch and wallwort regenerated on the plot naturally (Janíček, 1990).

In 1992, the experimental plot of 62.5 m^2 inside the segment C1 was marked. There were 97 spruces growing; the originally planted ones and also those naturally regenerated. The average tree height was 4.6 m, average DBH 4.5 cm, the stand was completely closed. The total stand basal area at breast height was 34 $m^2 \times ha^{-1}$, stocking density 15 520 trees.ha^{-1}. The DBH ranged between 1 and 12 cm (Fig. 1), the most frequent class 3 (i.e. 2 to 3 cm) contained 20%. Overall 67% of all trees on the plot had DBH 2 to 5 cm. The tree size distribution showed two peaks, the first one at 3.4 cm, the second one at 9.7 cm. The first peak coming from natural regeneration was about four times higher than the second one corresponding to originally planted trees. Fig. 2 shows regression between tree diameter and height with determination coefficient (R^2) of 0.9178.

Vertical needle dry mass distribution

Seven sample trees of different social position (2 dominant, 2 co-dominant, and 3 subdominant) have been chosen for the analysis of the needle biomass distribution in the vertical profile of crown according to the method of Čermák, Michálek (1991). Dry mass of all foliage in the individual whorls was estimated by means of destructive analysis in order to determine the needle dry mass in the whole crown vertical profile. The needles of each whorl were collected, dried by a standard procedure and weighed. The needle dry mass of each whorl was related to the height of middle of the next internode where the center of needle biomass was supposed.

Parameters of vertical needle dry mass distribution were found out for each sample tree by the method of nonlinear multi-regression analysis using a public domain program "SUPREG" according to equation

$$Q = A \,.\, \exp\,[-B\,.\,(h^{0.5} - C)^2], \tag{1}$$

where Q is the needle dry mass of one whorl and h is the height above the soil surface (see above). Since the parameter A is proportional to the needle biomass of the whorl and it principally depends on the number of whorls, it had to be modified when the dry mass values in levels with regular step of 25 cm were required. It was modified proportionally in such a way that the total amount of approximated and measured needle dry mass was identical.

Canopy modeling

Than, the dependence of needle dry mass distribution parameters A, B and C on the parameters of the whole tree was analyzed in order to calculate the needle dry mass in each 25 cm layer of each tree on the plot. This dependence was characterized sufficiently by a second order polynomial

$$y = a_0 + a_1 \cdot x + a_2 \cdot x^2\,, \tag{2}$$

where y represents the parameters A, B or C from eq. (1) and x is a whole tree parameter (DBH). Total needle dry mass of individual layers was calculated according to equation (1), where parameters A, B and C were calculated for each tree on the study plot according to the eq. (2). Sum of the needle dry mass of all individual trees, calculated in 25 cm layers, represents the vertical profile of the stand, and their total related to the plot size represents the total needle biomass per unit of the ground area (kg.m^{-2}).

Penetration of radiation through the canopy

Radiation penetrating through the stand is composed of two parts: one part of the light is transmitted through the leaves (transmittance), another part runs through the openings directly to the ground. The transmission depends on the wave length of radiation and on the structure and thickness of leaves (very thin leaves transmit up to 40% and the thick, rigid ones sometimes do not transmit the radiation at all). The radiation filtrated by the foliage includes most of energy in spectral bands around 500 nm and above 800 nm. Just bellow the leaf the red-green radiation prevails, further downwards in lower forest layers only the red and infrared radiation remains (Larcher, 1988). As the needles are thick enough to transmit almost no radiation, it is clear that the spectral shift in the coniferous stands is not significant and so the measurement is not too sensitive to the spectral characteristics of sensors. Intensity of solar radiation penetrating into stand has been measured by means of sensors produced in cooperation with the Institute of unique instruments of VŠZ Brno (the present Mendel University of Agriculture and Forestry Brno). Light sensors were based on silicon diodes 1PP75 (Tesla Rožnov, CZ) with a spectral response in the wave-length interval between 400 and 1100 nm and with the maximum of sensitivity at 920 nm. Before installing in the stand, the sensors were trimmed (with accuracy of 3%) with parallel resistors in order to get their uniform output to radiation.

The spatial stationary network of spot sensors was built up on the experimental plot in order to evaluate the effect of the stand vertical structure on its radiation regime. It was assumed that 12 sensors on each measuring level would be sufficient for averaging the horizontal heterogeneity of the stand. The height levels of measurements were set at 1.50 m, 2.75 m, 3.75 m, and 6.20 m above the soil surface with regard to the study carried out in the year 1992 (Bednářová, 1992). The 3 times 4 meters large steel-wire grid was mounted on each of the four mentioned levels, with 1 meter span between the lines oriented in East-West and North-South directions. The sensors were placed in each crossing of these steel strings (Fig. 3). Twelve sensors in each level were fixed in a way that allowed the shifting (sliding) of sensors according to tree movement under wind while keeping its leveling (Fig. 4). The sensors were connected to datalogger – six sensors of each level were connected in series to one channel. Additional two sensors measuring the incoming radiation were measured with an additional channel. These sensors were located 11 meters above the ground, certainly above the highest trees on the plot.

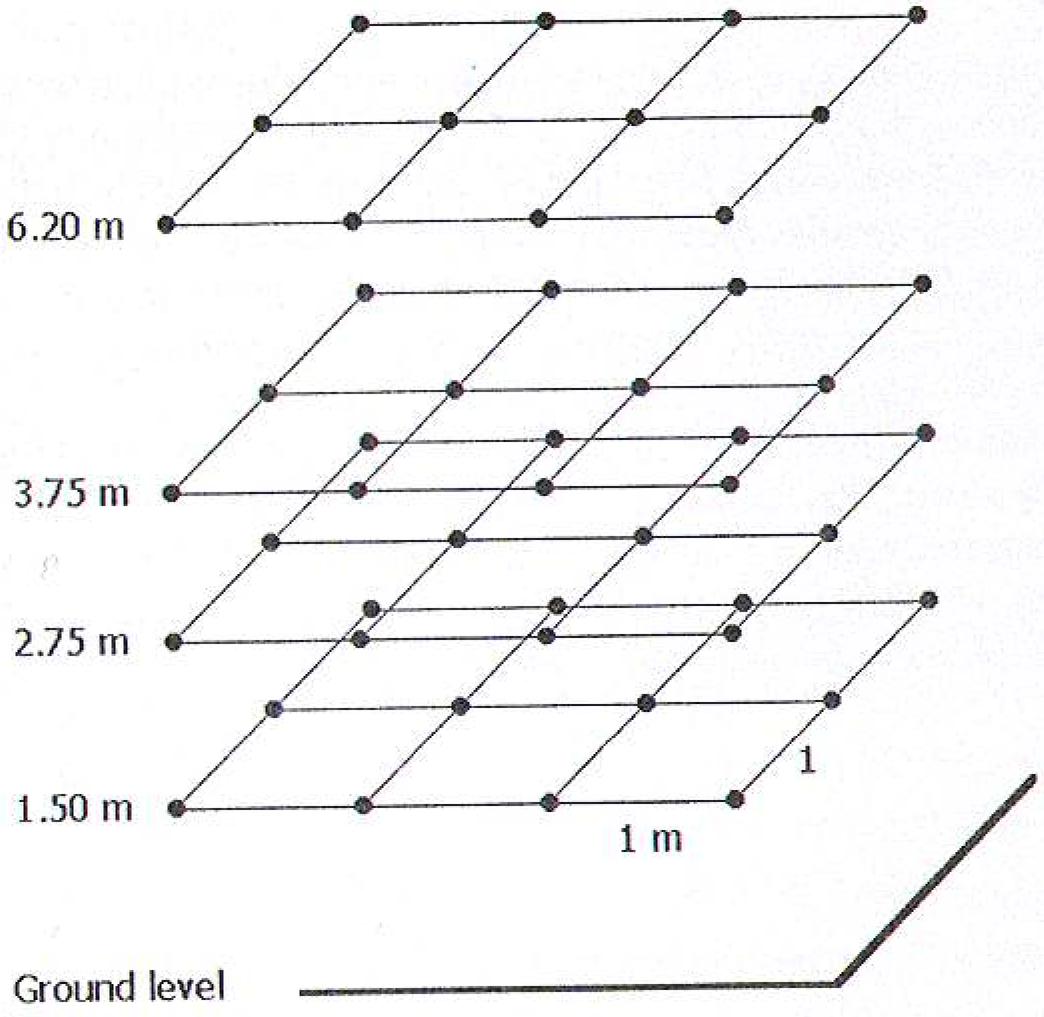

Fig. 3. Sensor grid structure (two sensors measuring radiation above the canopy are not shown).

The complete data set containing the fifteen-minute values (data were measured every minute and stored as 15 minutes averages) of the time period between June 15 and October 20, 1994 was used for processing. As a considerable time and space variability of the distribution of solar radiation was observed, the data were filtered during their processing according to the Sun elevation angel (h°) and cloudiness ratio. Only the Sun elevation values exceeding 20° were used for the analysis because of potential shading by surrounding fully grown stands. The exact values of the sunrise and sunset as well as theoretical clear sky radiation above the atmosphere on the given place were calculated according to the site latitude with computer program PGRAPH (J&C Ltd, Uppsala, Sweden). The vertical distribution of the solar radiation in the stand was approximated for the individual elevation angles by the exponential function

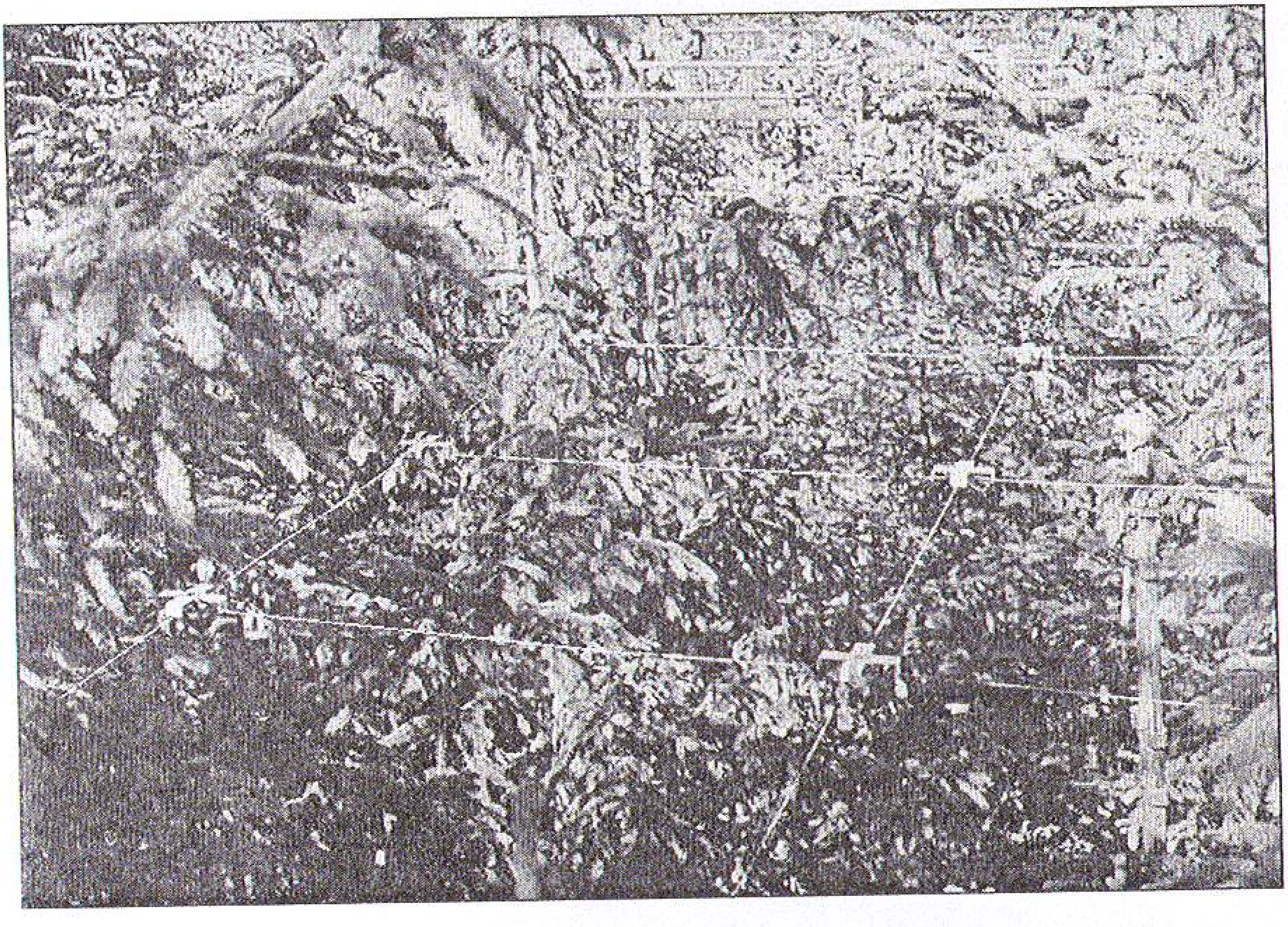

Fig. 4. Radiation sensors – detailed view.

$$y = c \cdot e^{b \cdot x}, \qquad (3)$$

where c and b are constants. There are different modifications of the exponential equation for the extinction of the light penetrating down into the vegetation canopy, suggested by Monsi, Saeki (1953), for example Oker-Blom, Kellomäki (1982), Anisimov, Fukshanski (1997), and others. In the present paper the values of penetrating radiation were normalized for the quantity of incoming solar radiation (i.e. that it is always equal to one, independently on the Sun elevation and cloudiness). Cloudiness was estimated according to the ratio between theoretical maximal radiation and the real one measured above the canopy. This ratio was typically 1.2 in clear sky days due to the absorption and diffusion in the atmosphere. The cloudless events were characterized by the value of the above mentioned ratio between one and two (number of occurrences fluctuated from n = 111 at h° = 20 to 25° to n = 208 at h° = 45 to 50° from totally about 1200 observations). Cloudy ones were taken when this ratio was above three (number of occurrences fluctuated from n = 32 at h° = 55 to 60° to n = 120 at h° = 45 to 50°). The averages of all 15-minute measurements which fitted to certain criteria of cloudiness and elevation, were taken from the whole data set for the regression analysis of radiation penetration eq. (3).

Results

Needle dry mass – sample trees data

Needle dry mass values of the individual whorls of sample trees are presented on Fig. 5. The needle dry mass of the individual whorls of subdominant trees S1, S2, and S3 ranged between 2.5 g (at the whorl of the S1 sample tree at the height 0.82 m) and 168 g (at the whorl of the S2 sample tree at the height 3.36 m). Most of the needle dry mass of the subdominant trees (63.5%) was concentrated on whorls at the heights between 2.0 and 2.99 m above the soil surface (i.e. between 48 and 72% of the average height (4.18 m) of these sample trees). The total needle dry mass of all whorls of the average sample tree equaled to 468 g.

Needle dry mass of the co-dominant sample trees C1 and C2 ranged from 17 g (on the whorl in the height 5.78 m, sample tree C2) to 798 g (on the whorl in the height

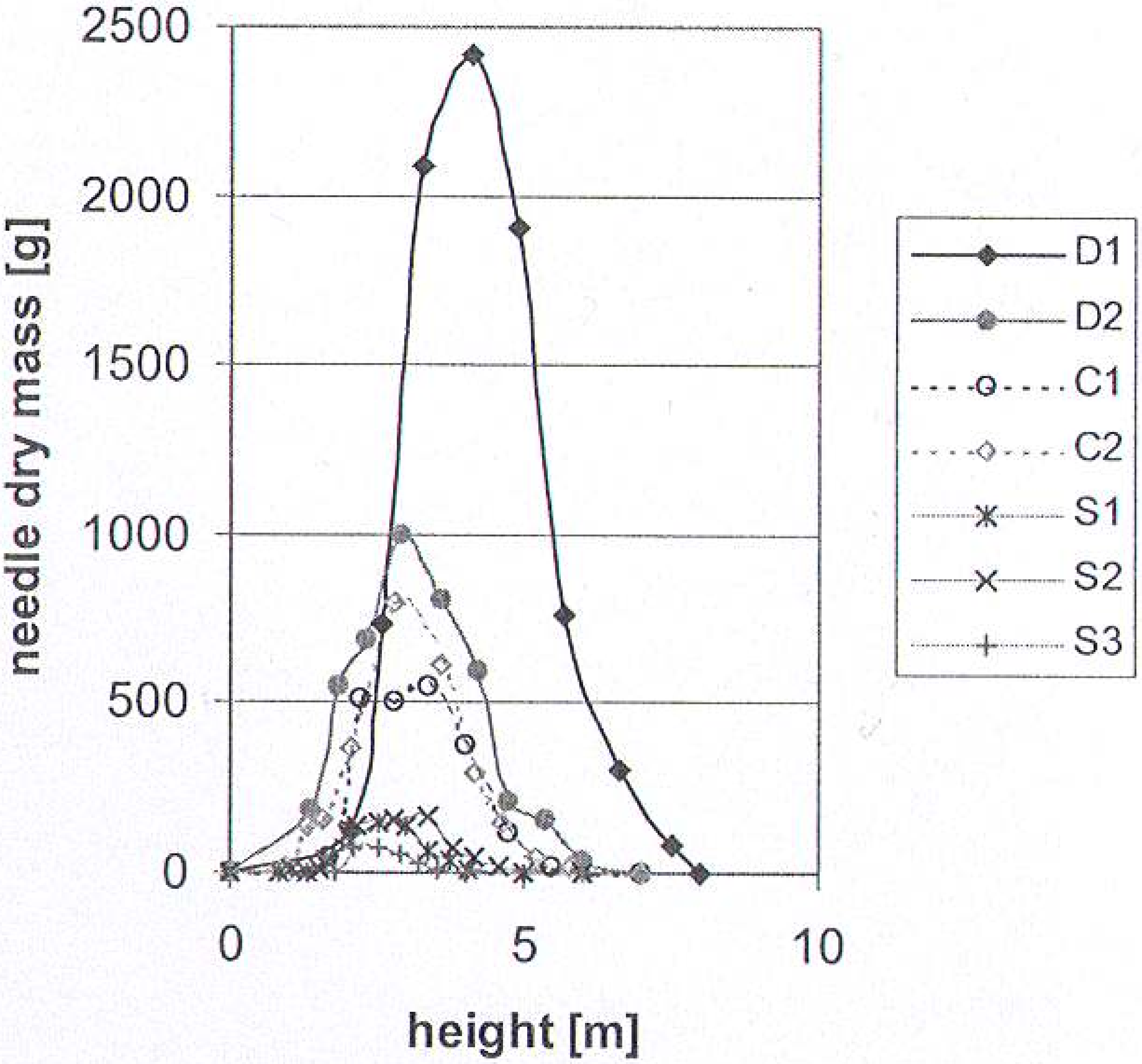

Fig. 5. The measured vertical needle dry mass profile of sample trees (C – co-dominant, D – dominant , S – subdominant).

2.81 m, sample tree C2). Needle dry mass of the co-dominant trees (70.9%) was mostly concentrated on whorls at the heights between 2.0 and 3.99 m (i.e. between 34 and 67% of the average height (5.92 m) of these sample trees). The total needle dry mass from all whorls of the average co-dominant sample tree equaled to 2366 g.

The lowest value of the needle dry mass (38 g) of the dominant trees was measured on a whorl at the height of 6.01 m (sample tree D2) and the highest one (2414 g of needle dry mass) on whorl at the height of 4.1 m (sample tree D1). More than 80% of needle dry mass of an average dominant sample tree were concentrated between the heights of 2 and 5 meters, i.e. between 28 and 70% of its height (7.2 m). The total needle dry mass of the average dominant sample tree was equal to 6310 g.

The vertical distribution of needle dry mass in crowns of 19-year-old spruces can be represented by one peak curve, with the maximum approximately in the half of tree height. Crown zone, defined as a vertical span with needle dry mass per unit height above 10% of its maximum, reached 97% (subdominant trees) and 86% (co-dominant and dominant trees) of the relative tree heights. Whereas all vertical profiles of needle dry mass had similar shape, the relative lengths of crown zones differed significantly between the groups of trees with different social position in stand. If the crown zone of subdominant trees made at average 69% of the relative height of crown, in the co-dominant trees it was already 67% and for the group of dominant trees it reached 65%.

Needle dry mass – parameters of vertical distribution of the needle dry mass in crowns of sample trees

Estimated parameters of approximation of vertical needle dry mass distribution for the individual sample trees using eq. (1) with high coefficient of determination (0.901 to 0.990, mostly above 0.95) are shown in Table 1. Fig. 6 shows both measured and approximated vertical needle dry mass distributions. Parameters A (describing quantity of needles) and C (characterizing the height of needle biomass maximum) are significantly related to the social position of an individual sample tree in stand. The parameter A ranged for the dominant and co-dominant sample trees within values 238.43 and 807.33; for the subdominant

Table 1. Parameters A, B, C of needle dry mass distribution of sample trees (eq. 1) with the coefficient of determination

Sample tree	d.b.h. [cm]	Amodif	B	C	R^2
Dominant D1	11.8	807.33	7.42	2	0.990
Dominant D2	7.33	397.48	5.29	1.72	0.984
Co-dominant C1	6.52	238.43	7.54	1.73	0.933
Co-dominant C2	6.68	312.98	8.5	1.71	0.984
Supressed S1	3.6	90.55	14.1	1.61	0.986
Supressed S2	3.7	81.69	10.1	1.67	0.945
Supressed S3	2.6	57.28	27.6	1.57	0.901

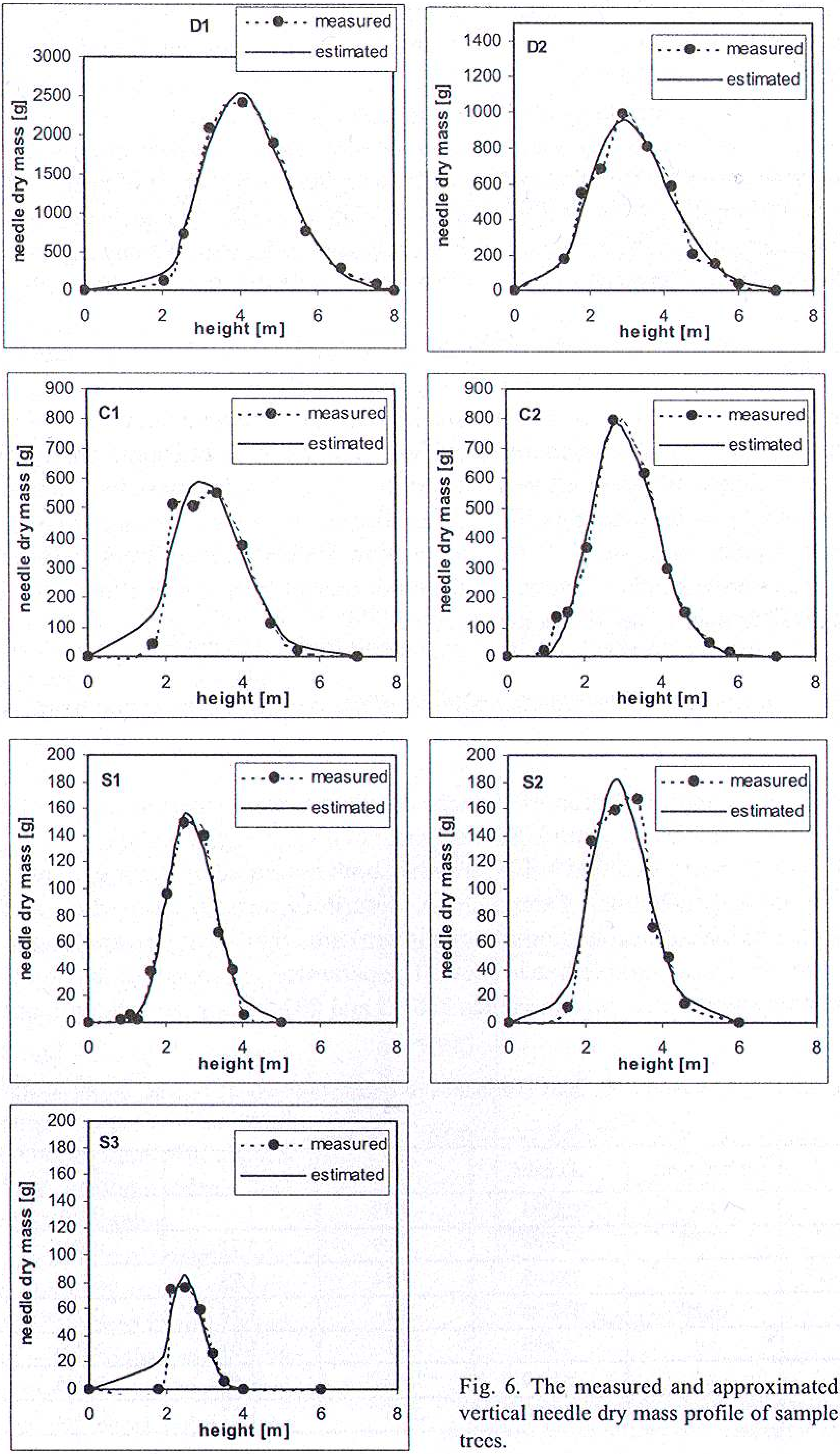

Fig. 6. The measured and approximated vertical needle dry mass profile of sample trees.

trees its values were lower by one order (90.55 to 57.28). In contrast, the value of parameter C was lower in subdominant level (decreasing from C = 2.00 for the dominant sample tree D1 to C = 1.57 for the subdominant sample tree S3). Concerning the parameter B which depends on the vertical shape of crown, the effect of the social position of trees was not pronounced for dominant and co-dominant trees and was manifested only at the subdominant level by an increasing tendency with the decrease of DBH.

Canopy modeling

The dependence of parameters A, B, and C of eq. (1) on DBH – eq. (2) is shown in Table 2. The quality of this approximation follows from the values of R^2 varying from 0.767 for the parameter B to 0.986 for the parameter A (see Table 2).

Table 2. Results of regression of parameters A, B and C of eq. (1) for individual trees on tree DBH by the polynomial of second order (eq. 2)

Parameters	Constant	Linear	Quadratic	R^2
A	0	9.9582	5.0387	0.9860
B	23.360	3.8106	0.2080	0.7673
C	1.4577	0.0428	0	0.9297

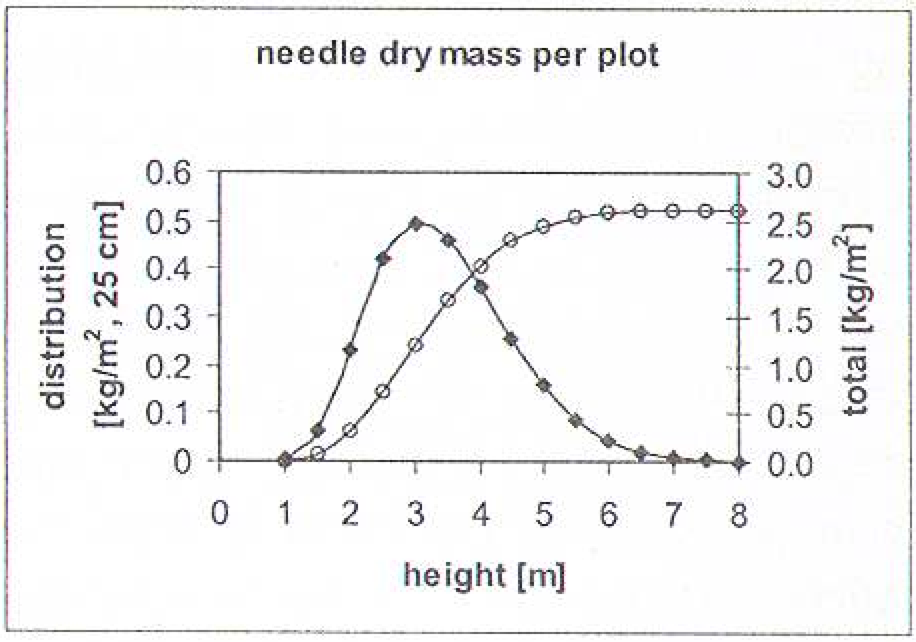

Fig. 7. Modeled distribution of canopy vertical needle dry mass and the cumulated vertical canopy needle dry mass.

The vertical distribution with the step of 25 cm as well as total amount of needle dry mass calculated according to tree DBH are shown in Fig. 7. Maximum of the needle dry mass in the vertical profile of stand can be found ca in the height of 3 m above the soil surface, i.e. in 65% of the average height of the stand (4.6 m). Total needle dry mass was 164 kg per plot (97 trees including samples). Consequently, the mean needle dry mass per tree was 1690.7 g and the canopy needle dry mass was 2.624 kg×m^{-2}.

As for LAI, when considering 19.5 mm^2 one needle projective area and ca 5 mg of dry mass per needle (Bednářová, unpubl. estimation), the leaf area index value can be assessed roughly to 10.5.

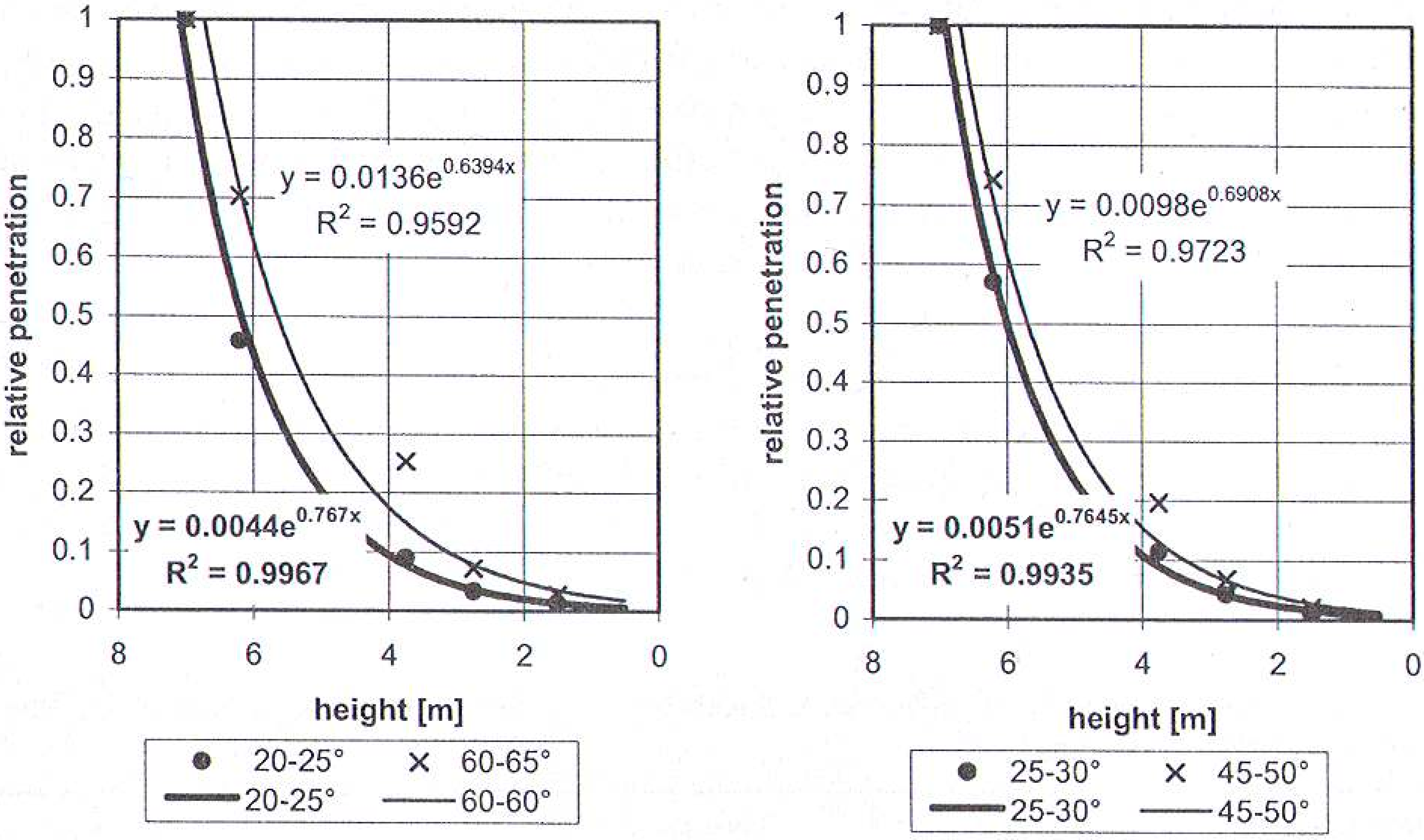

Fig. 8. Vertical profiles of relative irradiation according to Sun elevation angles.

Light penetration – vertical distribution of solar radiation in stand

Vertical profile of solar radiation penetrating through the experimental stand (eq. (3), R^2 from 0.960 to 0.994), according to the Sun elevation angles, is shown on Fig. 8. The parameter *c* increased with the increasing Sun elevation angle (from *c* = 0.0044 for h° = 20 to 25° to *c* = 0.0136 for h° = 60 to 65°), in contrast the parameter *b* decreased from *b* = 0.767 for h° = 20 to 25° to *b* = 0.6394 for h° = 60 to 65° (Fig. 9). The dependence of the parameter I_o on Sun elevation angle was linear (R^2 = 0.964), while the dependence of parameter *c* can be characterized by an exponential equation (R^2 = 0.9668).

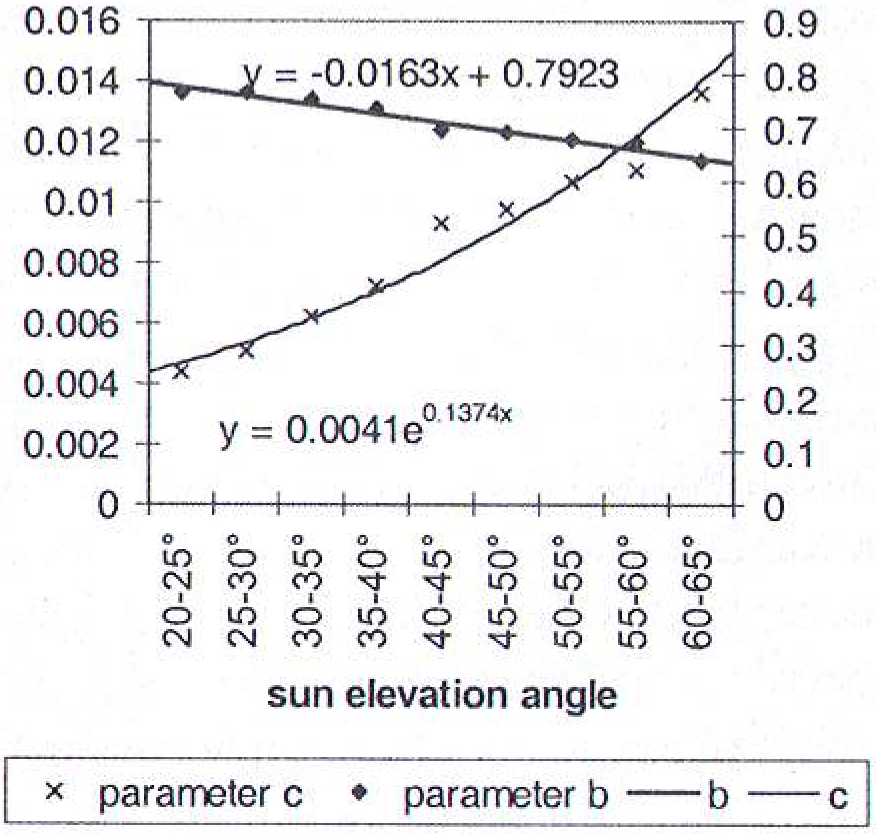

Fig. 9. The dependence of parameters of relative irradiation vertical profile (eq. 3) on Sun elevation angle.

Light penetration – penetration of solar radiation through stand as a function of the sun elevation angle

The following charts (Fig. 10) show the relative penetrability (incoming solar radiation above the stand equals always to one) of different levels within the canopy against the Sun

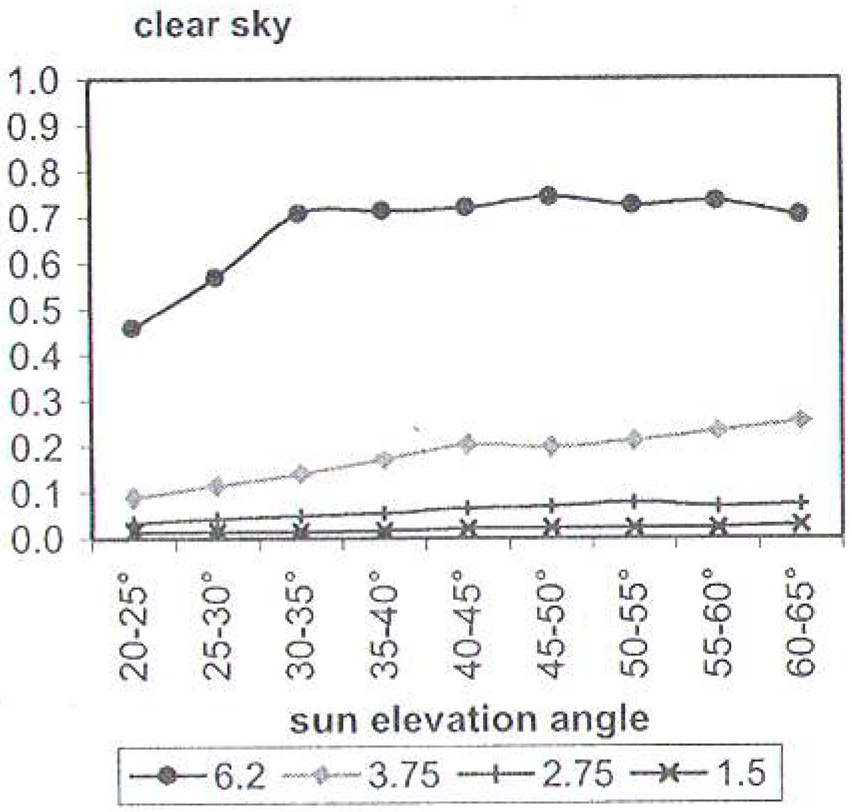

Fig. 10. The dependence of penetration of relative irradiation down to the given levels on the Sun elevation angle for clear sky events.

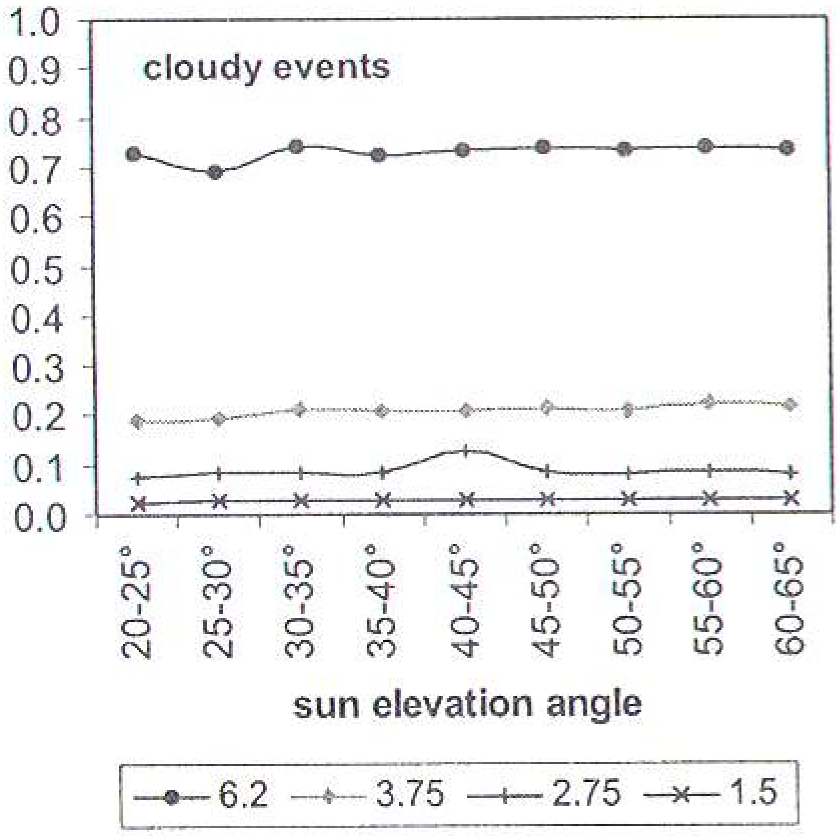

Fig. 11. The dependence of penetration of relative irradiation down to the given levels on the Sun elevation angle for cloudy sky events.

elevation. The differences in penetration in different levels were found the most pronounced under the clear sky condition. The highest changes (25%) occurred at the height of 6.2 m above the soil surface (i.e. in the region of crown tops). The penetrability increased on this level proportionally to the elevation angle for elevation angles 20 to 40°, and then reached a plateau. The penetrability in the levels from 3.75 (i.e. ca in places where the dry matter in the crown profile is in its maximum), down to the height of 1.5 m above the soil surface increases proportionally to the height of the Sun up to its elevation peak (63°).

Thus, the maximum radiation energy available in upper canopy layers in clear days is more or less independent on the Sun elevation above 35-40°. Lower layers take profit from any higher elevation in its whole range. In other words, the solar radiation penetrating through the stand with sun elevation angles greater than 40° contributes mainly to the lower layers of the stand.

The lowest penetration of solar radiation through the whole vertical profile of the stand occurs with Sun elevation angles up to 25°. Under such circumstances the highest canopy level (above 6.2 m) got 46% of the total incoming radiation and only ca 2% reached the 1.5 m level. The whole 71% of total incoming radiation reached the same level of 6.2 m for Sun elevation angles between 30 and 40° but again, only 2% of the total quantity reached the level of 1.5 m. The higher the Sun is, the higher percentage of solar radiation reaches, under the same weather conditions, the soil surface.

In cloudy events (Fig. 11) the irradiation was mostly independent on the Sun elevation. Ca 70% of solar energy reached the 6.2 m level independently on the Sun elevation (from 69% at h° = 25 to 30° to 73.8% at h° = 55 to 60°). Some 3% of the input energy reached the level of 1.5 m. So, in the overcast days the penetration of solar radiation is quite independent on the Sun elevation angle in the whole vertical profile.

Discussion

Needle dry mass

The exponential-based function – eq. (1) was used in order to estimate the vertical distribution of the needle dry mass of individual sample trees. The application of the chosen equation ($R^2 = 0.901$ to 0.990) with parameters derived from the stem diameter – eq. (2) – to next 90 trees on the plot ($R^2 = 0.7673$ to 0.986) gave quite valuable data of the needle biomass distribution of the spruce stand.

The work of Barták et al. (1993) can be mentioned among the Czech papers describing the needle dry mass in crowns of spruce trees with respect to their social position. In this paper the maxima of distribution curves for co-dominant and dominant trees were found out in the interval of 40 to 50% of the relative height of crown, which corresponds also to our data concerning trees of the same social position in stand (co-dominant 47%, dominant 49%).

We found out, that the total needle dry mass of an average 19-year-old Norway spruce represented 468, 2366, and 6310 g for the subdominant, co-dominant and dominant tree, respectively. Data obtained by Chroust (1993) for an average 14-year-old Norway spruce sample tree can be applied for comparison. He gives for stands with different density the needle dry mass from 2850 g (for stocking density 690 pieces per 0.10 ha) to 4800 g (250 pieces per 0.10 ha). He gives for the average 24-year-old spruce sample tree the needle dry mass value 5260 g (for 561 pieces per 0.10 ha) and 10500 g (for 242 pieces per 0.10 ha). Our data on co-dominant trees fit to those ones of Chroust, but as Chroust made a detailed analysis only at sample trees close to the stand average, the comparison of possible effect of the tree social position is impossible. Needle biomass value estimated for the co-dominant tree (2400 g) is identical with the value found by Vyskot (1981) for the 24-year-old co-dominant Norway spruce sample tree (2400 g).

Total needle dry mass of an average co-dominant sample tree (2366 g) was very similar to the value of the canopy needle dry mass density ($2.624\ kg.m^{-2}$). It means that the average tree crown projected area of the given stand was approximately 1 m^2. This value is smaller compared to those given by Chroust (1993) for a 14-year-old stand (6900 trees per ha), i.e. projection (projective area) 2.5 to 3.8, and for a 24-year-old one (5610 trees per ha) a projection 2.2 to 8.0 m, which can be explained by the higher stocking density of the stand under consideration (15 520 trees per ha) due to the natural regeneration.

Light penetration

In the present paper the radiation vertical profile in the stand was approximated by exponential eq. (3) for individual Sun elevation angles. The relevance of the chosen curve was confirmed by the high values of R^2 (from 0.960 to 0.994) for most of Sun elevation angles. The intensity of the radiation penetrating into the upper part of canopy (down to 6.2 m) in clear days increased proportionally with the elevation angle for the elevation angles up to

40° and then became almost independent on h°. The same concluded also Hassika, Berbigier (1998). They found the penetration of light through the canopy of a 27-year-old maritime pine (*Pinus pinaster* Ait.) forest with a density of 660 trees per hectare and the mean tree height 16 m down to 1 m above the ground being independent on solar elevation smaller than 10° and higher than 50° and being proportional to solar elevation for angles between 10 and 50°. However, such a comparisons don't take into consideration under which weather conditions the light penetration patterns were evaluated. As we have shown, in the case of overcast sky the light penetration into the stand is quite independent on the Sun elevation angle in the whole vertical profile.

In clear days and in the layer of 1.5 to 3.75 m above the soil surface the values of radiation intensity penetrating into the stand increased proportionally to the height of the Sun up to its peak (63°); the higher the Sun was, the higher percent of solar radiation, under the same other conditions, penetrated down to the soil surface. From the point of view of the vertical distribution of the needle dry mass, only 3 to 10% of the total incoming radiation, in dependency on the elevation angle, reached the height of its maximum. Still, only some 2% of the total radiation reached the level of 1.5 m. So, the quantity of solar radiation available for the understorey is very limited. Jarvis et al. (1976) gives the transmission of PAR by young spruce forest of 1 to 5%. Johansson (1987) gives the value of radiation penetrating beneath the spruce stand 1-3% of the total radiation coming onto the stand. In our 19-year-old spruce stand the irradiation dropped on its half in the height corresponding to ca 90% of the total needle dry mass, i.e 50% of solar energy were absorbed by the top 10% of biomass.

Conclusions

The presented results confirm the relevance of the applied equation for the approximation of the vertical distribution of needle dry mass of individual sample trees and its applicability to the up-scaling of needle biomass to the stand level using data from sample trees and forest inventory data. Light penetration pattern can be expressed with a sufficient accuracy by the exponential curves. Lower needle layers benefit from the highest sun elevation preferably in cloudless days.

The percentage of radiation caught by different horizontal canopy layers depends not only on the needle biomass and on the stand structure but also on the Sun elevation. This fact should be considered for forest management particularly when predicting changes in canopy structure in response to thinning or similar silvicultural treatments.

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Kučera J., Bednářová E., Kamlerová K.: **Vertikální profil biomasy jehlic a prostup radiace smrkovým porostem.**

Pro analýzu rozložení biomasy jehličí v profilu koruny bylo vybráno sedm vzorníků smrku ztepilého různého sociálního postavení v 19-letém porostu. Vertikální rozložení sušiny bylo aproximováno jednovrcholovou křivkou dle rovnice $Q = A \, . \exp[-B \, . (h^{0.5} - C)^2]$. Korunové zóny s maximem sušiny nezasahovaly nad 70% relativní výšky stromu. Pro skupinu podúrovňových vzorníků tvořila tato zóna v průměru 24% relativní výšky koruny, pro úrovňové 33% a pro skupinu nadúrovňových 42%. Celková sušina jehličí 19-letých smrků ve sledovaném porostu byla 2.624 kg.m^{-2} s maximem v ca 3 m nad zemí. Pro hodnocení vlivu vertikální členitosti porostu na jeho radiační režim byla vytvořena čtyřúrovňová prostorová stacionární síť zahrnující 48 čidel. Exponenciální pokles intenzit radiace prostupující do porostu (I) s ubývající výškou nad zemí byl vyjádřen pro jednotlivé elevační úhly ($h°$) samostatně. V jasných dnech se intenzita $I_{6.2\,m}$ pro 20° < h° < 40° zvyšovala úměrně s $h°$, při úhlech nad 40° byl již prostup na $h°$ nezávislý. Od hladiny 3,75 m k výšce 1,5 m nad povrchem půdy se intenzita I zvyšovala úměrně s $h°$ až do jeho vrcholu (63°). Prostup záření do porostu v zatažených dnech byl na elevačním úhlu slunce nezávislý. Z pohledu vertikální distribuce sušiny jehlic, dosahovaly v oblasti jejího maxima intenzity prostupující radiace, v závislosti na elevačním úhlu, pouze 3 až 10% celkového záření nad porostem. Ve sledovaném porostu ozářenost poklesla na polovinu ve výšce odpovídající ca 90% celkové sušiny jehlic, tedy 50% sluneční energie bylo absorbováno horními 10% biomasy.