6 Stem and crown parameters related to structural root systems of Douglas fir

L.C. Kuiper, A.J.J. Bakker and G.J.E. van Dijk
(Agricultural University Wageningen, Chair of Silviculture & Forest Ecology)

Summary

To analyse the relationship between crown, stem and root system of Douglas fir (*Pseudotsuga menziesii*) in relation to social position and to identify a simple above ground parameter to estimate the size of the root system, up to ten trees dispersed over all social classes in 28 stands on dry sandy soils in the Netherlands were pulled over and various above ground and subterranean parameters were assessed.

Size and shape of the crown projected area proved to be no good parameters to estimate root system size. The same holds true for d.b.h. and available growing space as estimators for root system diameter. However, the correlations between d.b.h. or basal area and root system size as indicated by root cross sectional area are high.

Social position has no appreciable influence on this relationship. This means that d.b.h. can be used as a diagnostic tool to evaluate the impact of various silvicultural treatments on root development.

6.1 Introduction

In silviculture most thinning strategies are based on observations of the aboveground parts of a tree. Information about the subterranean parts is often restricted to root system morphology (Groth, 1927; Hengst, 1958; Koestler & al., 1968; Eis, 1974; Sutton, 1980). Recently more attention has been paid to tree stability in relation to root system architecture (Sommerville, 1979; Coutts, 1983 a, 1983 b and 1986; Deans & Ford, 1983; Kuiper & Schooten, 1985; Nielsen, 1982 and 1986). To silviculturists it would be of some help if a simple parameter could be identified by which the size of the root system can be estimated throughout the life cycle of a tree. With such a parameter current silvicultural practices could be adjusted to optimize root development.

In literature there are some contradictions about the extension of Douglas fir root systems: according to Smith (1964) root spread can be estimated by crown width. Mc Minn (1963) states that Douglas fir root systems in general are smaller than the crown periphery, whereas Hengst (1958) indicates that Douglas fir roots protrude somewhat outside the crown radius. Figure 6.1 shows an example of a Douglas fir tree at the side of a 10 year old windthrow gap in The Netherlands, with an extremely long and thick root. Such roots, however, are rare in Douglas fir.

Kuiper & Schooten (1985) found a positive linear relationship between the mechanical anchorage of the root system and stem volume for 30-65 year old Douglas fir trees. Their observations were based on 25 trees only. They suggested a study of the relationship between the aboveground and subterranean parts

Fig. 6.1. Root system of a 40 year old Douglas fir tree bordering a 10 year old windthrow-gap in a forest near Kootwijk. Note the exceptional development of the lateral root, as a result of lack of competition for water and nutrients in the gap (photograph: L.C. Kuiper, 1984).

of Douglas fir trees in more detail (see also Bakker & Dijk, 1987), which is the main objective of the work presented here.

6.2 Objectives

1. To analyse the relationship between crown, stem and structural root system of Douglas fir for a large number of trees;
2. To measure possible effects of social position, available growing space and tree age on the root-shoot relationship;
3. To identify a simple stem or crown parameter to estimate the size of the structural root system.

6.3 Materials and methods

Twenty-eight plots were established throughout the Douglas fir area in The Netherlands, in which a total of 200 trees were selected to be pulled over by a handwinch. In order not to exceed the safety limits of the winch, the trees had to be limited in size (Kuiper & Schooten, 1985). Thus only stands younger than 40 years old were included. The study has focussed on Douglas fir trees in stands on relatively poor sites, characterized by dry sandy soils and an annual precipitation of 700-800 mm. Water stress is a commmon feature on many of these sites (Mohren, 1987). A few sites with no water stress (high groundwater table) were included. Usually 10 trees per plot were pulled over, which were mostly confined to the social classes of dominant, codominant and intermediate trees. Tree selection was based on a rough diameter distribution, which was constructed by measuring the d.b.h. of approximately 50 trees in each stand randomly. The trees to be pulled over formed a representative sample of this diameter distribution.

Fieldwork was done in winter and early spring 1986. With a crew of three men about 15 trees could be handled per day. By pulling over trees with a winch at least half the root system becomes quickly available for direct observation. On the sandy soils to which Douglas fir was largely restricted in this study, only small roots and rootlets with a diameter smaller than 0.5 cm stayed behind in the soil. The rest of the root system remained largely intact.

The following parameters were measured and calculated: d.b.h., basal area, tree height, stem volume (according to Dik, 1984), crown surface area (according to Assmann, 1961) and available growing space (according to Hamilton, 1975). From the subterranean parts root system diameter was calculated as two times the mean value of the three longest lateral roots down to a root diameter of 0.5 cm, regularly distributed over the root system. Root plate volume was calcu-

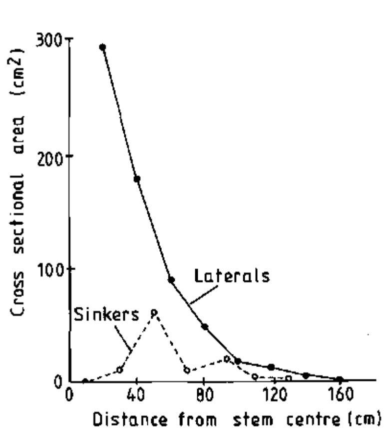

Fig. 6.2. Total cross sectional area of lateral roots (solid line) and sinker roots (broken line) of *Picea sitchensis*, measured at different distances from the anatomical stem centre (Coutts, 1983b): the total c.s.a. of the lateral roots decreases exponentially with distance from the stem base.

lated with the mean value of the radius of the root plate in three directions and the mean depth of the root plate. Cross sectional area (c.s.a.) of the roots was taken as a parameter for root volume. The root-c.s.a. is the sum of the basal areas of all roots at a certain distance from the anatomical stem centre. It is essential to choose this distance not too close to the stem centre due to buttresses, but also not too far away from the stem centre, because of pronounced root taper (Fig. 6.2). A distance of 40 cm seems to have become an international standard for root-c.s.a. (Coutts, 1983a and 1983b; Nielsen, 1982 and 1986). A non- linear relationship between above-ground and subterranean parts was established. The relationship that showed the highest correlation was used in further analysis to check possible effects of social position, growing space and age.

6.4 Results

The following hypotheses were tested:

1. D.b.h., basal area, stem volume and crown surface area are all highly correlated with c.s.a. of the roots, but stem volume will show the highest correlation (as expected from Kuiper, 1986).
2. Social position, growing space and tree age have no significant effect on this relationschip.

Figure 6.3 shows the plot locations; in Figure 6.4 the plots are represented according to site class. Table 6.1 gives additional plot information.

From 102 sample trees that were used to check the notion that tree roots extend as far as the crown periphery (Smith, 1964), 51 trees had roots that did not extend as far as the crown perihery; 14 trees had roots as long as the crown radius and 37 trees had roots that were longer than the crown radius. Typically the majority of the roots (to a diameter of 5 mm or less) were confined to an area close to the stem within a radius of 1-1.5 m: the usual root plate size. A

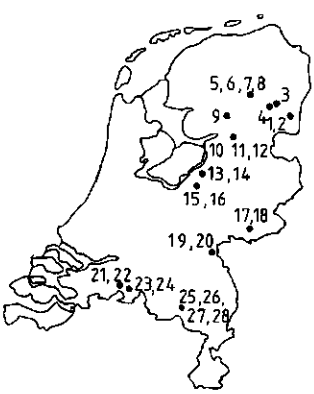

Fig. 6.3. Plot locations (numbers refer to Table 6.1).

Table 6.1. Additional plot information.

nr	location and section	age	initial spacing (m)	initial number of stems	present number of stems	ground water class*	soil type **
1	Emmen, 122 A	37	1.5x1.5	4444	1360	VI	hp
2	Emmen, 124	37	1.5x1.5	4444	1270	VII	hp
3	Borger, 44 A	37	2.0x1.5	3333	1620	VII	gp
4	Schoonloo, 52 A	32	1.5x1.5	4444	1010	VII	gp+hp
5	Smilde, 52 A	22	2.0x1.5	3333	1430	VII	gp
6	Smilde, 108	8	2.0x1.5	3333	3333	VII	gp
7	Smilde, 111	10	2.5x1.5	2667	2667	VI	gp
8	Smilde, 113	13	2.5x1.5	2667	2667	VII	gp+hp
9	Woldberg, 102 J	41	1.2x1.3	6410	1112	VII	gp
10	Staphorst, 49 E	17	1.2x2.0	4000	2500	VI	gp+hp
11	Staphorst, 49 E	28	1.2x1.5	5333	1620	VI	gp+hp
12	Staphorst, 49	11	natural regeneration				
13	Nunspeet, 42 A	22	1.5x1.5	4444	1854	VII	hp
14	Nunspeet, 42 A	30	1.5x1.5	4444	1854	VII	hp
15	Speulderbos, 202 E	23	1.2x1.5	5333	1935	VII	bps
16	Speulderbos, 202 G	23	1.2x1.5	5333	2719	VII	bps
17	Slangenburg, 8 C	23	1.2x1.2	6400	992	V	bps
18	Slangenburg, 30 J	13	2.5x3.0	1333	1292	VI	gp
19	Groesbeek, 51 B	25	1.7x1.5	3810	2136	VII	bps
20	Groesbeek, 51 B	14	1.7x1.5	3810	3810	VII	bps
21	Mastbos, 15 F	11	2.0x2.0	2500	1860	VI	gp
22	Mastbos, 14 K	27	1.0x1.5	6667	2056	VI	gp
23	Chaem, 49 A	25	2.0x1.5	3333	1615	V	gp
24	Chaem, 52 D	35	2.0x1.5	3333	524	V	gp
25	Leende, 6 D	42	1.2x1.2	6944	718	VI	gp
26	Leende, 8 A	56	2.0x2.0	2500	530	VI	gp
27	Leende, 54 A	50	1.2x1.3	6410	475	V	gp
28	Leende, 54 A	10	natural regeneration			V	gp

* ground water classes (STIBOKA classification, 1964):

	mean highest level	mean lowest level
V	< 40 cm	> 120 cm
VI	40-80 cm	> 120 cm
VII	> 80 cm	> 160 cm

** soil types: gp = gley-podzol
hp = humuspodzol
bps = brown podzolic soil

limited number of lateral roots exended as far as the crown radius, and only very few roots extended 1-1.5 m beyond the crown periphery, not necessarily linked up with assymmetric parts of the crown projection area. This rooting pattern was confirmed by data from excavations of Douglas fir root systems by the Dorschkamp Research Institute in Wageningen (Burg, unpublished data). A linear relationschip was calculated between mean crown diameter and mean root system diameter of 95 trees, but only a poor correlation was found (Table 6.2). Thus, size and shape of the crown projection area do not seem to be good

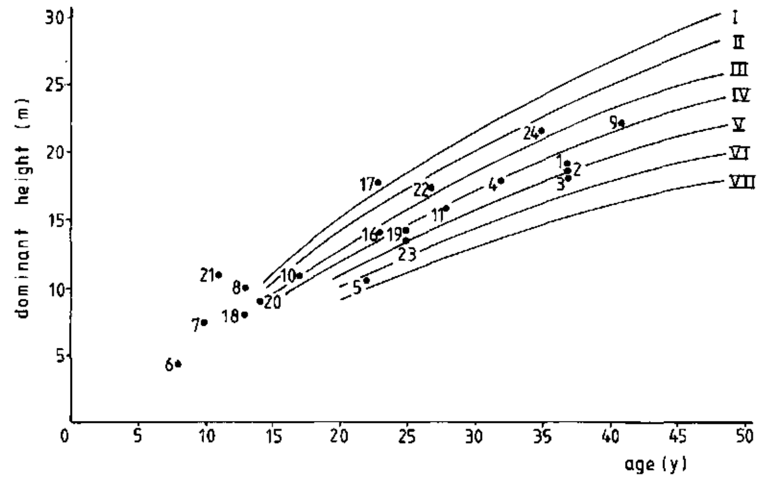

Fig. 6.4. Representation of the plots according to site class (site classes according to La Bastide & Faber, 1971). Plot numbers refer to Table 6.1.

Table 6.2. Relationship between crown diameter and root system diameter; between d.b.h. and root system diameter; and between growing space and root system diameter.

root system diameter = 0.54 (crown diameter) + 1.15 ($r = 0.50$; $n = 95$)
root system diameter = 0.83 $(\text{d.b.h.})^{0.51}$ ($r = 0.53$; $n = 94$)
root system diameter = 2.78 $(\text{growing space})^{0.1}$ ($r = 0.17$; $n = 91$)

root system diameter in m; crown diameter in m; d.b.h. in cm and growing space in m^2.

parameters to estimate the size of the structural root system of Douglas fir.

Relationship between diameter at breast height and root system diameter, and between available growing space and root system diameter also showed very poor correlation (Table 6.2).

Although the results of earlier tree pulling experiments with Douglas fir (Kuiper, 1986) suggested that stem volume would be best correlated with root-c.s.a., the results of the present study indicated that both diameter at breast height and basal area showed the highest correlation for all trees (Table 6.3). D.b.h. has the practical advantage over basal area that it is directly measurable. Its relationship with root-c.s.a. is presented in Figure 6.5.

When stratified according to social position it appeared that there were no appreciable differences between the regression lines of the d.b.h.- c.s.a. relationship for the different social classes. Dominant trees, when considered as a single group, had the highest correlation coefficient ($r = 0.95$; Table 6.3). Because root-c.s.a. usually decreases exponentially with distance within the zone of rapid taper near the stem (Fig. 6.2), this could account for the higher correlation coefficient

Table 6.3. Regression and correlation coefficients of various relationships studied, with the general equation $y = a\,x^b$

x	y	n	a	b	r
dbh	csa	199	0.26	2.54	0.92
basal area	csa	199	0.33	1.28	0.92
stem volume	csa	199	2.93	0.93	0.84
crown surface area	csa	199	0.19	1.80	0.85
dbh dominants	csa	70	0.22	2.60	0.95
dbh codominants	csa	45	0.44	2.37	0.85
dbh intermediates	csa	55	0.17	2.65	0.84
dbh suppressed	csa	29	0.65	2.11	0.79
growing space	ba	40	29.8	1.17	0.89
growing space	csa	40	28.3	1.52	0.86
age	ba	60	3.13	1.42	0.89
age	csa	60	1.30	1.89	0.88
root plate volume	csa	35	1.00	0.80	0.74

csa = total cross sectional area of the roots in cm^2; ba = basal area in cm^2; stem volume in dm^3; crown surface area in m^2; growing space in m^2; root plate volume in dm^3.

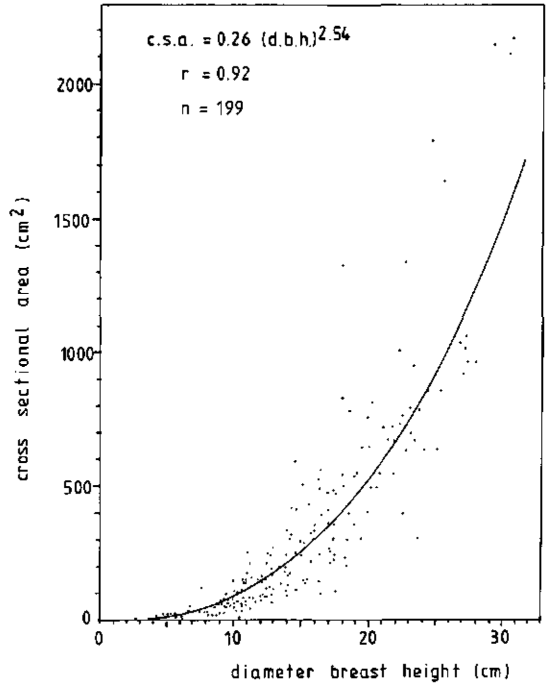

Fig. 6.5. Relationship between diameter at breast height and root-cross sectional area for all trees.

values for dominant trees, compared with trees of other social classes.

As has been demonstrated by Coutts (1983) for 20 year old Sitka spruce only a limited number of lateral roots contribute significantly to the total root-c.s.a. This could be confirmed for 15-25 y old Douglas fir in the present study: for dominant trees 80% of total root-c.s.a. on the average was determined by 6 prominent lateral roots.

Figure 6.6 shows that higher values for growing space of individual trees corresponded with much higher values for root-c.s.a. compared with values for stem basal area. Similar trends could be observed for increasing age, which of course, is closely linked to increasing growing space (Fig. 6.7).

The relationship between root-c.s.a. and root plate volume is given in Table 6.3.

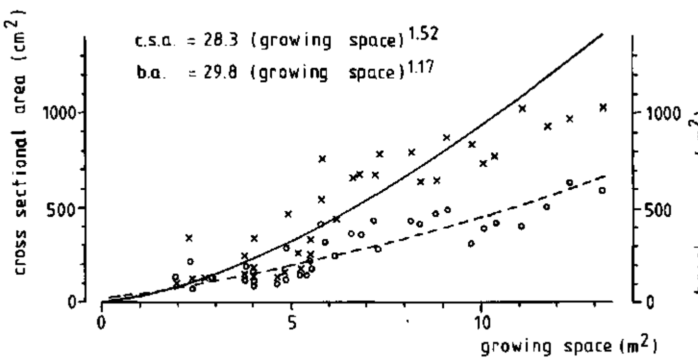

Fig. 6.6. Relationship between growing space and root-cross sectional area (solid line) and between growing space and basal area (broken line) for dominant Douglas fir trees (n = 34).

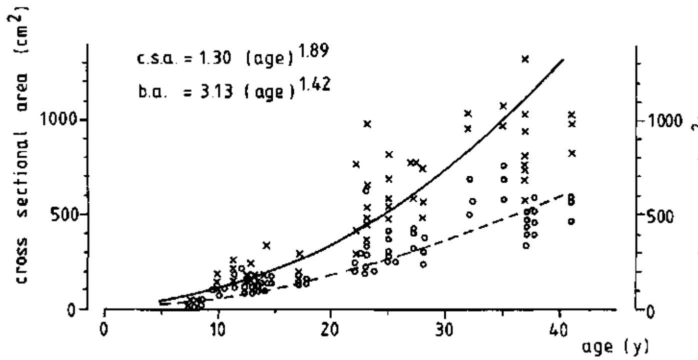

Fig. 6.7. Relationship between age and root-c.s.a. (solid line) and between age and basal area (broken line) for dominant Douglas fir trees (n = 55).

6.5 Discussion

In Figure 6.4 and Table 6.3 it was shown that diameter at breast height is a good parameter to estimate the size of the root system, as indicated by root-c.s.a. We now have a diagnostic tool at our disposal in the form of the diameter at breast height, to evaluate different silvicultural treatments with respect to their impact on the size of the structural root system. This can be useful in forestry praxis: e.g. measures that influence diameter increment also will have a strong influence on root system development, i.e. on the development of large structural roots.

Roots-c.s.a. is highly correlated with root volume (Nielsen, 1986), but the present study suggests that it seems to be only moderately correlated with root plate weight. Its significance as a parameter for tree stability comes from the close relationship with prominent lateral roots. Figure 6.5 showed that more growing space gives a large root-c.s.a. This implies that at wider spacings lateral roots will be thicker further from the tree. According to Coutts (1986) the resistance of roots under tension on the windward perimeter contributes most to the total anchorage. When windward roots are thicker, this anchorage component of tree stability will be greater. On the other hand, the good correlation between root-c.s.a. and crown surface area shown by this study, suggests that wider spacings might also produce high wind loading on a large crown and actually decrease tree stability. The exact magnitude of the various components of stability and their combined effects is an area that needs more study.

The results of the present study can help us to design silvicultural systems that aim at increasing root development. Such systems could include wider initial spacings and stronger precommercial thinnings than commonly used (Savill, 1983; Cremer & al., 1982). It is still a question whether the penalties of such systems in terms of decreased timber quality (wider growthrings, heavier branching) are acceptable. Grading rules which have been established for Dutch grown Douglas fir construction timber recently (N.N.I., 1986) suggest that most of the timber produced in such a system will be of B- and C-quality.

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