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Growth dynamics of superficial roots in Portuguese plantations of *Eucalyptus globulus* Labill. studied with a mesh bag technique

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Summary The variation in growth of the fine roots of blue gum (*Eucalyptus globulus* Labill. ssp. *globulus*) in the 0–40 cm soil layer was studies from March 1982 to March 1983 at Quinta do Furaduoro, Óbidos, Portugal. A mesh bag method was used; bags of nylon net were inserted into a clay soil and a sandy soil and filled with root-free soil. They were resampled after 2, 4, 6 and 12 months in both places and, in a separate series in the sandy soil every second month throughout the year.

The ingrowth of roots was high during the winter months but there was also a surprisingly high ingrowth during the spring-early summer period. There was also some root growth during the driest part of the year *viz.* July–September.

The amount of fine roots reached a maximum of about 260 g dw m^{-2} after about 6 months in the sandy soil, whereas it took at least 12 months to reach the somewhat higher level of 450 g dw m^{-2} in the clay soil. At that level the decomposition of dead roots was expected to equal the formation of new roots. Dead roots appeared after only 2 months. There was a higher proportion of dead roots in the clay soil than in the sandy soil, 35% as compared with 20% on an average, which indicates a slower decomposition or a higher mortality at equal decomposition rates in the clay than and in the sandy soil. The present data gives an indication of a minimum fine root production in mature Eucalyptus stands of at least 600 g dw m^{-2} yr^{-1}.

Introduction

Blue gum, *Eucalyptus globulus* Labill. ssp. *globulus*, was the first eucalyptus to be widely planted outside Australia. FAO reports that the current acreage in commercial eucalyptus plantations is 4 million hectares and is spread throughout 58 countries[10]. It has been found in several Mediterranean countries for more than 100 years. The first eucalyptus planted in Portugal are from 1829[10]. However, large plantations did not occur until after the middle of the 19th century[20]. The economic value of this species is increasing due to its importance to the pulp industry.

In Portugal, Eucalyptus plantations totalled 216 000 hectares in 1980. The average rate of planting[10] is about 15 000 ha yr^{-1}. There are also about 178 000 hectares of mixed stands where *E. globulus* is not the dominant species[1]. Ninety-five percent of the eucalyptus plantations in Portugal consist of *E. globulus,* which is best adapted to the prevailing climate and soil conditions. Almost all *E. globulus* plantations in Portugal are harvested 10–15 years after planting. New sprouts develop from which one or several are allowed to form new trunks. This coppicing system can be repeated 3–4 times, after which planting of new seedlings is necessary.

Most of the work on *E. globulus* in Portugal has focused on the growth of above-ground parts, especially the trunks, and very little is known about roots, although there are some Australian studies on the stem and root development of other eucalyptus species, *e.g.*, as *E. marginata, E. signata* and *E. regnans*[2,5,11,27].

Eucalyptus globulus has a framework of coarse roots 1–10 cm in diameter from which a dense fine root system (< 2 mm in diameter) penetrates the soil to 0.5 m and from which sinker roots (usually > 5 mm in diameter) penetrate to a considerable depth[8].

In mature eucalyptus stands the fine roots are usually relatively homogeneously distributed in the top soil[10]. This superficial root mat is probably very important for the uptake of water as well as nutrients such as nitrogen and phosphorus. Mycorrhizae are also involved in the uptake system[6,7,21].

The main objective was to study the root production in the top-soil in *Eucalyptus globulus* plantations when influenced by plantation technique, soil type and age of stands. Other objectives were to study annual growth dynamics within the year, *i.e.* the dynamics of root growth and chemical composition of the roots in relation to growth in the above-ground parts.

Materials and methods

Bags filled with root-free soil taken from the experimental site were inserted into 7 × 40 cm deep holes drilled into the soil. The mesh size (0.5 cm) of the stocking-like bag allowed the surrounding roots to penetrate relatively easily. Insertion of the bags was accomplished by fitting the bags onto plastic tubes. The tubes were gradually filled with soil compacted with a wooden dowel. The tube was slowly withdrawn from the hole. The bag with its soil content then completely filled the hole. The mesh bags were taken out of the soil using a spade, a sharp knife and/or a pair of scissors, the latter for cutting off surrounding roots. the equipment needed for the whole procedure is illustrated in Fig. 1.

The rate of ingrowth of new roots was determined by sequential resampling of the mesh bags. The mortality of the roots was evaluated from the variation in the amount of dead and living roots in the samples. The criteria used in order to distinguish live fine roots from dead ones were similar to those described by Persson[16,17,18], who carried out extensive root studies

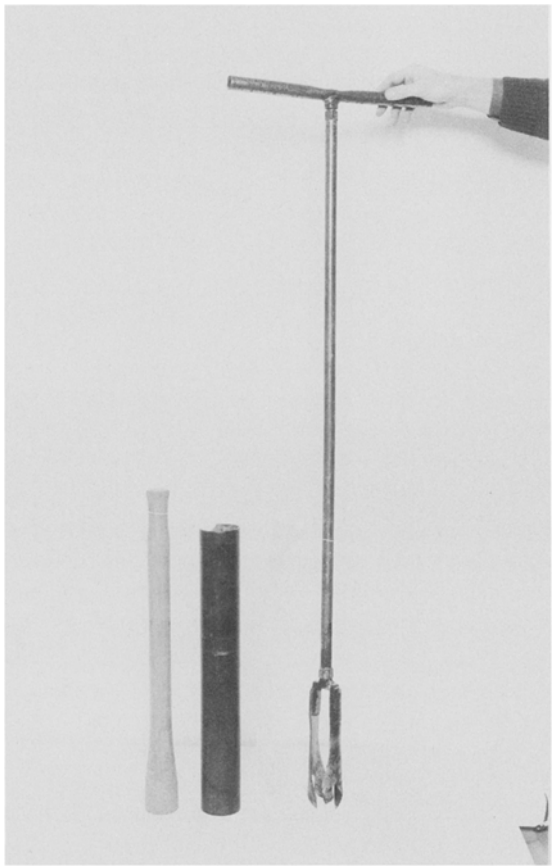

Fig. 1. Equipment used with the mesh bag method. From left to right wooden dowel, plastic tubes, mesh bag, spade auger.

using this method in stands of Scots pine (*Pinus sylvestris* L.) of different ages in Central Sweden. The method was also used in agricultural crops by Steen[23,24], Larsson and Steen[12], Steen *et al.*[26], Steen and Al-Windi[25].

Field experiments

The field experiments were carried out in two stands of *Eucalyptus globulus,* 11 and 16 years old. These were located at Bom Successo which had a lighter soil and at Alto do Vilão close to the Celbi station at Furadouro which had a clay soil. Soil preparation before planting consisted of deep ploughing and harrowing. No surface organic layer remained and the total soil profile consisted of a fairly uniform mineral soil. No fertilization was carried out. The tree spacing was 2 × 4 m at Bom Successo and 3 × 3 m at Alto do Vilão.

The mesh bags were inserted on 2–8 March 1982, with 175 bags at Bom Successo and 62 at Alto do Vilão. They were spaced in rows at intervals of about 1 m and about 2 m from the tree rows. There are two time series at Bom Successo, one taken up after periods of 2, 4, 6 and 12 months and a second one taken up and replaced every 2 months throughout the year. At Alto do Vilão the mesh bags were resampled after 2, 4, 6 and 12 months. This lay-out

Table 1. Ingrowth of *Eucalyptus* roots in mesh bags removed at regular intervals from the soil. Estimates (g dw 85°C m^{-2}) are given ± one standard error. The bags at Alto do Vilão and at Bom Successo were inserted on March 2–8th 1982. The 2-month bags at Bom Successo were inserted and subsequently excavated every second month from March 2–8th 1982 until March 7th 1983. n = number of samples

Site	Time of sampling	n	Live roots	Dead roots	Live plus dead roots
Alto do Vilão	12 May	10	16.1 ± 5.7	17.4 ± 7.8	33.5 ± 9.4
Increasing	16 July	10	65.7 ± 15.1	99.0 ± 13.0	164.7 ± 17.9
intervals	14 Sept.	10	83.2 ± 35.1	80.6 ± 15.9	163.7 ± 47.0
	7 March	10	363.8 ± 106.5	81.3 ± 18.2	445.1 ± 119.5
	12 Sept.	10	390.0 ± 269.7	99.8 ± 9.6	490.1 ± 266.6
Bom Successo	12 May	16	23.6 ± 2.9	27.8 ± 6.2	51.4 ± 7.8
Increasing	14 July	15	201.4 ± 19.7	57.4 ± 4.7	258.8 ± 20.0
intervals	13 Sept	15	237.5 ± 28.3	54.0 ± 5.5	291.5 ± 29.6
	8 March	15	210.0 ± 39.2	48.3 ± 5.2	258.0 ± 37.7
	12 Sept	15	181.1 ± 34.6	78.2 ± 10.9	259.3 ± 32.2
Bom Successo	12 May	16	23.6 ± 2.9	27.8 ± 6.2	51.4 ± 7.8
2-month intervals	14 July	16	402.2 ± 55.3	55.3 ± 5.5	457.6 ± 55.9
	8 Nov	15	95.9 ± 16.4	47.0 ± 6.8	142.9 ± 21.6
	10 Jan	15	174.4 ± 23.4	35.1 ± 3.4	209.4 ± 23.6
	7 March	15	142.7 ± 26.5	15.3 ± 1.8	158.0 ± 26.0
Cumulative totals	6 Mar–14 Jul	32	425.9 ± 13.9	83.2 ± 2.1	509.0 ± 14.1
2-month intervals	6 Mar–14 Sep	47	486.4 ± 14.2	129.4 ± 16.8	615.8 ± 19.1
	6 Mar–8 Nov	62	582.3 ± 17.6	176.4 ± 27.4	758.7 ± 19.1
	6 Mar–10 Jan	77	756.7 ± 17.6	211.5 ± 27.2	968.1 ± 20.2
	6 Mar–7 Mar	92	899.4 ± 18.7	226.8 ± 27.2	1126.1 ± 29.2

provided a good cover of the seasonal variation in root production in the top soil (0–40 centimeters).

On each sampling occasion the mesh bags were transported directly to a deep-freeze and stored. The samples were taken out of the freeze some hours before sorting. They were dry sieved on a mesh with a net size of 1 mm. The live and dead roots remaining in the sieve were sorted into diameter classes by hand, namely live roots < and > 2 mm and dead roots < and > 2 mm. The sorted root fragments were then dried in an oven at 85°C for at least 60 hours until constant weights were attained. They were weighed to the nearest 0.001 gram. The root samples were stored for dry root length measurements and for chemical analyses.

Results

Some general features of the data are apparent, *viz.* a gradual increase in live, dead and total dry matter at both sites during the first 4 months or until July 10th (Table1, Figs. 2, 3). Thereafter there was only a small increase (Bom Successo) or no increase at all (Alto do Vilão) until September 10th. The next 6 months until March 1983 show a different picture at the two sites, with a clear decline in the sandy soil at Bom Successo and a marked increase in the clay soil at

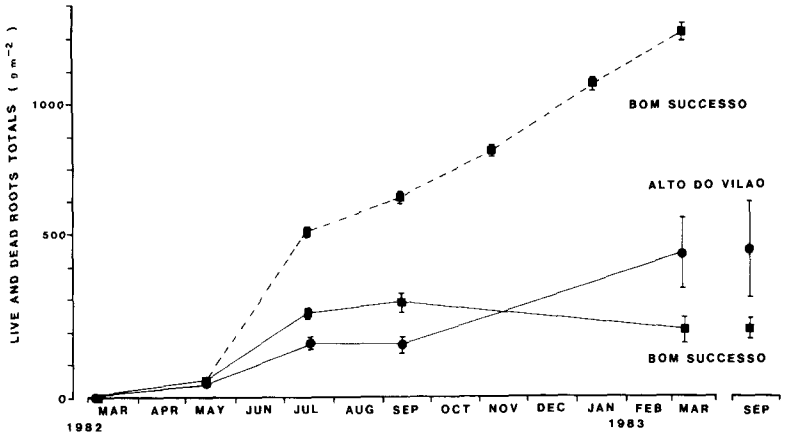

Fig. 2. The amount of live and dead fine roots (< 2 mm in diameter) in mesh bags removed on regular intervals from the soil. *Standard errors* are indicated for the samplings at Alto do Vilão (n = 9) and Bom Successo (n = 14) (*solid line*) with increasing intervals. The *diagram* also shows the cumulative totals from samplings at two-month intervals (n = 14) at Bom Successo (*broken line*).

Alto do Vilão. However, the data from the last sampling in September 1983 indicated a maximum level of 260 g dw m^{-2} at Bom Successo and 450 g dw m^{-2} at Alto do Vilão.

In the bags collected at 2-month intervals at Bom Successo there was substantial ingrowth in the May–July period and restricted ingrowth in July–September, corresponding to the long-term bags. In contrast, there was a rather high ingrowth in all the three subsequent 2-month samplings when there was a decline in the amount of roots in the long-term bags.

One feature of importance is the proportion of living and dead roots (Table 1, Fig. 3). After 2 months there was a considerable amount of dead roots at both sites but there were proportionally more dead roots at Alto do Vilão than at Bom Successo; 35 and 20% on average respectively. Further, the amount of dead roots was remarkably constant on most sampling occasions during the period July 1982–January 1983 and was generally of the same order in the 2-month samples as in the samples taken at increasing intervals. The apparent variation between sampling occasions is therefore mainly related to the live-root fraction.

The results should be considered in relation to some meteorological data from the nearest meteorological station at Cabo Carveiro (Table 2). The period March–May was relatively dry in 1982 but there were some rain showers in April–early May. From mid May to mid July the precipitation was low, which is normal (40 mm in 2 months). The

Table 2. Meteorological data for *Cabo Carvoeiro* (39°21′ N; 9°24′ E; 32 m a.s.l.) *ca* 5 km from the investigated stands. The temperature (maximum and minimum temperature, respectively) are the highest and lowest values during each month. The precipitation is the total figure for each month. The normal monthly precipitation is also given (Average figures 1936–1960)

Month	Max. (°C)	Min. (°C)	Precipitation (mm)	Normal precipitation (mm)
1982				
January	18.5–12.8	14.0– 6.0	60.8	83.2
February	19.0–12.5	13.2– 8.5	85.7	56.6
March	20.0–12.7	13.4– 8.0	10.0	79.5
April	22.5–14.3	15.0– 9.5	43.2	43.0
May	19.8–14.0	15.4–10.7	31.8	33.5
June	20.5–16.7	17.0–12.5	9.0	12.6
July	22.2–17.0	18.6–14.6	7.9	3.5
August	26.4–17.8	18.2–14.2	9.8	4.5
September	30.5- 17.5	18.3–15.0	56.8	25.2
October	22.2–15.6	17.5–10.2	26.3	53.4
November	23.3–13.8	15.8– 6.8	80.0	71.1
December	16.0–11.2	14.6– 6.5	41.8	83.3
1983				
January	15.8–11.8	11.8– 5.0	8.3	83.2
February	15.2– 9.0	13.8– 1.5	48.8	56.6
March	24.0–12.2	13.8–10.2	2.9	79.5

period July–September also represented normal weather conditions at that time with only small amounts of rain and high temperature. The months September–March comprise the rainy period of the year.

Discussion

One striking feature of the results is the high ingrowth in May–July. It is also evident that there is a growth of fine roots during the very dry summer months indicated by the 2-month samples for the period July–September. On the other hand, the growth during the winter months is comparatively high but, nevertheless, lower than expected.

The data from the long-term bags suggested that the ingrowth has reached a maximum after about 6 months in sandy soil (Bom Successo) when ingrowth of new roots is counterbalanced by the decomposition of old dead roots. The clay soil (Alto do Vilão) differed since the ingrowth took place more slowly and the optimum level was obtained after about 12 months. This is confirmed by data from the last sampling (Sept. 12th, 1983) when there was no further increase.

The data suggest, especially if the 2-month intervals are compared with the long-term series, that there was a considerable decomposition

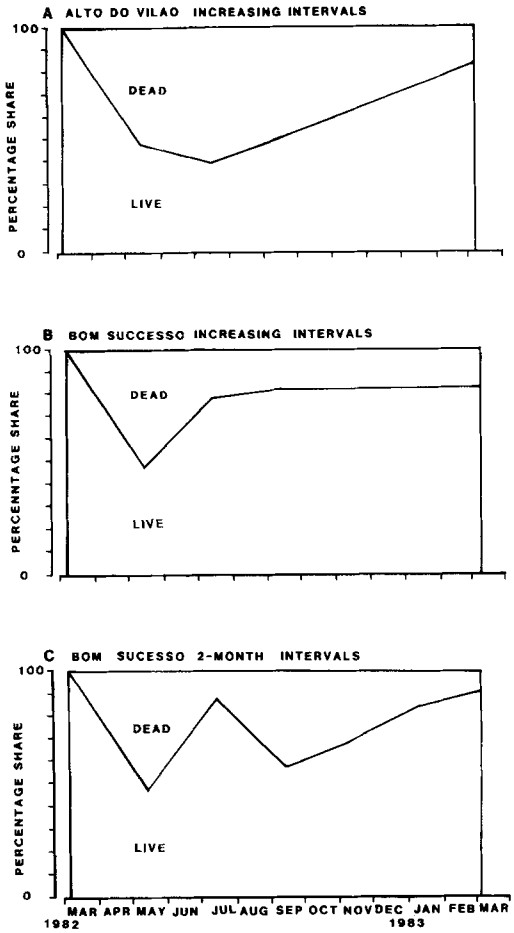

Fig. 3. The amount of live and dead fine roots (< 2 mm in diameter) expressed as a percentage of the total amounts of roots on each sampling occasion. A and B = samplings at Alto do Vilão and Bom Successo at increasing intervals; C = samplings at Bom Successo at two-month intervals.

of dead roots. Apparently this disappearance through decomposition occurred throughout the year with a probable maximum when the soil is wet and the soil temperature rather high.

In most Mediterranean regions a substantial growth in both above- and below-ground parts takes place during the wet winter months. Thus, Leshem[14] found a considerable growth activity during the winter in a *Pinus halepensis* stand in Israel. However, it is likely that the annual growth rhythm of *Eucalyptus globulus* differs from mediterranean pines, which can explain the comparatively high root growth during the period mid May–mid July. This is also in agreement with growth data obtained by Pereira[15] on shoot growth and leaf expansion

and the growth of twigs, bark and trunk, which have their maxima during the spring and early summer.

It is important to emphasise that the data obtained by the mesh bag method cannot directly be compared with data obtained, *e.g.*, from soil coring. The eucalypt fine roots occupy fairly quickly any root-free soil volume, *e.g.* a mesh bag filled with soil. After some time the soil in the bag will be infiltrated by the roots. This seems to happen after about 6 months in lighter soil and after at least 12 months in clay soil. This level is about 300–400 g dw m^{-2} in the mature Eucalyptus stand, which is low when compared with average levels in other broad-leaved woods[22]. However, it fits well with the data from the excavations at Bom Successo and Alto do Vilão of whole tree root systems (Fabião, unpublished), which give a fine root quantity of about the same level in the upper 40 cm of the profile. A comparatively low standing crop of roots can mean that there is a rapid turnover of fine roots in the superficial soil layer. If 6 months is expected to be a probable turnover time in the sandy soil, a minimum estimate of fine-root production of 600 g dw m^{-2} yr^{-1} is obtained. This estimate is reasonable since the size of root litter production should be at least in the order of the annual leaf-litter fall in mature Eucalyptus plantations[3,4] which is about 400–500 g m^{-2} $year^{-1}$. In the clay soil there seems to be a higher root mortality or a slower decomposition. It is therefore difficult to estimate the annual fine root production in the clay soil.

The accumulated amount of fine roots in the 2-month bags was about 110 g dw m^{-2}, which represents the ingrowth capacity into a root-free soil volume. This must be a maximum which is not obtained in a soil already containing living fine roots. Instead, new roots are formed and old roots die off, giving a fine-root production which is lower than 110 g dw m^{-2} yr^{-1} but higher than the estimated amounts in the long-term bags. The amount of dead roots in the 2-month bags in the sandy soil were of the same order as in the bags with increasing time intervals. In most samplings the bulk of the excavated root mass consisted of live fine roots (Fig. 3). Similar experiences have been described by Persson[17,19] in Scots pine stands. However, over a longer period of study the rate of production, mortality and decomposition would be more balanced in the bags and the dead root content would to some extent increase. This makes it difficult to indicate the rate of decomposition from the present data.

This study gives some technical experience of the mesh bag method in a rather stony soil in Southern Europe. The soil in the upper layers of the profile can be very hard during parts of the year. Neither a steel

corer nor a spade auger can penetrate the soil easily. However, the mesh bags were inserted into the soil during the wet part of the year. Furthermore, they can be re-sampled during droughts and when the soil is hard, which is acceptable for long-term trials. Holes can then be drilled during the wet part of the year with a spade auger and bags be inserted, whereas an ordinary cylindrical steel corer can hardly be used[18].

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