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Research paper

# Green Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco) in Călimănești Forest District: a successful long-term use

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**Abstract.** Green Douglas-fir was introduced in the Călimănești Forest District at the beginning of the 20th century. Currently, there are 78 stands with green Douglas-fir covering 1451.1 ha, of which the species itself is found on 389.15 ha. Only seven of these stands are pure (share of green Douglas-fir at least 80 per cent), whereas the majority of them (71) are mixed with both softwoods (e.g., Norway spruce, silver fir, Scots pine and European larch) and broadleaves (predominantly European beech, sessile oak, hornbeam, and sycamore maple, but also wild cherry, small-leaved linden, and common ash). The species was used especially in the European beech vegetation layer, at altitudes ranging from 250 m to 1100 m. Consequently, the soils under these stands are extremely variable, from brown to brown podzolic or even podzols. Green Douglas-fir has shown remarkable high resistance to disease and pathogens, as well as no damaging effects of snow or wind. Throughout the area, diameters and heights of the species are higher than those of cohabitants, either softwoods or broadleaves. In the oldest stand (115 years old) green Douglas-fir has reached 83.2 cm in diameter and 40.5 m in height, with a wood production of 1167.1 $m^3 \cdot ha^{-1}$.
**Keywords.** green Douglas-fir, Călimănești Forest District, mixed stands, diameter, height and volume growth

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## Introduction

The non-native tree species, particularly from North America and Asia, have been used in European forests since the beginning of 17th century. Their number has increased especially during the 19th century and these species are currently found growing in European forests on an area of 8.54 million hectares, or 4.0 per cent of the continent's forest area (Brus et al.

2019). Among them, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), a major tree species having recognized two geographic varieties (the coastal variety or green Douglas-fir (*P. menziesii* var. *menziesii*), and the interior variety (*P. menziesii* var. *glauca* (Beissn.) Franco), also called Rocky Mountain or blue Douglas-fir) (Hermann and Lavender 1999), was introduced to Europe (Perthshire, Scotland) by David Douglas in 1827 (Haralamb 1967). Currently, the species is used as forest tree in 35 European countries and covers over 0.83 million ha, being the second most widespread non-native conifer species in Europe after Sitka spruce (*Picea sitchensis* (Bong.) Carr) (van Loo and Dobrowolska 2019).

The green variety of Douglas-fir has proved much better adapted to European conditions than the interior variety: has a higher growth rate, is resilient to frost and more resistant to fungal diseases (Bastien et al. 2013, Lavender and Hermann 2014, Petkova et al. 2014, Konnert 2016), so green Douglas-fir is preferred throughout the continent (Konnert and Bastien 2019).

In Romania, the species was introduced in 1887, on the Fântânele-Bacău Estate belonging to the Prince Schönburg-Waldenburg (Ianovici 1912, in Popa-Costea 1973). Between 1887 and 1947, Douglas-fir plantations were established on only 59 hectares, the most representative stands being located in the western part of Romania (Lugoj, Anina, Aleșd, Marghita, and Dobrești Forest Districts (FD) - Ionuț 1956, Lăzărescu 1964 and Ionescu 1966, both in Popa-Costea 1973).

After WWII, during the C.A.E.R consultation on the issue of fast-growing forest species (Budapest 1960), it was decided that the area covered with these species in Romania should grow up to ca. 300,000 hectares in 1975 (Avram 1960). Green Douglas-fir was one of the tree species to focus on therefore the area of plantations established afterwards, using enormous amounts of seeds imported from the U.S.A. since 1956 grew at a sustained rate: 421 ha in 1960, 2,960 ha in 1964, after which the rate of afforestation was maintained at approx. 2,600 ha·yr$^{-1}$ until 1970. Consequently, only in the period 1960-1970, a total area of 23,582 ha was forested with green Douglas-fir, of which 7,409 ha in Banat, followed by Crișana (3,955 ha) and Oltenia (2,685 ha) regions (Popa-Costea 1973).

Unfortunately, during this period, the species was planted in very different site conditions, from the plains to the Norway spruce (*Picea abies* (L.) Karst) subzone of natural vegetation, which led to numerous failures (Stănescu et al. 1997). The altitudinal limits of the introduction of green Douglas-fir in Romania were the Cobia Forest, Segarcea FD (Dolj County: 120 m a.s.l., average annual temperature 10.7°C, average annual precipitation 530 mm), respectively the Dobrun Forest, Voineasa FD (Vâlcea County: elevation 1,400 m a.s.l., mean annual temperature (MAT) 1.7°C, average annual precipitation (MAP) 1,100 mm) (Popa-Costea 1973). These altitudes are much wider than the ones recommended for green Douglas-fir in Romania: maximum 800 (1000) m a.s.l., in the hilly and low mountainous regions (Pașcovschi and Purcelean 1954, Negulescu and Săvulescu 1957, 1965). In these areas, the climate is moderate, with minimum annual precipitations of 600 mm (Haralamb 1967), generally of 700-800 mm, like in the west and south-west of the country (Stănescu 1979, Stănescu et al. 1997).

As a result of those failures in using green Douglas-fir, the area covered currently by the species in Romania is only about 12,700 ha, the majority of them being located in the western part of the country (Stănescu et al. 1997, Șofletea and Curtu 2007). Out of this region, a quite important area is covered by plantations including Douglas-fir in the Călimănești FD, part of Vâlcea County Branch, subsidiary of National Forest Administration (NFA)-ROMSILVA.

In this FD, comprising eight Forest Management Units (FMU) which cover 18,958.10 ha, the forests grow at altitudes between 200 and 1650 m a.s.l., in a D.f.b.x.-type climate, with MAT of 5.1-10.1°C, MAP of 707-951 mm, the length of growing season

3-5 months (INCDS 2022). Brown forest soil is dominant throughout the FD, covering 60% of the total area and showing a high fertility for sessile oak (*Quercus petraea* (Matt.) Liebl.)-dominated stands, sessile oak-European beech (*Fagus sylvatica* L.) mixed stands, mountainous and hilly European beech stands, European beech-Norway spruce-silver fir (*Abies alba* L.) stands. The native vegetation is mostly part of the pre-mountainous European beech layer (44% of total area) and of the hilly layer of pure sessile oak and mixed sessile oak-European beech (41% of area). Consequently, the species composition of stands in this FMU is dominated by European beech (63% of total area) and sessile oak (11%), and the two species are joined by Norway spruce (10%), silver fir (4%), Scots pine (*Pinus sylvestris* L.) (3%), silver birch (*Betula pendula* L.) (2%), etc. The stands of Călimănești FD show a mean standing volume of 265 $m^3 \cdot ha^{-1}$, a mean current volume increment of 4.9 $m^3 \cdot ha^{-1}$, and a mean age of 98 years (INCDS 2022).

Green Douglas-fir was introduced in the region at the beginning of the 20$^{th}$ century and has been used widely in the last 50 years. Consequently, 78 stands including green Douglas-fir cover currently 1451.1 ha, of which the species itself is found on 389.15 ha (INCDS 2022). Only seven of these stands are pure (share of green Douglas-fir at least 80 per cent), whereas seventy-one are admixtures with both softwoods (e.g., Norway spruce, silver fir, Scots pine, European larch *Larix decidua* Mill.,) and broadleaves (predominantly European beech, sessile oak, hornbeam *Carpinus betulus* L., and sycamore maple *Acer pseudoplatanus* L., but also wild cherry *Prunus avium* L. and small-leaved linden *Tilia cordata* Mill.) as a result of the long-standing official Romanian forest policy of using green Douglas-fir only in enrichment planting not in pure stands. In 21 stands (total area 117.89 ha), green Douglas-fir is the dominant species (share at least 50 per cent). At FD level, green Douglas-fir shows a mean age of 51 years, has a mean current volume increment of 14.6 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ and a mean standing volume of 560 $m^3 \cdot ha^{-1}$ (INCDS 2022).

The species was used especially in the hilly and mountainous European beech vegetation layers, but also in the sessile oak or even Norway spruce vegetation layers, at altitudes ranging from 250 m to 1,100 m and on different aspects (from sunny to shady, but predominantly south, south-east and south-west facing), and slopes (from horizontal land to over 30 degrees centigrade) conditions. Consequently, the soils under these stands are extremely variable, from brown soils, in the lower part of the range, to brown podzolic soils or even podzols in its upper part (INCDS 2022).

Under these circumstances, our study aims at presenting the most relevant issues related to the long-standing use of green Douglas-fir in the Călimănești FD such as density, stocking and species composition of stands including the species as well as the biometrical traits (e.g., diameters, heights, basal areas, and volumes) of those stands.

## Material and methods

The fieldwork related to the objectives of the paper was carried out in six sub-compartments belonging to Călimănești FD, FMU I Muereasca, III Căciulata and VI Berislăvești, considered as representative for the use of green Douglas-fir in this FD. The main characteristics of these sub-compartments are depicted in Table 1.

In addition to these six sub-compartments from Călimănești FD, we have also chosen sub-compartment 92G from the Dobrun Forest, part of former FMU VIII Cataracte, belonging to Voineasa FD (Figure 1).

This stand was already mentioned as being located at the highest elevation of a stand with green Douglas-fir in Romania. It was restituted recently to the pre-WWII owners, and is the oldest sub-compartment with green Douglas-fir established in the Vâlcea County Branch of NFA-Romsilva. Its main characteristics are: area 0.90 ha, landform slope, aspect SW, mean slope 25$^g$,


**Figure 1** Location of Călimănești FD (1) and of Dobrun Forest (Voineasa FD) (2) in Romania

**Figure 2** Vigorous and high quality green Douglas-fir trees (with green dots), selected as final crop trees in plot no. 2, sub-compartment 129E

soil type 4101 Brown podzolic, site type 2312 Mountainous of Norway spruce, moderate fertility, with spodic soils and *Vaccinium myrtillus*, and natural vegetation type 1151 Norway spruce with *Vaccinium myrtillus* and *Oxalis acetosella* (moderate productivity).

During the field work, carried out in year 2022, two rectangular sample plots (SP) of 300-500 m$^2$ each were installed in each sub-compartment in Călimănești FD. In sub-compartment 92G, a single SP of 800 m$^2$ was installed. In sub-compartment 128E (both plots), final crop trees were selected based on the criteria vigor (the thickest and tallest)-quality (without forks, cankers, other defects)-spacing/distribution (as regularly spaced as possible) (Figure 2).

In all sample plots, diameters at breast height (dbh) were measured for all existing trees. In sub-compartments 25B, 41B, 109B, and 129E four crown radii ($r_1$,..., $r_4$), arranged at 90 degrees to each other, two on the contour line and two on the line of the greatest slope, were measured in green Douglas-fir trees. In some of the trees of various species, with as varied dbh as possible, the total heights (h) were also measured. The instruments used for the establishment of plots and biometric measurements were: 5 m, 20 m and 50 m long tapes, with a

**Table 1** The main characteristics of the six sub-compartments

| FMU | Subcompartment | Area (ha) | Landform | Altitude (m) | Aspect | Mean slope (g) | Soil type* | Site type** | Natural vegetation type*** |
|---|---|---|---|---|---|---|---|---|---|
| I | 129E | 1.96 | Slope | 400 | SW | 6 | 3101 | 5134 | 5131 |
| III | 25B | 10.10 | Slope | 510-770 | SW | 20 | 3101 | 4420 | 4114 |
| III | 45B | 1.51 | Slope | 510 | S | 28 | 3101 | 4430 | 4111 |
| III | 45C | 0.37 | Slope | 500 | S | 15 | 3101 | 4430 | 4111 |
| VI | 41B | 1.03 | Slope | 840 | S | 10 | 3101 | 4420 | 4121 |
| VI | 109B | 19.00 | Slope | 590-850 | NW | 20 | 3101 | 5233 | 4221 |
| Total | - | 33.97 | - | - | - | - | - | - | - |

***Soil type**: 3101 Brown forest soil; ** **Site types**: 4420 Mountainous-premountainous of European beech, moderate fertility, with brown forest soil and *Asperula-Dentaria*; 4430 Mountainous-premountainous of European beech, high fertility, with brown forest soil and *Asperula-Dentaria*; 5134 Hilly of sessile oak, high fertility, brown podzolic soil with grasses; 5233 Hilly of European beech, moderate fertility, brown podzolic/pseudogleic, with *Carex pilosa*; ***Natural vegetation types**: 4111 Mountain European beech with mull flora (high productivity); 4114 Mountain European beech on skeletal soils with mull flora (moderate productivity); 4121 Mountain European beech on brown and brown-yellow soils, moderately acid (moderate productivity); 4221 Hilly European beech with *Carex pilosa* (moderate productivity).

precision of 5 mm ($r_i$), a Haglof caliper, with a precision of 1 mm (dbh), and a Romanian hypsometer, with a precision of 50 cm (h). Based on the field data, the quadratic mean diameter (QMD), the height corresponding to the QMD ($h_g$), as well as the mean crown diameter (mean crown d = $(r_1+r_2+r_3+r_4)/2$), were calculated. In addition, the correlation between dbh and mean crown d, expressed graphically, was analyzed. The dbh values were used for the calculation of the basal area per species and plots, and the volume tables per species (Giurgiu et al. 1972, 2004) were used for the calculation of the volume of individual trees and stands.

## Results

### Density and stocking of stands including green Douglas-fir

In the thirteen sample plots, as the age of stands is variable (from 25 years to 115 years, but each individual stand is even-aged), the density (number of trees per hectare) is also very variable (Table 2).

Normally, the highest density (2,866 trees·ha$^{-1}$) was found in the youngest stand (25 years old) while the lowest density (360 trees·ha$^{-1}$) characterizes one of the oldest stands (60 years old). This value is similar to the one (400 trees·ha$^{-1}$) found in the oldest stand of 115 years. However, the density of all these stands is high (e.g., ca. 800 trees·ha$^{-1}$ at 45 years; over 1,000 trees·ha$^{-1}$ at 55 years of age; ca. 700 tree ha$^{-1}$ at 60 years of age) regardless the age and species composition in each sub-compartment.

**Table 2** Density and stocking of trees in the thirteen sample plots

| FMU | Sub-compartment | Mean age, years | Plot no. | Density, no. of trees·ha$^{-1}$ | Stocking, m$^2$·ha$^{-1}$ |
|---|---|---|---|---|---|
| I | 129E | 45 | 1 | 640 | 36.95 |
| | | | 2 | 460 | 44.09 |
| III | 25B | 60 | 1 | **360** | 45.55 |
| | | | 2 | 520 | 62.84 |
| III | 45B | 55 | 1 | 1,100 | 73.69 |
| | | | 2 | 980 | 64.19 |
| III | 45C | 60 | 1 | 660 | 71.77 |
| | | | 2 | 779 | 70.14 |
| VI | 41B | 25 | 1 | **2,866** | 39.56 |
| | | | 2 | 940 | **28.15** |
| VI | 109B | 45 | 1 | 867 | 60.03 |
| | | | 2 | 783 | 64.59 |
| VIII | 92G | 115 | 1 | 400 | **90.70** |


**Figure 3** Aspects of sub-compartments 45B, plot 1 (a), and 92G (b)

Regarding the stocking (m$^2$·ha$^{-1}$), it is also very variable, with the minimum value (28.15 m$^2$·ha$^{-1}$) in the youngest stand (25 years old) and the maximum value (90.70 m$^2$·ha$^{-1}$) in the oldest one (115 years old). As in case of density, the stocking is extremely high at all ages regardless the species composition and reaches over 60 m$^2$ ·ha$^{-1}$ at 45 years or over 70 m$^2$·ha$^{-1}$ at 60 years.

Two examples of such dense stands are shown in Figures 3a and 3b.

**Table 3** Species composition in research stands

| FMU | Sub-compartment | Plot no. | Species composition by number of trees, % | Species composition by basal area, % |
|---|---|---|---|---|
| I | 129E | 1 | 47DF 16SO 37HO | 83DF 11SO 6HO |
| | | 2 | 100DF | 100DF |
| III | 25B | 1 | 50DF 22SY 17EL 11EB | 69DF 16EL 14SY 1EB |
| | | 2 | 46DF 19SY 16EL 19EB | 76DF 11SY 11EL 2EB |
| III | 45B | 1 | 60DF 33(EB,HO,SYC,ME,GW) 7(SLL,WC) | 84DF 8(EB,HO,SYC,ME,GW) 8(SLL,WC) |
| | | 2 | 47DF 37(HO,ME,SY) 17(SLL,CA) | 69DF11(HO,ME,SY) 20(SLL,CA) |
| III | 45C | 1 | 79DF 21(EB,HO,SY) | 91DF 9(EB,HO,SY) |
| | | 2 | 78DF 22(EB,HO) | 94DF 6(EB,HO) |
| VI | 41B | 1 | 94DF 3(NS,SF) 3SY | 92DF 7(NS,SF) 1SY |
| | | 2 | 100DF | 100DF |
| VI | 109B | 1 | 46DF 43EB(+WC,CA) | 73DF 27EB(+WC,CA) |
| | | 2 | 56DF 33EB 11(WC,CA) | 78DF 8EB 14(WC,CA) |
| VIII | 92G | 1 | 63DF 37NS | 71DF 29NS |

**Conifers**: DF Green Douglas-fir, NS Norway spruce, SF silver fir, EL European larch
**Broadleaves**: EB European beech, SO sessile oak, HO hornbeam, SY sycamore maple, SLL small-leaved linden, WC wild cherry, CA common ash *Fraxinus excelsior* L., ME Mountain elm *Ulmus glabra* L., GW goat willow *Salix capraea* L.

## Species composition of stands including green Douglas-fir

In the even-aged stands including green Douglas-fir, the species composition is very variable, with the share of this species ranging from 46% to 100% (composition by number of trees) and between 69% and 100% (composition by basal area) respectively (Table 3).

As shown below Table 3, green Douglas-fir was associated with both conifers (e.g., Norway spruce, silver fir, European larch) and broadleaves such as European beech, sessile oak, sycamore maple, hornbeam, small-leaved linden, wild cherry, common ash, mountain elm, etc. Green Douglas-fir was solely regenerated artificially (planted) either in intimate or grouped admixtures, to fill in the gaps occurring in naturally regenerated stands, mostly European-beech dominated, or as small pure stands. If conifer species were all planted, all broadleaves were naturally regenerated by seed.

In almost all cases (with the exception of sub-compartment 41B, plot no. 1), as green Douglas-fir diameters (consequently basal areas), as shown below, were bigger than the ones of associated species, its share in species composition by basal area is much higher than the one by number of trees.

## Biometrical performances of individual trees and stands including green Douglas-fir

### *Quadratic mean diameter and height corresponding to QMD*

The values of these biometric parameters in the thirteen sample plots are shown in Table 4.

In terms of QMD, green Douglas-fir has reached important values in all stands e.g., over 35 cm at 45 years of age, up to 50 cm at 60 years of age, and over 57 cm at 115 years of age. With the exception of sub-compartment 41B, plot no. 1, where QMD of NS and SF is a bit bigger, the QMD of green Douglas-fir in all plots is much higher than that of all cohabitant species, both conifers and broadleaves.

**Table 4** Quadratic mean diameters and heights corresponding to QMD in the seven sub-compartments

| FMU | Subcom-partment | Mean age, years | Plot no. | Quadratic mean diameter (QMD), cm | Height corresponding to the QMD ($h_g$), m |
|---|---|---|---|---|---|
| I | 129E | 45 | 1 | **DF 36.03**; SO 22.28; HO 11.42 | **DF 30.84**; SO 19.30; HO 14.40 |
| | | | 2 | DF 34.93 | DF 29.58 |
| III | 25B | 60 | 1 | **DF 47.29**; SY 33.97; EL 39.22; EB 12.10 | **DF 32.97**; EL 30.50; SY 25.80 EB 12.10 |
| | | | 2 | **DF 50.38**; SY 30.19; EL 33.57; EB 9.77 | **DF 33.20**; SY 24.70; EL 29.20; EB 11.15 |
| III | 45B | 55 | 1 | **DF 34.51**; (EB,HO,SYC,ME,GW) 14.57; (SLL,WC) 30.80 | **DF 30.29**; (EB,HO,SYC,ME,GW) 17.90; (SLL,WC) 22.70 |
| | | | 2 | **DF 34.96**; (HO,ME,SY) 15.79; (SLL,CA) 32.13 | **DF 33.19**; (HO,ME,SY) 18.70; (SLL,CA) 23.80 |
| III | 45C | 60 | 1 | **DF 39.88**; (EB,HO,SY) 24.87 | **DF 30.39**; (EB,HO,SY) 24.70 |
| | | | 2 | **DF 37.05**; (EB,HO) 17.54 | **DF 30.13**; (EB,HO) 20.20 |
| VI | 41B | 25 | 1 | **DF 13.16**; (NS,SF) 19.20; SY 6.86 | **DF 13.28** (NS,SF) 16.30 SY 8.20 |
| | | | 2 | **DF 19.53** | **DF 15.04** |
| VI | 109B | 45 | 1 | **DF 37.36**; EB(+WC,CA) 21.00 | **DF 28.30**; EB(+WC,CA) 20.30 |
| | | | 2 | **DF 38.49**; EB 15.90; (WC,CA) 35.87 | **DF 29.10**; EB 18.80; (WC,CA) 24.30 |
| VIII | 92G | 115 | 1 | **DF 57.39**; NS 46.98 | **DF 36.67**; NS 32.01 |

**Conifers**: DF Green Douglas-fir, NS Norway spruce, sF Silver fir, EL European larch
**Broadleaves**: EB European beech, SO sessile oak, HO hornbeam, SY sycamore maple, SLL small-leaved linden, WC wild cherry, CA common ash *Fraxinus excelsior* L., ME Mountain elm *Ulmus glabra* L., GW goat willow *Salix capraea* L.

The same conclusions are drawn also in terms of height corresponding to the QMD of green Douglas-fir, with values of 28-30 m at 45 years of age, 30-33 m at 60 years of age, and over 36 m at 115 years of age. In all plots, with the same exception (sub-compartment 41B, plot no. 1), green Douglas-fir is much taller than the other species, either conifers or broadleaves. In three sub-compartments, owing to these relevant differences in height between green Douglas-fir and the admixed species, the stands are two-storied (vertically irregular), with DF forming the upper layer and the adjoining species, mostly broadleaved (e.g., EB, HO, SY), the lower layer.

### *Minimum and maximum diameters at breast height of different tree species*

These values, in the seven research sub-compartments, are shown in Table 5.

As in the case of QMD, green Douglas-fir is thicker in all plots (with the same exception as above) than the adjoining tree species – both conifers and broadleaves - in terms of minimum and maximum diameters. Even though all stands are even-aged, the differences between these extreme values of diameters are very relevant and can be as high as 20 cm, even 30 cm for maximum diameters.

Individual green Douglas-fir trees have reached important diameters (e.g., over 46 cm

**Table 5** Minimum and maximum diameters at breast height of different tree species found in the seven sub-compartments

| FMU | Subcom-partment | Mean age, years | Plot no. | Minimum diameter, cm | | Maximum diameter, cm | |
|---|---|---|---|---|---|---|---|
| | | | | DF | Other tree species | DF | Other tree species |
| I | 129E | 45 | 1 | 23.1 | SO 9.8; HO 7.3 | 47.7 | SO 27.5; HO 16.3 |
| | | | 2 | 22.7 | - | 46.5 | - |
| III | 25B | 60 | 1 | 36.0 | EL 33.8;SY 24.4 | 61.8 | EL 41.9;SY 38.0 |
| | | | 2 | 37.3 | EL 23.2; SY 22.9 | 60.7 | EL 43.4;SY 34.7;EB 13.8 |
| III | 45B | 55 | 1 | 14.2 | (EB,HO,SYC, ME,GW) 8.1; (SLL,WC) 10.8 | 69.4 | (EB,HO,SYC, ME,GW) 24.2; (SLL,WC) 40.4 |
| | | | 2 | 10.8 | (HO,ME,SY) 6.9; (SLL,CA) 26.0 | 62.2 | (HO,ME,SY) 31.2; (SLL,CA) 37.1 |
| III | 45C | 60 | 1 | 21.4 | (EB,HO,SY) 10.3 | 60.0 | (EB,HO,SY) 38.3 |
| | | | 2 | 12.3 | (EB,HO) 6.9 | 62.1 | (EB,HO) 41.5 |
| VI | 41B | 25 | 1 | 5.1 | SY 5.0; (NS,SF) 11.3 | 29.3 | SY 8.8; 24.9 (NS,SF) |
| | | | 2 | 13.9 | - | 25.7 | - |
| VI | 109B | 45 | 1 | 23.3 | EB(+WC,CA) 8.5 | 55.8 | EB(+WC,CA) 33.9 |
| | | | 2 | 16.5 | EB 13.0; (WC,CA) 32.3 | 66.8 | EB 22.7; (WC,CA) 39.2 |
| VIII | 92G | 115 | 1 | 20.2 | NS 17.9 | 83.2 | NS 54.0 |

**Conifers**: DF Green Douglas-fir, NS Norway spruce, SF silver fir, EL European larch
**Broadleaves**: EB European beech, SO sessile oak, HO hornbeam, SY sycamore maple, SLL small-leaved linden, WC wild cherry, CA common ash *Fraxinus excelsior* L., ME Mountain elm *Ulmus glabra* L., GW goat willow *Salix capraea* L.

**Figure 4** The thickest green Douglas-fir tree in the sample plots (sub-compartment 92G, tree no. 16: dbh 83.2 cm)

at 45 years of age, over 60 cm at 60 years of age), the thickest tree showing a dbh over 83 cm (Figure 4).

The fact that the stands are even-aged is confirmed by the values of coefficients of variation of diameters in case of green Douglas-fir trees: in quasi-totality of plots (exception sub-compartment 45B, both plots), this parameter ranges between 30 and 45%, these values characterizing regular/even-aged stands (Giurgiu 1969).

### *Standing volume and mean annual increment*

In all stands and plots, the standing volume reaches high values, from over 200 $m^3$ $ha^{-1}$ at 25 years of age to over 1160 $m^3 \cdot ha^{-1}$ at 115 years of age (Table 6).

Volumes over 550 $m^3 \cdot ha^{-1}$ have been reached at 45 years of age, while standing volume is

**Table 6** Standing volume and mean annual increment in research stands

| FMU | Subcompartment | Mean age, years | Plot no. | Standing volume, $m^3 \cdot ha^{-1}$ | Mean annual increment, $m^3 \cdot ha^{-1} \cdot yr^{-1}$ |
|---|---|---|---|---|---|
| I | 129E | 45 | 1 | 462.8 | 10.28 |
| | | | 2 | 566.0 | 12.58 |
| III | 25B | 60 | 1 | 588.2 | 9.80 |
| | | | 2 | 772.3 | 12.87 |
| III | 45B | 55 | 1 | 913.3 | ***16.61*** |
| | | | 2 | 832.0 | 15.13 |
| III | 45C | 60 | 1 | 847.1 | 14.12 |
| | | | 2 | 869.7 | 14.50 |
| VI | 41B | 25 | 1 | 283.0 | 11.32 |
| | | | 2 | 206.5 | 8.26 |
| VI | 109B | 45 | 1 | 644.5 | 14.32 |
| | | | 2 | 703.5 | 15.63 |
| VIII | 92G | 115 | 1 | ***1167.1*** | 10.15 |

over 800 $m^3 \cdot ha^{-1}$ at 55-60 years of age in five out of six plots.

Under these conditions, the mean annual volume increment at different ages is high and ranges between 8.26 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ and 16.61 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ (Table 6). However, in 11 out of 13 plots, this increment is higher than 10 $m^3\ ha^{-1}\ yr^{-1}$, values as high as 13-15 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ being the most frequent.

### *Relationship between diameter at breast height and mean crown diameter*

In green Douglas-fir trees of sample plots, diameter at breast height and mean crown diameter are strongly correlated, with a coefficient of correlation (r) ranging between over 0.75 and over 0.90, as shown in Figures 5a and 5b.

This strong correlation is used in crop tree silviculture of green Douglas-fir: final crop trees are selected at the beginning of pole stage (mean diameter 12-15 cm) among the thickest ones, with large and balanced crowns, and subsequent thinning are performed from both above and below (but predominantly from above), around such vigorous trees (in addition, of the best quality and as uniformly spaced as possible).

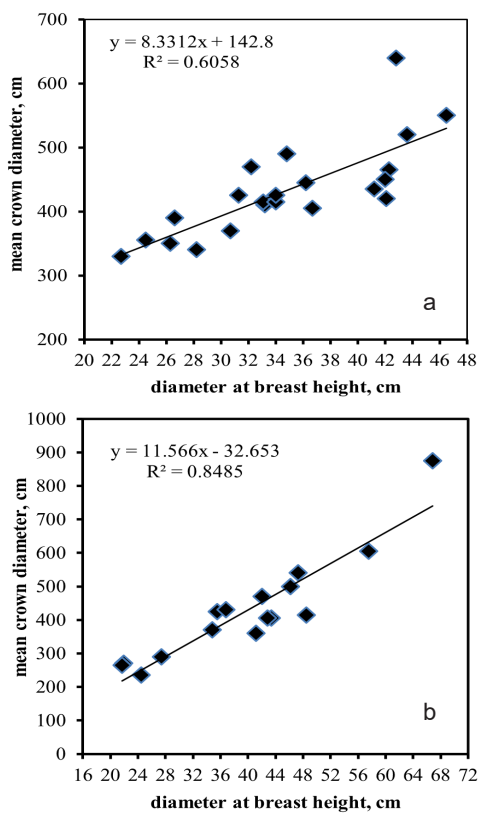


**Figure 5** Aspects of sub-compartments 45B, plot 1 (a), and 92G (b)

### *Natural pruning of green Douglas-fir trees*

In all stands and plots, the natural pruning of green Douglas-fir trees, regardless the age, density/stocking or species composition of stands was imperfect, as its branches are very persistent and their natural shedding is very slow. In these circumstances, their artificial pruning is a must, when targeting the production of knot-free logs, for superior uses.

### *Miscellaneous*

In addition to the above issues we should mention two other aspects in relation to this species in Călimănești FD:

(i) green Douglas-fir has shown a high resistance to disease and pathogens, as well as no damaging effects of snow or wind regardless the location, age or species composition of stands.

(ii) in open areas bordering the stands with green Douglas-fir, as well as below sparse canopies, the species was able to regenerate naturally by seed. However, it was not acting as an invasive species, but competing normally/growing jointly with both conifer and broadleaved native tree species.

## Discussion

All research stands show high stand density and stocking due to (i) the high initial density of plantations with green Douglas-fir and (ii) the quite low intensity of tending operations (e.g., cleaning-respacing and thinning), mandatory through the official Romanian technical norms since long ago. Regarding the (i) issue, it was (MS 1987) and still is (MMAP 2022a) 4,400 plants·ha$^{-1}$ (1.5 x 1.5 m) when using green Douglas-fir on bare land and 2,500 plants ha-1 (2.0 x 2.0 m) when using the species to fill up the gaps within natural regenerations. Such high initial density is not very much reduced through the application of cleaning-respacing (moderate, with maximum 15% intensity by basal area, reducing the canopy cover to minimum 0.8) and thinning (MMAP 2022b). In the latter case, the intensity (by volume) of mixed-type (from above and from below) interventions is also moderate (16% at age 21-30 years, and 12% at age 31-40 years). Thinning target the reduction of stand density to 500-550 crop trees·ha$^{-1}$ (high fertile sites) and to 550-700 crop trees·ha$^{-1}$ (moderate fertile sites) at age 50 (MMAP 2022b).

The species composition of stands with green Douglas-fir in Călimănești DF is very diverse, including many conifer and broadleaved tree species, as recommended in the past and currently by the Technical norms (MS 1987, MAPPM 2000) and Guides of good practice (MMAP 2022a). This situation is similar to other European countries, where the species is admixed with European beech (Czech Republic, France, Germany, Switzerland), Norway spruce (Bulgaria, Czech Republic, Germany, Slovenia), silver fir (Czech Republic, France, Slovenia), European larch (Bulgaria, UK) (Čokl 1965, Petkova 1989, Alexandrov et al. 2000, MAPPM 2000, Horgan et al. 2003, Wilson and Cameron 2015, Petkova et al. 2017, Keane et al. 2018, Novák et al. 2018, COFORD 2020, Nicolescu et al. 2021, Royal Forestry Society 2021). An interesting situation encountered in Călimănești FD is the use of green Douglas-fir in mixtures with sessile oak and hornbeam, in the sessile oak layer of native vegetation. Such use of DF in mixed broadleaved stands dominated by sessile oak has never been recommended in Romania by the specialized Technical norms and guides (MS 1987, MAPPM 2000, MMAP 2022a), but this kind of stands has shown quite high wood production and volume increment.

Throughout the research stands, green Douglas-fir has demonstrated its important diameter and height increment at all ages, being (in the quasi-totality of cases) both the thickest and the tallest tree species compared to the admixed ones. This growth potential has led to high standing volumes, such as 600-700 m$^3$ ha$^{-1}$ at 45 years of age, similar to green Douglas-fir

stands of the same age in Slovenia (Smolnikar et al. 2021) or Italy (La Marca et al. 2016) but lower than the one reached in the Czech Republic at age 100 (750 $m^3 \cdot ha^{-1}$ – Remeš and Zeidler 2014). The maximum standing volume (over 1000 $m^3 \cdot ha^{-1}$) in sub-compartment 92G (115 years old) has also been reached in Slovenia (1154 $m^3 \cdot ha^{-1}$) - Čokl 1965) and Bulgaria (1166 $m^3 \cdot ha^{-1}$ - Popov 2006, 2009), but in younger stands (60) 70-80 years old). The mean annual volume increment confirms the high growth potential of the species, similar to the ones reached in green Douglas-fir stands of Slovenia (7.8-15.9 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ - Čokl 1965), Croatia (8.3-18.5 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ – Klepac 1962), France (14.8 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ - Kohnle et al. 2019) or Italy (15 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ – La Marca et al. 2016).

## Conclusion

Green Douglas-fir, a North-American tree species introduced to the Călimănești FD about one century ago, had proved to be a very valuable acquisition to the local forests in different ecological conditions and admixed with native tree species, both conifers and broadleaves. Its easy establishment by planting and further use either in pure or mixed stands, its quick early growth, its high increment and wood production, its resistance to diseases, pathogens, snow, and wind, its potential for natural regeneration, without becoming invasive, its very valuable timber, with many important end-uses, are all making green Douglas-fir an important tree species to be used locally and nationally on a larger scale than currently.

This further use will require the change of existing Technical norms and Guides of good practice to allow for a wider use in Romania of this valuable tree species under favourable ecological conditions, mostly at moderate elevations, typical to the European beech layer of natural vegetation.

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## Author contribution statement

All authors contributed to the study conception and design. Material preparation and data collection were performed by Gheorghe Mihăilescu, Roxana-Mihaela Tăut, Radu Tampa, and Valeriu-Norocel Nicolescu. Data analysis was performed by Valeriu-Norocel Nicolescu. The first draft of the manuscript was written by Valeriu-Norocel Nicolescu and all authors commented on it. All authors read and approved the final manuscript.

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