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Silviculture of artificial, pure and young Norway spruce stands: an example

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Abstract. The paper shows the results of a small-scale R&D project on early silviculture of Norway spruce, carried out in a pure plantation of 0.4 ha, 2 x 1 m (5,000 plants ha^{-1}), established in 2001. In 2009, following the application of an access pruning on all stand trees, 60 ”potential” final crop trees were selected throughout the stand, based on the vigour-quality-distribution criteria, being subsequently pruned up to 4-4.5 m. In the same year, two plots, each of 300 sq.m, were established and a mixed and heavy cleaning-respacing was carried out classically (typical to stand silviculture, in plot 1) or dynamically (as in case of crop tree silviculture, in plot 2). A classical cleaning-respacing (mean canopy cover 80% after intervention) was also performed at stand level, leaving the ”potential” final crop trees in a free-growth state at the crown level. A mixed thinning, similar to the intervention in 2009, was carried out at both plot and stand level in 2013, with the remaining density of 1,167 trees ha^{-1} (plot 2) and 1,567 trees ha^{-1} (plot 1) and basal area of 20.67 sq.m ha^{-1} (plot 2) and 23.47 sq.m ha^{-1} (plot 1). In 2020, the mean arithmetic diameter and mean quadratic diameter of trees in plot 2 and ”potential” final crop trees reached 20 cm. Out of these trees, over 50% are at least 20 cm in diameter. The basal area in plots 1 and 2 is over 35 sq.m ha^{-1} so a new thinning is due to be carried out in 2020, to reduce the basal area under the critical value of 30 sq.m ha^{-1}. Mean height reached 15 m in 2020, and the slenderness (stability) index has grown significantly only in plot 1, reaching the value of 85. The R&D project showed clearly the possibility of producing Norway spruce trees of 20 cm d.b.h. in 20 years, by using intensive crop tree silviculture started earlier, during the thicket development stage.
Keywords Norway spruce, cleaning-respacing, thinning, crop tree silviculture, diameter increment.

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Introduction

Norway spruce (*Picea abies* (L.) Karst) is one of the most important conifer species in Europe, with a major ecological role in pure or mixed stands with Silver fir (*Abies alba* Mill.) and European beech (*Fagus sylvatica* L.) in the mountainous regions of the continent. The species is also of major economic importance, due to its simple culture, quick growth, high wood production and generally short rotations, being considered for a long time in various European countries such as Germany, France, Belgium, Austria, Great Britain, the Czech Republic, as a bread-tree (Schmidt-Vogt 1967, in Marcu 1974).

Unfortunately, the widespread use of Norway spruce since the 19th century as "the first species of afforestation in Europe" (Riou-Nivert 1996) has led to the emergence of many problems in Norway spruce stands over time, some catastrophic due to wind, snow, summer drought (Caudullo et al. 2016).

To these have been added, in recent years, injuries due to strong outbreaks of bark beetles, both in Scandinavia and in countries such as Germany, France and especially the Czech Republic, where millions of m^3 of Norway spruce wood have been infested of Ipidae species against the background of extreme drought (https://madeira.fordaq.com/news/France_spruce_bark_beetle_64805.html, Duduman and Lupaştean 2019).

In addition, Norway spruce stands in Europe are expected to be significantly affected by future climate change, which has led to the search for alternatives to its culture, such as establishing the species only in mixed stands and not in monocultures or even replacing Norway spruce with Silver fir, using Mediterranean origins or from drier areas of the Alps (Caudullo et al. 2016), or with Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco), a species considered more adapted to the expected climate changes in Germany (Pukall 2019) or the Czech Republic (Zeidler and Bořůvka 2018, van Loo and Dobrowolska 2019).

The various problems of Norway spruce plantations, especially stability to the action of snow or wind, are related to the number of seedlings ha^{-1} at establishment, respectively with the silvicultural interventions applied to young stands. Thus, the obvious trend of the last decades of the last century, respectively the beginning of the 21st century, to increase stand stability, but also to reduce establishment and labour costs, is to reduce the initial stocking of Norway spruce plantations.

If, at the beginning of the last century, it reached or even exceeded 10,000 ha^{-1} seedlings, now it does not exceed (1600) 2000-2500 ha^{-1} seedlings (2 x 2 m, 2 x 2.5 m, even 2.5 x 2.5 m) in countries such as Germany (Mäkinen and Hein 2006, Vor pers.comm.), Austria (Weinfurter 2004), Belgium (Bary-Lenger et al. 1988, Hébert et al. 2002, Perin 2016), France (Tisserand and Pardé 1982, Pardé 1984, Changsheng et al. 1998), Croatia (Orlić 1989), Ireland (Anonymous 2009), Great Britain (Hart 1994, Savill et al. 1997), Lithuania (Zeltiņš 2017, Katrevičs et al. 2018), Italy (La Porta pers.comm.), Slovenia (Brus pers.comm.), Bosnia and Herzegovina (Cvjetkovic pers.comm.), Northern Macedonia (Mandzukovski pers.comm.).

Such recommendations also exist in the Romanian forestry literature (for example, Barbu 1982 - to use Norway spruce, in sites prone to snowfalls, at 2 x 2 m or 2.5 x 2.5 m, respectively with 1600-2500 seedlings ha^{-1}), but they were not taken into account in the elaboration of technical guidelines and norms for afforestation in 1987 and 2000. In the same context, it is interesting to note that, almost 100 years ago, Professor Marin Drăcea recommended that Norway spruce to be planted, "in very good soils", at 1.75 x 1.75 m (3265 seedlings ha^{-1}) (Drăcea 1923).

If planting is done with higher initial densities, up to 4000-5000 (even 6000) seedlings ha^{-1} (the case of Romania: Anonymous 2000a; Hungary: Rédei pers.comm.; Bulgaria: Petkova pers.comm.; Poland: Klisz pers. comm.; Czech Republic: Podrázský pers.

comm.; Ukraine: Lavnyy pers.comm.), it is recommended to apply early (at the end of the thicket stage) and heavy cleaning-respacings, in order to produce trees with mean slenderness indices (SI) below 75-80, with large and symmetrical crowns, stable to the action of snow or wind (Petrescu et al. 1962, Petrescu et al. 1967, Petrescu and Haring 1977, Kramer 1980, Barbu 1982, Tisserand and Pardé 1982, Savill et al. 1983, Becquey and Riou-Nivert 1987, Scohy 1989, Szymański 2007).

Other important aspects for the management of Norway spruce stands for wood production are (i) the target diameter at rotation age, respectively (ii) the width of the growth (annual) rings, required by the users of Norway spruce logs or imposed by European or national standards / norms. Thus, the trend in some European countries (eg France, Germany, Italy, Poland, Hungary, Northern Macedonia) is to reduce the target diameter for the 'sawlogs' assortment to values not exceeding 50 cm (preferably 40 - 45 cm), for handling reasons in the logging areas, on the log discharge platforms or in the sawmills (Pain 1996, Bastien 1997, 2000, Buculei pers.comm., Mandzukovski pers.comm., La Porta pers.comm., Rédei pers.comm., Vor pers. comm.).

In this context, it is worth noting that, in a panorama of the European wood processing industry (Bary-Lenger et al. 1999), it was pointed out that logs (with a length of 2 - 4.5, even 5 m) used in industrial sawmills (which processed wood volumes of at least tens of thousands of m3 per year) must not exceed 30 cm in top diameter.

The recommendation that the target diameter of Norway spruce trees to be processed in lumber must not exceed 50 cm is in line with the target diameter of the species in naturally regenerated stands and managed with selection cuttings, where it reaches 45 - 50 (55, rarely 60) cm in countries like Switzerland (Borel 1929), France (Perrin 1954, Cochet 1971), Slovakia (Saniga 2007) etc.

The most sought after wood in Norway spruce logs for sawmilling is the one with radial increments of 3-4 mm year^{-1} (class A in the standards of France - Baylot and Vautherin 1991, Pain 1996, AFNOR 1999; Italy - Pollini 2006; Germany - Vor pers.comm.; Romania - Buculei pers.comm.), followed by the one with growth rings 5-6 (7) mm wide (class B). In this respect, it should be noted that the increase in the width of the softwood growth ring affects neither the initial density of early wood (consisting of thin-walled tracheids) nor the width of late wood (thick-walled tracheids), this increase being almost entirely concentrated on the width of early wood (Horodnic 1999).

Due to this phenomenon, the density of wood decreases, making it "lighter" (for example, from 435 kg m^{-3} in slow-growing trees / narrow rings to 403 kg m^{-3} in fast-growing trees / wide rings - Hébert et al. 2002), and compression wood is formed, with weaker physical-mechanical properties (Beldeanu 1999, 2008; Hébert et al 2002). In contrast, trees with more radial growth / wider rings have better dimensional stability, due to lower shrinkage (Dumitriu-Tătăranu et al. 1983, Hébert et al. 2002).

However, the fact that Norway spruce wood with wider growth rings is produced is not a problem for the production of lumber (boards, thick planks, beams, etc.), because it “generally does not require high mechanical strengths, so no high density” (Dumitriu-Tătăranu et al. 1983). According to the same renowned Romanian specialists, "... for softwood (for timber production - n.a.) a high proportion of late wood is not required and, therefore, the rapid growth of trees with wide rings is not a disadvantage". The same lower density wood is also considered most suitable for the production of chipboard ("... the density of the wood determines the density of the particle boards, and the higher the bending strength of the boards, the lighter the wood"), as well as for plywood and other laminates from veneer (“... the suitable wood is the one with ... wide growth rings for softwoods, ... with low density and shrinkage”) (Dumitriu-Tătăranu et al. 1983).

As the processing industry can use wood with various physical and mechanical properties, it was possible to produce forestry models / scenarios (from the establishment of stands to the rotation age) depending on the two qualities (A and B) targeted: to produce "wood with narrow rings”, of 3-4 mm, in logs of 50 - 55 cm in diameter, respectively “wood with wide rings”, of 5 - 6 mm, in logs of 40-45 cm (France: Pain 1996).

In this broad context, our paper aims to present the most important results of a research and demonstration (R & D) work, lasting over 10 years (started in 2009), on the silvicultural interventions in pure and young Norway spruce stands. A series of aspects specific to it have already been presented in several papers: Pătrăucean and Nicolescu 2011, Pătrăucean 2012, Faure et al. 2015. This experimental-demonstration work tries to harmonize the objective of stability to the action of snow / wind with the need to produce saw logs at rotation ages shorter than those imposed by the Romanian technical norms in use (from 100 years in IV production class to 120 years in class I - Anonymous 2000c). These rotation ages are longer than in some European countries, where they generally do not exceed 70 - 80 years (France: 50 - 80 (100) years - Bastien 1997, 2000; Great Britain: 49 - 75 years - Hart 1994; Belgium: 53 - 83 years - Perin 2016; Ireland: 45 - 60 years - Anonymous 2009; Lithuania: 81 years - Zeltiņš 2017; Estonia: 80 years - Läänelaid et al. 2016; Poland: 80 years - Klisz pers.comm.).

Material and Method

Fieldwork for performing demonstration research was carried out in the sub-compartment 112D (coordinates 45.535170 oN, 25.586204 oE), Working Circle III Postăvaru, from the Kronstadt (Brasov) Local Public Forest District. This sub-compartment has an area of 0.4 ha, and the main characteristics of the site are: mean altitude 840 m, mean slope 5g, site type 3333 Mountainous of mixtures, high fertility, deep Eutricambosol, with *Asperula-Dentaria*. The climate is boreal (Dfck), with a mean annual temperature of 6-7 ^{o}C and 750-800 mm mean annual rainfall.

The studied stand consists of a pure Norway spruce plantation established in 2001 with a scheme of 2 x 1 m (5,000 seedlings ha^{-1}), using 2-year-old seedlings produced in its own nursery located in the immediate vicinity of the sub-compartment 112D. In April 2009, when the plantation was 8 years old, after an access pruning was practiced on a maximum height of 2.5 m for all existing trees in the stand, 60 “potential” final crop trees (PFCT, 150 ha^{-1} individuals) were selected and painted, based on the vigour (thickest trees), quality (straight, grown vertically, with branches as thin and horizontal as possible, large and symmetrical crowns, without forks, cankers, wounds, etc.), and spacing (located at the most constant distances, generally 4 - 6 m) criteria. These treese were pruned up to 4 - 4.5 m in height.

Two plots (P1 and P2) of 300 m^2 (20 x 15 m) were then established in the stand, in which all the trees were numbered with white paint and their x - y coordinates were measured. In both plots other individuals were selected on the basis of the same criteria, in addition to the "potential" final crop trees previously chosen, so that their number was 9 (300 trees ha^{-1}), in P1, respectively 10 (333 trees ha^{-1}), in P2. These trees were subsequently pruned up to 4 - 4.5 m in height.

Subsequently, in the two plots, a cleaning-respacing work was applied in 2009 in two variants:

i. P1: *classic intervention*, specific to *stand silviculture*, through which individuals were extracted (forked trees, with wounds, from too dense areas, etc.), without paying any special attention to favouring the “potential” final crop trees. Following the intervention, the canopy cover was reduced relatively evenly, as far as possible, to the average level of 0.8.

ii. P2: *dynamic* intervention, characteristic for crop tree silviculture, in which cleaning-respacings were concentrated around the "potential" final crop trees, by extracting their most important competitors, in order to ensure a regime close to the state of ”free-growth” at the crown level. Following the intervention, the level of canopy cover decreased relatively unevenly, reaching the average level of 0.7, with a variation from 0.5 (in the areas around the "potential" final crop trees) to 0.9, in the areas without such valuable individuals.

In addition, in the stand surrounding the two plots a “classic” cleaning-respacing was carried out (maintaining a canopy cover after intervention of 0.8), only around a part of the 60 “potential” final crop trees intervening similar to P2, to allow them to evolve in conditions close to the state of "free-growth" (Figure 1).

In 2013, at the level of the entire stand, of the plots and of the “potential” final crop trees, the second intervention, this time of thinning, was applied, in a similar way to the intervention carried out in 2009 (Figure 2).

For the trees in the two plots, as well as for the 60 “potential” final crop trees, the following biometric parameters were measured:

- diameter at breast height (dbh) (in 04.2009, before and after cleaning-respacing; 05.2010; 06.2011; 05.2012; 07.2013, before and after cleaning-respacing; 09.2015; 04.2018 and 03.2020); a 30 cm Haglöf caliper with an accuracy of 1 mm was used.
- total height (h) (in 04.2009, after cleaning-respacing; 05.2010; 07.2013, after thinning; 04.2018 and 04.2020); in 2009, 2010 and 2013; a telescopic rod made in the USA, with a length of 15 m and an accuracy of 1 cm, was used. In 2018 and 2020 the Romanian hypsometer with pendulum (+ dendometer Suunto, for control), with an accuracy of 10 cm, were used.
- four crown radii (r1, r2, r3, and r4), arranged at an angle of 90 degrees to each other, on 04.2009 (after cleaning-respacing), 05.2010, 07.2013 (after thinning), 09.2015 and 04.2018, using a metal tape 5 m long, with an accuracy of 1 cm. In 2020 it was no longer possible to measure the crown radii, due to the full canopy closure.

Figure 1 Sub-compartment 112D in 2009 (age 8 years) after cleaning-respacing and artificial pruning, with ”potential” final crop trees selected and painted

Figure 2 Sub-compartment 112D in 2013 (age 12 years) after thinning, with ”potential” final crop trees selected and painted

During the office works, with the help of these field data, various biometric calculations were performed using Microsoft Excel: arithmetic mean diameter đ, quadratic mean diameter dg, basal area G, arithmetic mean height ħ, height corresponding to the quadratic mean diameter hg, mean slenderness index SI, mean crown diameter dmedcor. Using the same software, the correlations initial dbh 2009 - diameter increment 2009-2020 and dbh - dmedcor in several years were determined graphically.

Results

Applied silvicultural interventions

The cleaning-respacing works applied in 2009, starting from high stocking (trees ha^{-1}) and high densities (m^2 ha^{-1}), were predominantly mixed, but especially from below (intensity by number of trees IN higher than the one by basal area IG) and with very heavy or heavy intensities in both plots. However, the intensity of intervention was much higher in P2, where only 1400 trees ha^{-1}, respectively 9.85 m2 ha-1, remained after the intervention, compared to 2100 trees ha^{-1} and 14.24 m^2 ha^{-1} in P1 (Table 1).

Thinnings in 2013 showed the same character of mixed intervention, but with a lower from below character and lower intensities both by the number of trees and by the basal area, but being higher in P1. The residual stocking after thinning was reduced to 1167 trees ha^{-1} (P2) and 1566 trees ha^{-1} (P1), while the remaining density had levels above 20 m^2 ha^{-1} in both plots (Table 2).

The effects of silvicultural interventions carried out in 2009 and 2013 on some biometric and statistical parameters of plot trees and "potential" final crop trees

Between 2009 and 2020, the arithmetic mean diameter đ increased by significant values, ranging from 8.47 cm in P1 to 11.08 cm in the "potential" final crop trees, ie an increase, expressed in relative values, from 91.54% (P1) to 115.73% (PFCT), which means doubling the initial values from 2009 (Table 3).

The arithmetic mean diameter of the trees in P2 and those in the PFCT category approached or even exceeded the value of 20 cm. The share of trees that reached a diameter of 20

Table1 Main characteristics of cleaning-respacing carried out in plots 1 and 2 in 2009

Plot no.	Number of trees (N) per ha			I_N (%)	Basal area (G) per ha (m^2)			I_G (%)
	Initial	Extracted	Residual		Initial trees	Extracted trees	Residual trees	
1	2933	833	2100	**28.40**	17.84	3.60	14.24	**20.18**
2	3000	1600	1400	**53.33**	18.23	8.38	9.85	**45.97**

Table2 Main characteristics of thinning carried out in plots 1 and 2 in 2013

Plot no.	Number of trees (N) per ha			I_N (%)	Basal area (G) per ha (m^2)			I_G (%)
	Initial	Extracted	Residual		Initial trees	Extracted trees	Residual trees	
1	2033	467	1566	**22.97**	29.04	5.57	*23.47*	**19.18**
2	1400	233	**1167**	**16.64**	23.56	3.20	**20.36**	**13.58**

Table 3 Dynamics of arithmetic mean diameter (đ) of trees in plots 1 and 2 and of "potential" final crop trees

Plot no.	Mean arithmetic diameter in... (cm)						Range of dbh increment in individual trees (cm)	Proportion of trees with a minimum dbh of 10 cm in 2009, (%)	Proportion of trees with a minimum dbh of 20 cm in 2020, (%)
	09.04. 2009	04.07. 2013 Before	04.07. 2013 After	13.03. 2020	đ increment between 2009 and 2020 (cm)	đ increment between 2009 and 2020 (%)			
1	9.25	13.30	13.49	**17.72**	8.47	91.54	2.3-13.8	30.65	23.91
2	9.35	14.40	14.24	**19.70**	10.35	110.77	2.6-16.4	33.33	51.43
PFCT	9.57	14.67	14.67	**20.65**	11.08	115.73	7.2-14.2	35.00	62.71

Table 4 Dynamics of quadratic mean diameter (d_g) of trees in plots 1 and 2 and of ”potential” final crop trees

SP nr.	Quadratic mean diameter in... (cm)					
	09.04. 2009	04.07. 2013 Before	04.07. 2013 After	13.03. 2020	Increase of d_g between 2009 and 2020	
					(cm)	(%)
1	9.29	13.49	13.66	**18.04**	8.75	94.19
2	9.46	14.64	14.90	**20.21**	10.75	113.64
PFCT	9.67	14.80	14.80	**20.78**	11.11	114.89

cm in 2020 exceeded 50% in both cases (Table 3), and the thickest tree with the maximum increase in diameter between 2009 and 2020 is found in P2 (Figure 3).

The quadratic mean diameter dg shows a dynamic similar to đ, exceeding the value of 20 cm in P2 and PFCT, where it at least doubled in the period 2009-2020 (Table 4).

If one consider only the “potential” final crop trees in P1 and P2, we can also see here the influence of lower stocking and densities in P2 on the dynamics of the two mean diameters, which increased significantly more in this plot. In addition, the share of PFCT in P2 with increases in diameter of at least 10 cm between 2009 and 2020 is 80%, compared to only 33.33% in P1 (Table 5).

The coefficients of variation of tree diameters in the three situations considered have evolved differently: they increased in P1 and P2, to values around 20 ± 3%, while the diameters of the 60 PFCT tended to be uniform, their coefficient of variation decreasing from 14.89% in 2009 to 11.81% in 2020 (Table 6).

Figure 3 The thickest tree (no. 78 in plot 2, current d.b.h. 28.2 cm), with the maximum d.b.h. increment (16.4 cm) between 2009 and 2020

Between 2009 and 2020, the arithmetic mean height ħ increased by important but very similar values in absolute terms, ranging from 8.21 m in the 60 PFCT to 8.62 m in P1, ie an increase, expressed in relative terms, from 118.47% (PFCT) to 132.41% (P1), which means at least doubling the initial values from 2009 (Table 7).

The location of the stand in a favourable site, with a soil of high fertility, allowed the achievement of arithmetic mean heights of over 15 m in the three situations analyzed, which represents an average increase in height of about 80 cm / year at the age of 19 years. The increase of the height corresponding to the quadratic mean diameter hg shows a similar dynamics, with its increases, in absolute terms, of over 8 m, respectively of over 115% in relative terms (Table 8).

In the trees of the two plots, as well as in the

Table 5 Dynamics of arithmetic mean diameter (đ) and quadratic mean diameter (d_g) of ”potential” final crop trees in plots 1 and 2

Plot no.	Arithmetic mean diameter đ in ... (cm)				Quadratic mean diameter d_g in ... (cm)				Share of PFCT with diameter increments of minimum 10 cm between 2009 and 2020 (%)
	09.04. 2009	13.03. 2020	Increase of đ between 2009 and 2020		09.04. 2009	13.03. 2020	Increase of dg between 2009 and 2020		
			cm	%			cm	%	
1	10.24	20.31	10.07	98.26	10.26	20.34	10.08	98.26	33.33
2	10.46	22.96	12.50	**119.50**	10.52	23.15	12.63	**120.06**	**80.00**

Table 6 Coefficients of variation of tree diameters in plots 1 and 2 as well as ”potential” final crop trees between 2009 and 2020

Plot no.	Coeficients of variațion of diameters in ... (%)			
	09.04. 2009	04.07. 2013 Before	04.07. 2013 After	13.03. 2020
1	16.09	13.49	13.66	18.04
2	16.34	18.66	19.71	23.55
PFCT	14.89	13.58	13.58	11.81

Table7 Dynamics of arithmetic mean height (ħ) of trees in plots 1 and 2 and of ”potential” final crop trees

Plot no.	Arithmetic mean height (ħ) in... (m)					
	09.04. 2009	04.07. 2013 Before	04.07. 2013 After	13.03. 2020	Increase of ħ îbetween 2009 and 2020	
					m	%
1	6.51	10.74	10.88	15.13	8.62	132.41
2	6.72	10.21	10.23	15.25	8.53	126.93
PFCT	6.93	10.87	10.87	15.14	8.21	118.47

Table 8 Dynamics of height corresponding to the quadratic mean diameter (h_g) of trees in plots 1 and 2 and of ”potential” final crop trees

Plot no.	Height corresponding to the quadratic mean diameter (h_g) in... (m)					
	09.04. 2009	04.07.2013 Before	04.07.2013 After	13.03. 2020	Increase of h_g between 2009 and 2020	
					m	%
1	6.69	10.85	10.94	15.18	8.49	126.91
2	6.83	10.34	10.39	15.14	8.31	121.67
PFCT	7.01	10.95	10.95	15.09	8.08	115.26

60 PFCT, the values of the mean slenderness index SI were calculated, as a ratio between (a) the arithmetic mean height (ħ) and the arithmetic mean diameter (đ), respectively between (b) the height corresponding to the quadratic mean diameter (hg) and this mean diameter (dg). Both values (height and diameter) are expressed in cm (Tables 9a and 9b).

In case (a), starting from similar values in 2009, the mean SI increased in 2020 by one (1.39%) and five (6.94%) units, respectively, in the case of the 60 PFCT and in P2, keeping below the maximum level (80) which defines a stand resistant to the action of snow or wind. In P1, the mean SI increased by 15 units (21.42%) and reached level 85, exceeding the mentioned threshold. A similar situation was found in case (b): the initial mean SI was 72 in all three situations, increasing for P2 and the 60 PFCT trees between 2009 and 2020 by only one (1.39%) and three respectively (4.17%) units, keeping below the maximum level of 80. In the case of P1, the mean SI increased by 12 units (16.67%), and its value in 2020 exceeded the level of 80 by four units, the stand penetrating into a lower stability area.

The study of the correlation between the initial dbh in 2009 and its increase in the period 2009-2020 (Figure 4a-c) indicates two interesting aspects:

(1) It has correlation coefficients R between the two parameters of 0.29 (PFCT), 0.39 (P1) and 0.70 (P2), which indicate a weak correlation between the two parameters in P1 and in the case of PFCT, respectively a strong one in P2.

(2) The coefficients of variation of the increase in diameter in the individual trees from the three compared situations are high and close to 30% in P1 (29.79%) and in P2 (30.35%). In PFCT the value of this coefficient is much lower (increases in diameter are much more grouped around the mean), representing less than half of the values achieved in P1 and P2.

Another important biometric aspect, with implications on the growth and production of individual trees, is the correlation between the

Table 9 Dynamics of mean slenderness (stability) index [($S_I = \bar{h}/\bar{d}$, (a), and $S_I = h_g/d_g$, table (b)] in trees of plots 1 and 2 and in "potential" final crop trees

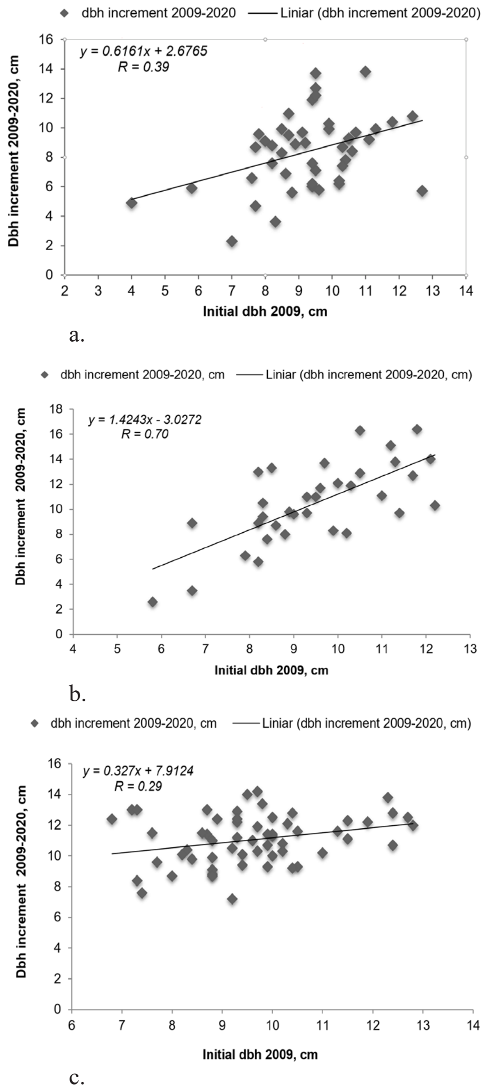
a.

Plot no.	Mean slenderness index (*SI*) in...					
	09.04 2009	04.07. 2013 Before	04.07. 2013 After	13.03 2020	Variation of *SI* between 2009 and 2020	
					Absolute values (+ sau -)	%
1	70	81	81	85	+ 15	+ 21.43
2	72	71	71	77	+ 5	+ 6.94
PFCT	72	74	74	73	+ 1	+ 1.39

b.

Plot no.	Mean slenderness index (*SI*) in...					
	09.04 2009	04.07. 2013 Before	04.07. 2013 After	13.03 2020	Variation of *SI* between 2009 and 2020	
					Absolute values (+ sau -)	%
1	72	80	80	84	+ 12	+ 16.67
2	72	71	70	75	+ 3	+ 4.17
PFCT	72	74	74	73	+ 1	+ 1.39

dbh and the mean crown diameter dmedcor. For this purpose, the data from the inventory carried out in 2018 were used, the last one in which it was possible to measure the four radii of the tree crowns (the canopy was completely closed later). The results indicate the close relationship between the two parameters, with values of correlation coefficients R of 0.62 (PFCT), 0.73 (P1) and 0.88 (P2) (Figure 5a-c). For trees with a dbh of 20 cm, the mean crown diameter ranges from 362 cm (P1) to 399 cm (P2), respectively 406 cm ("potential" final crop trees). The mean crown diameter of all trees measured in the three situations, regardless of their dbh, is 321 cm in P1 (range 200 - 450 cm, coefficient of variation of the mean crown diameter 106.04%) , 376 cm in P2 (from 190 to 490 cm, coefficient of variation 142.14%), respectively 394 cm for the "potential" final crop trees (range 285 - 465 cm, coefficient of variation 86.26%).



a. b. c.

Figure 4 Correlation between the initial d.b.h. (2009) and d.b.h. increment of trees in plots 1 (a) and 2 (b) as well as of "potential" final crop trees (c) between 2009 and 2020

The basal area of the trees in P1 and P2 has evolved from the values mentioned in tables 1 and 2 to very high ones, which exceed 35 m^2 ha^{-1} in both plots in the current year. Obviously, the increase of the basal area, in absolute and relative terms, in the most relevant interval (2013-2020), was more pronounced in P2, which showed the lowest stocking and density in 2013, after the application of thinning, and in which the individual trees made the largest increases in diameter (Table 10).

Discussions

The cleaning-respacing (2009) and thinning (2013) interventions, with a dominant mixed character and applied mainly with high intensities - heavy and very heavy - in the two plots and at stand level, led to low stocking, of maximum 2100 trees ha^{-1} (in 2009, at 8 years old), respectively about 1570 trees ha^{-1} (in 2013, at 12 years old). These stockings, characteristic of plantations in other European countries at the time of establishment, are much smaller than those recommended in our Norway spruce stands and which, in similar ecological conditions (sites of high fertility, with stands of production classes I and II) and plantations with the initial stocking of 6000 - 4000 seedlings ha^{-1}, it is recommended to have 2850 - 3350 trees ha^{-1} (at 10 years), respectively 2500 - 3000 trees ha^{-1} at 15 years (Vlad and Petrescu 1977, Anonymous 2000b).

The low stockings, remaining after the two interventions, favoured the increases in diameter of the individual trees in P1 and P2, which led to the consistent increase of the arithmetic mean diameter and the quadratic mean diameter. The latter is a parameter frequently used in Biometrics for auxological purposes to define the "mean tree of the stand", rather than the arithmetic mean diameter (Giurgiu 1979, Pardé and Bouchon 1988, West 2004).

As expected, the increase in the value of the two mean diameters was more important in P2, which presented the minimum values of the stand stocking and density after the interventions. This effect, of "accelerating the increase in diameter", is specific to early and high intensity interventions (cleaning-respacing and thinning), which leads to significant increases

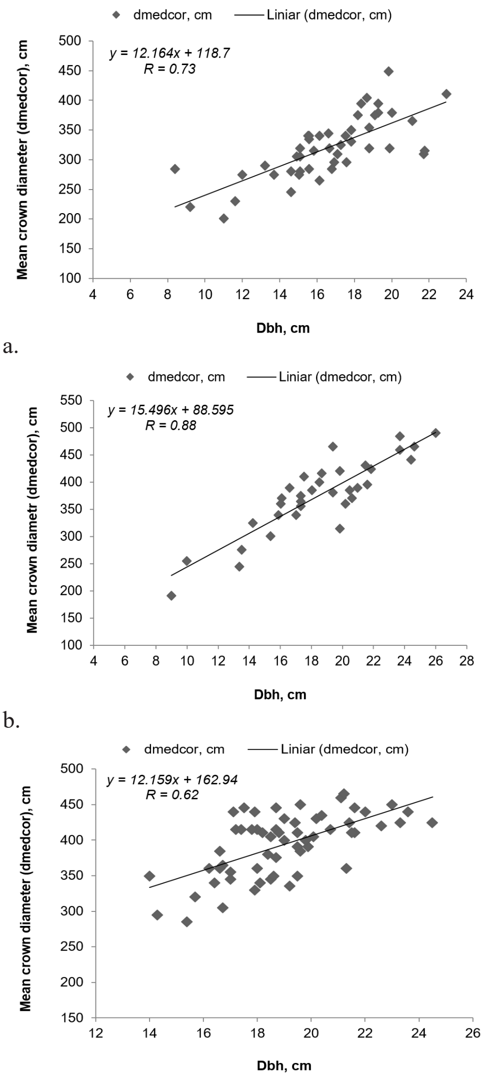


Figure 5 Correlation between d.b.h. and mean crown diameter of Norway spruce trees in plots 1 (a), 2 (b) as well as "potential" final crop trees (c) in 2018

in volume, but at the expense of the formation of wood with wide rings and lower densities (Vlad and Petrescu 1977, Giurgiu 1979, Krajnc et al. 2019). However, these interventions offer the advantage of forming trees with lower slenderness, with increased resistance to the harmful action of snow or wind (Haralamb 1967, Giurgiu 1979).

Table 10 Dynamics of basal area (G) in plots 1 and 2 between 2009 and 2020

Plot no.	Basal area (G) in ... (m^2 ha^{-1})									
	09.03. 2009 After	04.07. 2013 Before	04.07. 2013 After	13.03. 2020	Increase of G 2009-2013 Before		Increase of G 2013 After-2020		Overall G increase 2013-2020	
					m^2 ha^{-1}	%	m^2 ha^{-1}	%	m^2 ha^{-1}	%
1	14.24	29.04	23.47	**39.21**	14.80	103.93	15.74	67.06	30.54	170.99
2	9.85	23.56	20.36	**37.44**	13.71	139.19	17.08	83.89	30.79	223.08

A similar effect on growth had the intervention focusing around the "potential" final crop trees, which favoured the increase of crown size, with positive effects on the increase in diameter. In this way, both the trees in P2 and the "potential" final crop trees, spread relatively evenly throughout the stand, have grown in diameter around 1 cm $year^{-1}$, reaching dbh's of 20 cm and over at the age of 19 years.

Through the positive effects on dbh's, as well as on the crown dimensions (diameters), we consider that the early choice and favouring of the “potential” final crop trees, from the end of thicket phase, based on the criteria described in our paper, and as recommended in various European countries (Belgium: Wouters et al. 2000, Baar et al. 2004; France: Allegrini 2010), is an option to consider in our country as well. It is obvious that, for reasons related to the possibility of some of these trees to disappear before the rotation age (eg, injured during logging, killed by defoliating insects or bark beetles, injured by red deer, roe deer or brown bear, as happened on a small scale in the R & D stand), their number to be higher - up to twice - than the one targeted to exist in the stand at rotation age.

The early marking of these trees with obvious dots or rings of paint ensures their continuous pursuit by those who carry out the tree marking for thinning, favouring their protection during the harvesting works (felling and skidding).

If, in our country, the number of final crop trees recommended by the technical norms in force (Anonymous 2000b) is 400 - 600 ha-1, the one recommended in other European countries (Germany: Abetz 1993; Belgium: Wouters et al. 2000, Baar et al. 2004, Perin 2016; France: Bastien 2001, Allegrini 2010) in similar situations is 220 - 280 (300) trees $ha^{-1.}$ This stocking is considered an effective alternative for the management of pure Norway spruce stands, in the context of the obvious trend at European level to reduce their rotation age to a maximum of 70-80 years, to increase the stability of trees to the action of disturbing factors (snow, wind) and adaptation to climate change, which requires reduced competition for above- and belowground resources (Legay and Mortier 2006).

The studied trees, located in a site of high fertility for Norway spruce, also showed significant increases in height (either the arithmetic mean or that corresponding to the quadratic mean diameter), which is more influenced by the potential of the site than by silvicultural interventions, unlike the increase in diameter (Giurgiu 1979). The height, in the mentioned form, reached values of over 15 m, with a mean annual increment of about 80 cm. This value places the Norway spruce stand (in native range) in the production class I, where the hg at the age of 20 is 9.2 m (Giurgiu and Drăghiciu 2004). The height of 15 m also exceeds the value of hg in the production class I of Norway spruce stands located outside the native range, which is 12.2 m (Giurgiu and Drăghiciu 2004).

The interventions with higher intensities in P2, as well as on the PFCT, through which the increase in diameter exceeded the one in height, contributed to the increase of the mean slenderness index by 1-5 units, which keeps below 80 in both situations after 11 years from the beginning of R & D works. By comparison, the increase in slenderness in P1 was much more consistent (12 and 15 units, respectively), leading to values of 84 and 85 in the current year, so the stand here has a lower stability to snow / wind.

Research has also highlighted the correlation between the initial dbh (2009) of trees and dbh increment between 2009 and 2020, in the form of a regression line, as also found by Giurgiu (1967, 1979). The value of the correlation coefficient in P1, P2 and PFCT ranges between 0.29 and 0.70, compared to 0.4 - 0.9 in Giurgiu (1967, 1979).

The works carried out in the studied stand highlighted the close correlation between the dbh and the mean crown diameter of Norway spruce trees, these having large dbh's as an effect of large crowns, obtained by strongly opening the canopy after silvicultural interventions. The respective relationship, positive and linear, showed correlation coefficients between 0.62 and 0.88, values close to those mentioned in the literature (0.75 - 0.85; Giurgiu 1967, 1979). This fact has important implications both for the choice of final crop trees and for the management of young and middle-aged stands, in which it is recommended to perform heavy and predominantly from above interventions, with the same aim of reducing above- and belowground competition.

A last aspect worth mentioning is the strong increase of basal area in P1 and P2 at high values, of over 35 m^2 ha^{-1} at only 19 years old. According to the Romanian production tables in use (Giurgiu and Drăghiciu 2004), the basal area in a “pure and of normal density even-aged Norway spruce stand, managed with silvicultural interventions of moderate intensity”, aged 20, from the production class I, is 29.2 m^2 ha^{-1}. The difference in the additional basal area in P1 and P2, which leads to a density index of 1.34 (P1) and 1.28 (P2), respectively, requires the urgent application, during 2020, of a new thinning, even slightly delayed. By applying it, it is possible to reduce the density index to values close to the unit and bring the basal area closer to a maximum of 30 m^2 ha^{-1}, considered the *threshold value* (critical basal area), in countries such as Belgium (Hébert et al. 2002) and France (Bastien 2000), to prevent a significant reduction in the volume production of the stand.

Conclusions

Our paper wanted to offer a simple example of silviculture of artificial, pure and young, Norway spruce stands, different from the "traditional" and usually recommended in Romania. Through this, it has been demonstrated, on a small scale and in favourable site conditions, that, using silvicultural methods and solutions easily applied on a production scale, it is possible to amplify radial growths and produce wood assortments of Norway spruce for industrial use (eg, lumber, boards, even pulp) at ages younger than usual in our growing conditions. As Giurgiu pointed out since 1967, "It is known from now on that high-intensity thinning accelerates the growth process of the residual trees and thus contributes to reducing the absolute and technical rotation ages".

Based on these, we consider that the central authority responsible for Silviculture in Romania should pay much more attention to the issue of tending of our stands, especially young and middle-aged. Without taking into account the needs and requirements of the timber market, the economic aspects involved in forestry (for example, the cost of seedlings and of stand establishment and early tending operations, the constant increase in labour costs, given the dramatic decrease in its workforce for various silvicultural interventions), of the requirements and equipments specific to logging activities, a top-quality and long-term viable silviculture is not possible.

To these are added the needs of forests to adapt to potential climate changes, which involve a wide range of solutions, of which "management (of stands - n.a.) by selecting final crop trees and applying thinning around them" was recently recommended in our country too (Barbu et al. 2016).

The chance to move towards an adaptive and dynamic silviculture currently exists in Romania, in the context of the SIPOCA 395 Project, coordinated by the Ministry of Waters and Forests, and through which substantiation studies will be carried out for the elaboration of various specific simplified administrative procedures, respectively good practice guidelines (including for tending operations) and regulations for Silviculture. It is hoped that they will not only be copy-paste of current technical norms and regulations, but will bring relevant changes, necessary, even mandatory, in the issues of stand establishment and tending, silvicultural systems, tree marking and, above all, forest management.

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