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Growth Performance of 27-year-old Norway Spruce (*Picea abies*) at Four Plantations in Korea

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Abstract : This study was conducted to elucidate the mid-growth of Norway spruce at the age of 27 and select the superior provenances in Korea. Growth performance of twenty-four provenances from Germany and Rumania were investigated in four plantations. Significant differences were found in growth (height, DBH, volume) with plantations. Maximum growth were detected on plantation Chuncheon which located in most northern area, and minimum growth were detected on plantation Wanju located in most southern area. The rank of height in provenances has fluctuated, but superior/inferior groups have been almost fixed. 840-23, 840-10, 840-19 in Germany, G1-64-57, G1-64-54 in Rumania proved excellent provenances. Height in early stage positively correlated with that in late stage. The growth was positively correlated with latitude and altitude of plantations, but negatively correlated with temperature.

***Key words* :** *Norway spruce,* Picea abies, *positive/negative correlation, provenance test, volume growth*

Introduction

Norway spruce (*Picea abies* (L.) Karst.) is one of the economically most important species of northern Europe and distributes in the large natural ranges. This species occurs in the throughout Europe (excluding South-eastern Europe), from 43° to 69° in longitude, 5° to 60° in latitude (Fowler and Coles, 1979).

Because of wide distribution, lots of researches have been accomplished for a variety of topics - genetic variations, morphological/physiological variation, growth differences among provenances, and so forth (Lagercrantz and Ryman, 1990; Persson and Persson, 1992; Weisgerber, 1979). Since the Working Parties of Norway spruce had been organized in IUFRO, many provenance studies have been conducted (Balut, 1988; Fottland and Skroppa, 1989; Giertych, 1984). The oldest provenance experiment (IUFRO series, 1938~1939) includes 51 provenances planted on 27 plantations in 14 countries (Baldwin *et al.*, 1973; Dietrichson and Krutzsch, 1976).

The growth of trees mainly depends on differences of plantations and provenances rather than those of genetic characteristics, so the main purpose of provenance test is selecting superior provenances in plantation areas (Wright, 1976). Especially, when exotic species being introduced, the provenance test is prerequisite before intensive afforestation works (Zobel and Talbert, 1984).

In Korea, it is not certain when the first import of Norway spruce was with official record, but known as early 1900's by missionaries or Japanese botanists by small quantities (Yoon, 1959). From 1924 to 1992, this species has been imported from 124 provenances of 19 countries. A first scientific survey was performed by Hwang and Hyun (1979), with growth performances of 50 years' Norway spruce from Germany, Rumania and Sweden.

This study was conducted to elucidate the mid-growth of Norway spruce at the age of 27 and select the superior provenances in Korea. Growth performance of Norway spruce was carried out with four plantations from twenty-four provenances of Germany and Rumania.

Materials and Methods

The seeds were introduced from Germany and Rumania, and sowed at experimental garden by 20 g/m^2 in 1976 and 1977, respectively. Seedlings were transplanted to the fields in Department of Forest Genetic Resources, Korea Forest Research Institute and planted to each plantations in 1980.

Four plantations (Wanju, Chungwon, Jungson and Chuncheon) with 24 provenances from Germany and Rumania (Index 1) were established in a random block design with 3 blocks, each block with 5×5 individuals per provenances at a spacing of 1.8×1.8m (Figure 1,

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Index 1. Geographic information in provenances of Norway spruce from Germany and Rumania.

		Provenance region	Lat.(N)	Long.(E)	Alt.(m)
Germany	840-01	North-West German Plain	53° 00'	9° 00'	below 300
	840-02	West German mountain region	51° 00'	9° 06'	400~600
	840-04	Upper Harz below 600m	51° 42'	10° 30'	below 600
	840-06	South Harz	51° 36'	10° 38'	500~700
	840-07	Upper Sauerland	51° 05'	8° 28'	below 500
	840-08	Black forest with Barr. Upper Neckar and Klettgau	48° 11'	8° 20'	below 1,000
	840-10	Swabian/Franconian Forest, Middle Franconian keuper region	49° 00'	10° 00'	500~800
	840-11	Franconian Forest	50° 15'	11° 32'	below 600
	840-14	Fichtel gebirge mts, upper Palatinate forest and upper Palanate basin	49° 37'	12° 09'	below 800
	840-16	Bavarian forest	49° 00'	13° 00'	800~1,000
	840-19	South Bavarian, upper Swabia, Lake constance area, "vorallgauer Fichte"	48° 08'	11° 09'	500~600
	840-23	Rest of southern Germany	49° 25'	9° 40'	500~800
Rumania	G1-64-46	N. E. Carpathian Mts., Toplita	46° 55'	25° 25'	880
	G1-64-47	N. E. Carpathian Mts., Galu	47° 15'	25° 25'	650
	G1-64-48	N. E. Carpathian Mts., Borca	47° 06'	25° 48'	720
	G1-64-49	N. E. Carpathian Mts., Brosteni	47° 09'	25° 43'	940
	G1-64-50	N. E. Carpathian Mts., Cosna	47° 18'	25° 10'	1025
	G1-64-51	N. E. Carpathian Mts., Dorna Cindreni	47° 17'	25° 15'	975
	G1-64-52	N. E. Carpathian Mts., Frasin	47° 28'	25° 48'	750
	G1-64-53	N. E. Carpathian Mts., Moldovita	47° 35'	25° 34'	850
	G1-64-54	N. E. Carpathian Mts., Cimpeni	46° 20'	23° 05'	1370
	G1-64-55	N. E. Carpathian Mts., Brasov	45° 39'	25° 35'	1050
	G1-64-56	N. E. Carpathian Mts., Toplita	46° 51'	25° 20'	880
	G1-64-57	N. E. Carpathian Mts., Dorna Cindreni	47° 21'	25° 23'	900

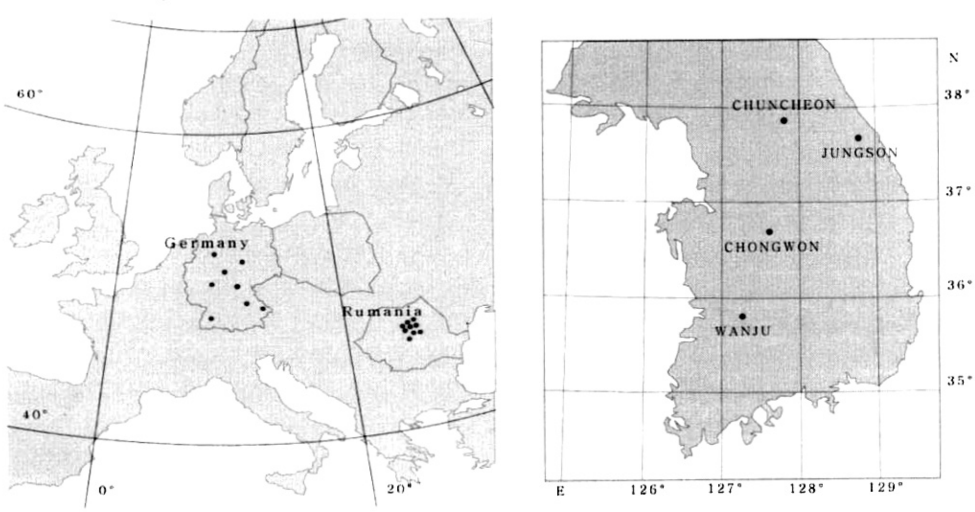

Figure 1. Provenances from Germany and Rumania (left), plantations in Korea (right).

Table 1). The plantations were established in order to study growth of Norway spruce to various sites (provenance test) and to select a superior provenances.

Main attention was paid to estimate evaluation of height, diameter and volume growth in provenances at the age of 27 years.

An ANOVA model was applied to investigate differences among plantations, provenances, blocks, and their interactions using SAS program (ver. 6.12; SAS Institute Inc., 1996). Duncan's multiple-range test was applied to rank provenances according to the height, diameter (DBH) and volume.

Pearson's correlation coefficient was used to assess correlations between growth parameters and geographic properties (latitude, longitude, altitude, and etc.) and between height growth by ages.

Table 1. Information on geographic and climatic properties of plantations.

Plantations	Slope (°)	Alt. (m)	Mean temp. (°C)	Mean precip.(mm)	Mean Rel. humi. (%)	Mean foggy days	Mean frost days
Wanju	35	290	13.1	1294	70.9	15	91
Chungwon	25	290	12.2	1239	36.6	37	106
Jungsun	15	490	13.0	1424	62.4	11	20
Chuncheon	35	500	10.9	1281	72.1	59	114

Han (1994) reported the growth performance in early stage with the same data of ours and we investigated and compared our results with his results.

Results and Discussions

1. Growth in plantations

Significant differences, and interactions between provenances and plantations were detected in the mean growth performance (Table 2). Maximum mean height, diameter, and volume were detected on plantation Chuncheon which located in most northern area. Minimum mean growth (height, diameter and volume) were detected on plantation Wanju (Table 3) which located in most southern area. Hwang and Hyun (1979) reported that the growth performance tended to be large with high latitude in 50 years' Norway spruce. On the contrary, in the study of same data at 15 years, the growth in Wanju was superior to other plantations (Han, 1994).

At early ages (4 to 7th year), the growth was mainly affected by environments of origin provenances such as latitude, longitude and altitude (Han, 1994), but this tendency have became weak with age increase. It might be thought the growth of Norway spruce was affected by conditions of plantations rather than those of provenances.

2. Growth and survival of provenances

The results of Duncan's multiple-range tests for height, diameter and volume growth across twenty-four provenances are presented in Tables 4 and 5. In the height growth, the provenances 840-10, 840-16 from Germany, and G1-64-57 from Rumania exceeded the mean value of all plantations by 5.8~9.4%. The height of the provenances G1-64-47, 55, and 48 from Rumania were inferior by 5.6~10.2% to mean height.

In the diameter (DBH) growth, G1-64-57, G1-64-54 from Rumania and 840-23 from Germany were superior by 6.8~8.2% to mean diameter. The diameter of the provenances G-64-47, 46, and 48 from Rumania were inferior by 4.9~11.1% to mean diameter. In the volume growth, 840-23, 840-19 and 840-10 from Germany were superior (Figure 2). Growth differences across plantations and provenances were detected in our result. Many researches reported the differences of growth across the plantations and provenances. Weisgerber (1979) reported that Carpathian mountains, North-east of Poland, and intervale of central Europe provenances were good provenances and Scandinavian, Alps, and Bulgarian provenances were poor ones in central European plantations. Rumanian provenances were mentioned among the best ones on the Danish plantations (Dietrichson, 1979).

At the age of 15 years (Han, 1994), growth of German

Table 2. Variance analysis of height, DBH and volume across 4 plots with 24 provenances.

Factor	D.F.	Mean Squares		
		Height	DBH	Volume
Provenances	23	22.55**	46.65**	0.012**
Plantations	3	1661.44**	954.2**	0.398**
Plantations×Provenances	69	33.24**	47.37**	0.014**

**All mean square values are significant at $p<0.01$.

Table 3. Mean height, diameter, and volume on 4 plantations with 24 provenances.

Plantations	Survival rate(%)	Height(m)	Diameter(cm)	Volume(m^3)*
Wanju	49.8	8.23 ± 0.05^{c}**	11.74 ± 0.14^{d}	0.050 ± 0.001^{d}
Chungwon	55.7	9.51 ± 0.13^{b}	12.36 ± 0.01^{c}	0.064 ± 0.004^{c}
Jungson	47.3	11.42 ± 0.25^{a}	13.14 ± 0.22^{b}	0.092 ± 0.004^{b}
Chuncheon	33.2	11.47 ± 0.12^{a}	14.40 ± 0.16^{a}	0.100 ± 0.003^{a}

*Values are volume per individuals.
**Different superscripts are significantly different at $p<0.05$(Duncan's multiple-range test)

Table 4. Duncan's multiple range test for mean height of the 24 provenances.

Provenances	N[a]	Duncan's grouping*	Mean height (m)
840-10	107		10.66
G1-64-57	107		10.42
840-16	110		10.31
840-19	121		10.24
G1-64-54	111		10.15
840-14	138		10.09
840-23	138		10.08
G1-64-50	86		9.99
840-02	155		9.92
840-07	132		9.83
840-04	129		9.79
840-08	154		9.74
G1-64-56	92		9.66
G1-64-53	118		9.65
G1-64-52	120		9.57
840-06	137		9.56
840-11	125		9.53
840-01	137		9.46
G1-64-51	113		9.31
G1-64-49	123		9.28
G1-64-46	87		9.22
G1-64-47	87		9.20
G1-64-55	114		9.18
G1-64-48	95		8.75

[a] : the number of individuals at each provenances
*$p<0.05$ significantly different

Table 5. Duncan's multiple range test for mean DBH of the 24 provenances.

Provenances	N[a]	Duncan's grouping*	Mean DBH (cm)
G1-64-57	107		13.73
G1-64-54	111		13.61
840-23	138		13.55
840-10	107		13.53
840-16	110		13.45
G1-64-56	92		13.41
840-19	121		13.28
840-14	138		13.25
G1-64-50	86		12.82
840-07	132		12.73
840-06	137		12.65
840-04	129		12.62
G1-64-55	114		12.41
840-02	155		12.41
840-08	154		12.38
G1-64-49	123		12.30
G1-64-53	118		12.30
G1-64-52	120		12.29
G1-64-51	113		12.27
840-11	125		12.16
840-01	137		12.14
G1-64-47	87		12.07
G1-64-46	87		11.79
G1-64-48	95		11.28

[a] : the number of individuals at each provenances
*$p<0.05$ significantly different

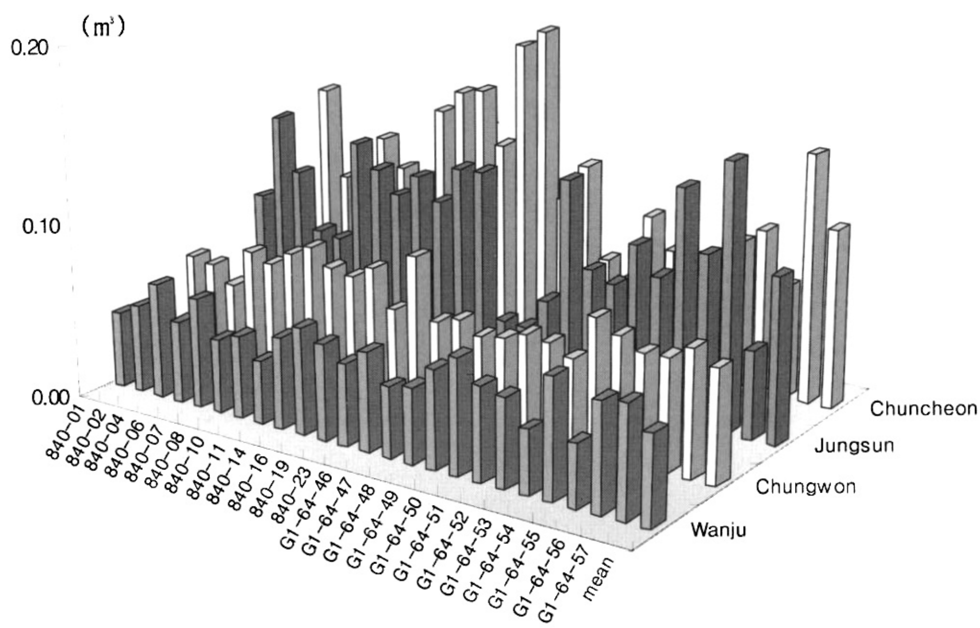

Figure 2. Volume per individual of Norway spruce in twenty four provenances.

provenances tended to be superior to that of Rumanian provenances. However, there were no significant differences in growth between each German and Rumanian provenances at present. Instead, differences of growth

Table 7. Correlations between height and diameter (DBH) by ages.

	4 yrs. height	7 yrs. height	12 yrs. height	15 yrs.		27 yrs.	
				height	dbh	height	dbh
1 yrs. height	-0.6198**	-0.4892*	0.0674	-0.0677	-0.4254*	-0.2549	-0.5922**
2 yrs. height	-0.1452	-0.0123	0.5364**	0.2609	-0.0695	0.0520	0.2019
3 yrs. height	-0.5805**	-0.4008*	0.1569	0.0866	-0.3407	-0.1868	-0.0758
4 yrs. height		0.9085**	0.4364*	0.4197*	0.6641**	0.6295**	0.4936*
7 yrs. height			0.6690**	0.6995**	0.7938**	0.6793**	0.5517**
12 yrs. height				0.7541**	0.4602*	0.5491**	0.5399**
15 yrs. height					0.7753**	0.5448**	0.5396**
15 yrs. dbh						0.6167**	0.5861**

*, ** : statistically significant at $p< 0.05$ and 0.01, respectively

resulted from each provenances and plantations. On the whole, the provenances 840-23, 840-10, 840-19 (Germany), G1-64-57 and G1-64-54 (Rumania) turned out to be superior provenances and G1-64-46, 47 and 48 (Rumania) be poor provenances in growth.

In the same plantations, growth was different by micro-topographic features such as ridge, valley, piedmont and so forth (block effects). Similar results were reported in *Pinus ponderosa* and *Pinus jeffrey* (Callaham and Liddicoet, 1961) and *Pinus radiata* (Falkenhagen, 1991). These results mean that it is important not only the selection of good provenances and plantations but also that of appropriate micro-environmental conditions for the target species.

Compared to other growth result of Norway spruce at the age of 26 years on the Slovak plantations (Pacalaj *et al.*, 2002), mean diameter was similar to our results (larger by 5%), but height was much larger than by 25%. We think that lower humidity compared to origin provenances, and insect plagues (i.e., aphids) might retard the height growth of Norway spruce.

The height ranks of provenances had been fluctuated in the 4th, 7th, 12th, 15th years' height growth (Han, 1994). This trend also continued in 27th years' height compared to 15th years' data. For example, rank of the provenance 840-08 has changed as 11th, 4th, 7th, 14th, and 11th respectively. But the superior/inferior provenances group rarely had changed at age from 15 to 27. It might be thought that the height growth tendency became fixed in late growth. Lim *et al.* (1976) reported the growth rank became to be fixed in the *Larix leptolepis* after 15~20 years.

Table 6. Correlations between growth and geographic factors of plantations.

	Latitude	Altitude	Temperature
Height	0.997**	0.943	-0.989**
DBH	0.912	0.881	-0.953*
Volume	0.987**	0.964**	-0.998**

*, ** : statistically significant at $p< 0.05$ and 0.01, respectively

3. Correlations

Correlations between growth and geographic/meteorological properties are presented in Table 6. Height and volume were positively correlated with latitude of plantations and volume were positively correlated with altitude of plantations. Mean temperature proved to be negatively correlated with growth. Because the latitudes of origin provenances are high (>45.6°N) and Norway spruce prefers cool and wet climate condition, growth was likely to be large in high latitude and cool plantation, that is Chuncheon. Some studies reported the growth of Norway spruce was positively correlated with latitude and altitude of origin provenances (Dietrichson and Krutzsch, 1976; Pacalaj *et al.*, 2002). In Rumanian provenances, the growth was large in high altitude and vice versa.

The height growth by ages was significantly positively correlated each other (Table 7). Gärtner (1976) reported there were highly positive correlations across height growth of Norway spruce in the age of 5, 9, 12, and 14 years each other. Other researches of different species also mentioned positive correlation of height growth between early and mid/late growth, and possibility for early selection (Han *et al.*, 1987; Konig, 1988; Lambeth, 1980; Ryu *et al.*, 2003).

In conclusion, It proved that Norway spruce growed well in area with high latitude and low temperature. The provenances 840-23, 840-10, 840-19 (Germany), G1-64-57 and G1-64-54 (Rumania) were superior provenances in volume growth. There was strong correlation in height among early stage and mid/late ages.

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