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Geographic Variation in Survival Rate and Height Growth of *Pinus densiflora* S. et Z. in Korea

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Abstract : This study was conducted to examine the geographic variation among provenances of *Pinus densiflora* in survival rate and height growth at four test plantations (Jungsun, Chungju, Naju, and Jeju). The plantations were parts of the eleven provenance trials of *Pinus densiflora* established by Korea Forest Research Institute in 1996. The survival rate and height growth were significantly different among test plantations at $p \leq 0.01$. Latitude and longitude of test plantation were negatively correlated with survival rate and height growth. On the other hand, annual mean temperature, mean temperature (Nov.~Feb.), extremely low temperature (Dec.~Feb.), and annual mean growing days of test plantation were positively correlated with these two. The relationships between growth variables and geographic variables were analysed with canonical correlation analysis. A considerable amount of variation in survival rate and height growth was explained by latitude, annual mean growing days, extremely low temperature (Dec.~Feb.) and extremely high temperature (Nov.~Feb.) of provenances. It is estimated that up to 47.1% and 67.4% of the genetic variability in survival rate and height growth was attributable to the environmental variability of the provenances, respectively. The response surface curve of survival rate and height growth was plotted against latitude and longitude to examine growth performance of provenances for each test site. Generally, the local provenances showed better survival rate and height growth.

Key words : Pinus densiflora, *provenance, geographic variation, climatic factor*

Introduction

P. densiflora is one of the most economically important timber species and the most widely distributed conifer species in Korea (Korea Forest Research Institute, 1999). Many studies have shown the genetic variation among *P. densiflora* populations and great potential for selection and breeding. For example, the species is variable in growth characteristics (Uyeki, 1928; Yim and Kim, 1975; Park and Lee, 1990), wood quality (Yim and Lee, 1979; Kim *et al.*, 2002) and molecular markers (Kim *et al.*, 1995; Lee *et al.*, 1997).

Known patterns of genetic variation among populations of forest trees are useful in gene resource management to provide guidelines for seed transfer in reforestation, to delineate breeding zones and for gene conservation programs (Rehfeldt, 1991). Therefore, provenance trials are important particularly at the initial stages of a tree improvement program, because they provide information about the genetic architecture of the species for maximizing gain for a given area (Andrew and Wright, 1976). A range wide provenance test for *P. densiflora* was established in 1996 by Korea Forest Research Institute (former, Forest Genetics Research Institute). However, the results of provenance experiment has not yet been reported.

There are two common approaches to quantify the distance of seed transfer and to determine the size of seed zone (Hamann *et al.*, 2000). One strategy attempts to minimize the risk of planting poorly adapted trees, which assumes that local sources are optimal and often imposes a linear relationship between provenance performance and geographic variables (Rehfeldt, 1991, 1995). The other strategy aims at maximizing productivity by selecting the best provenances for a defining planting environment, which relies on mathematical functions to model response of genotype to environment gradients (Raymond and Namkoong, 1990).

In this paper, we examined the geographic variation of *Pinus densiflora* provenances in survival rate and height growth to obtain basic information for gene resource management. To investigate the factors affecting growth performance of provenances, the relationship between

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growth performance and geographic variables was analysed.

Materials and Methods

From 1992 to 1993, the seeds were collected from an average of twenty trees at each of thirty six natural stands scattered throughout the species natural range. The sampling site was systematically selected to cover whole geographical range of *P. densiflora*, i.e., a point of intersection between latitudinal and longitudinal line was selected as a sampling site. The latitudinal and longitudinal range was 33° 30'~38° 08' and 126° 30'~129° 20', respectively. In both case, the interval was 30' (Hyun and Han, 1994). In addition, geographical races suggested by Uyeki (1928) was also considered to select sampling site.

Forest zone of Korea was divided into 4 categories, i.e., cool-temperate, mid-temperate, warm-temperate, and sub-tropical (Yim, 1985). The thirty six provenances were consisted of five from cool-temperate, twelve from mid-temperate, sixteen from warm-temperate, and three from sub-tropical zone. General description of provenances showed in Table 1.

The seeds were sown in a seed beds in March 1994 and one year later the seedlings were transplanted to nursery beds. The resulting 1-1 seedlings of thirty six geographic sources were planted at eleven test plantations in 1996. The planting site was selected to cover variable environmental conditions with similar manner of sampling site selection. Randomized complete block design with 5 replications were used for test plantations. Each provenance was planted with 10-tree row plot in each block and at a spacing of 1.8 m×1.8 m.

To examine the geographic variation of *Pinus densiflora*, we selected four test plantations (Jungsun, Chungju, Naju, and Jeju) among eleven provenance trials as a representative for each forest zone in Korea (Table 1). The location of four test plantations is ranged from 33° 10' to 37° 27' in latitude, from 126° 40' to 128° 42' in longitude, and from 100 m to 390 m in altitude.

To assess the performance of each provenance at test plantations, survival rate and height growth were measured and analysed. The data of survival rate and height growth were obtained from the measurement at age 3 and 6, respectively. All analyses were based on mean values per plot. Survival rate was analysed in terms of percentage with respect to the experimental unit. The value of survival rate and height were transformed using arcsine and logarithm, respectively, before analysis of variance to a normal distribution (Ræbild *et al.,* 2002).

Simple correlation analysis was conducted to examine the relationship between provenance performance and geographic and climatic factors of test plantations and provenances. Particularly, to examine the provenance effect on survival rate and height growth, correlation coefficient was calculated using original value of growth

Table 1. The location and forest zone of test plantations (above solid line) and provenances (below the solid line) of *Pinus densiflora.*

	Location			Forest zone
	Lat.(N)	Long.(W)	Alt.(m)	
Plantation				
Junsun	37° 27'	128° 42'	380	cool-temperate
Chungju	36° 53'	127° 57'	160	mid-temperate
Naju	35° 01'	126° 50'	100	warm-temperate
Jeju	33° 10'	126° 40'	390	sub-tropical
Provenance				
Inje	38° 08'	128° 12'	400	cool-temperate
Whachun	38° 03'	127° 49'	150	
Hongchun	37° 46'	128° 25'	700	
Jungsun	37.31	128.52	600	
Bongwha	37.01	128.50	500	
Yeonchun	38.01	127.04	100	mid-temperate
Heungsung	37.32	127.51	300	
Ichun	37.15	127.20	150	
Chunan	36.47	127.20	100	
Samchuk	37.15	129.17	100	
Uljin-seo	36.58	129.13	500	
Uljin-on	36.45	129.20	200	
Youngwol	37.18	128.19	300	
Joongwon	37.02	127.50	150	
Munkyung	36.47	128.18	400	
Boeun	36.31	127.50	250	
Jinan	35.45	127.20	300	
Andong	36.32	128.50	200	warm-temperate
Sunsan	36.16	128.20	150	
Taean	36.31	126.21	50	
Chungyang	36.30	126.50	200	
Wanju	35.55	127.15	150	
Youngil	36.15	129.21	250	
Kyungju	35.45	129.20	100	
Youngchun	36.02	128.50	200	
Koryung	35.45	128.20	150	
Milyang	35.30	128.51	150	
Haman	35.15	128.20	150	
Buan	35.42	126.36	100	
Hamyang	35.30	127.49	200	
Jungju	35.30	126.50	100	
Koksung	35.16	127.19	150	
Naju	35.01	126.50	50	
Hadong	35.01	127.52	50	sub-tropical
Haenam	34.31	126.31	150	
Seoguipo	33.20	126.30	1250	

variables and ecological distance. Ecological distance is the environmental changes caused by the displacement through transplanting, expressed as the difference in crucial ecological parameters between the test sites and locations of origin (Csaba, 1995). In this study, ecological distance was calculated as the value of climate variable for planting site minus that of provenance (Rehfeldt *et al.*, 1999). The fifteen climatic factors were obtained from mathematical formula for estimating climatic factors in Korea (Noh, 1988).

Canonical correlation analysis is a multivariate statistical method suitable for studying simultaneous relationships between two groups of self-correlated variables (Johnson and Wichern, 1998). The survival rate and height growth were treated as dependant variables and the ecological parameters were treated as independent variables. The canonical correlation analysis was conducted using SAS CANCORR procedure (SAS, 1990).

To visualize the pattern of geographic variation, the response surface curve of survival rate and height growth were plotted using non-parametric estimation procedure for scattered data. The analysis was conducted using TableCurve 3D program (SYSTAT, 2002).

Results and Discussion

1. Survival rate and height growth

Survival rate and height growth were significantly different among test sites at $p \leq 0.01$ (Figure 1). The highest value of survival rate and height growth was observed at Jeju plantation (92.4% and 282.3cm, respectively). The minimum value was found at Jungsun plantation (71.7% and 122.5 cm, respectively). There was an increasing tendency of survival rate and height growth along the forest zone i.e. from cool-temperate (Jungsun) to subtropical zone (Jeju).

To examine site effect affecting provenance performance, simple correlation analysis was conducted with geographic and climatic variables of test plantations and provenance performances. Among tested variables, some highly correlated variables were showed in Table 2. Latitude and longitude of test site were negatively correlated to survival rate and height growth. Annual mean temperature, mean temperature. (Nov.~Feb.), extremely low temperature. (Dec.~Feb.), and annual mean growing days were positively correlated. It was suggested that the latitude, temperature and growing season of test site were important factors affecting provenance performance.

Table 2. Simple correlations between geographic variables of test plantations and provenance performance (see the text for details).

	Survival rate	Height
Latitude	-0.85**	-0.97**
Longitude	-0.86**	-0.84**
Annual mean temperature	0.86**	0.82**
Mean temperature(Nov.~Feb.)	0.87**	0.89**
Extremely lowest temp.(Dec.~Feb.)	0.83**	0.87**
Mean humidity(March~May)	0.68**	0.79**
Annual mean growing days	0.86**	0.92**

**significant at α=0.01.

Generally, temperature increases with decreasing latitude and altitude. Decreasing latitude also results in a conspicuous increase in solar radiation. Both temperature and photoperiod are major importance for the regulation of phenological processes, and thus for the length of the active growth period (Persson and Beuker, 1997). Persson and Stahl (1993) reported that the manifestation of the properties on a site is controlled by temperature in Scots pine study. In *Pinus pinaster*, the difference of height and diameter among test site may be associated with climatic characteristics of the test sites relating to drought and temperature, as the variation in soil characteristics is minor (Alia *et al.*, 1995). Choi *et al.* (1999) reported that there was general tendency to decrease

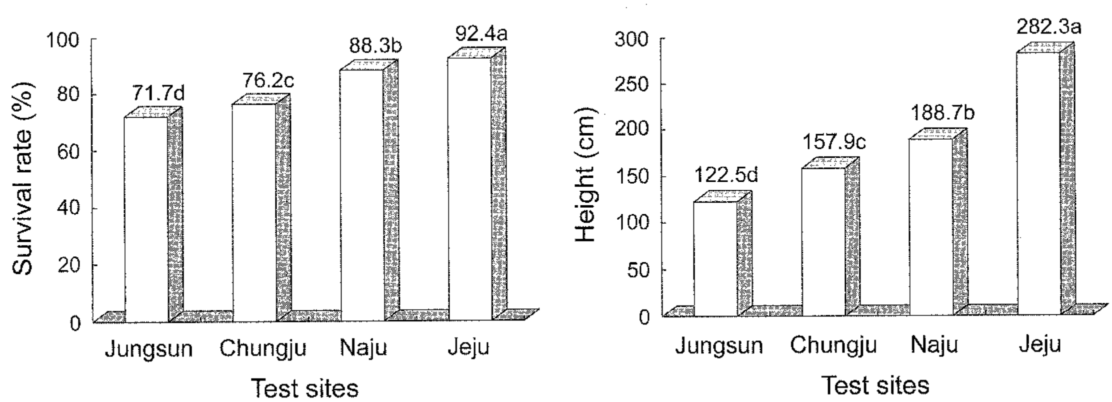

Figure 1. Survival rate and height growth at four test plantations. Different letters indicate significant differences at α=0.05.

Table 3. Survival rate and height growth of provenances at each plantation. Different letters indicate significant differences within plantation at α=0.05.

Plantations	Forest zone of provenances	Survival rate		Height growth	
		mean(%)	CV(%)	mean(cm)	CV(%)
Jungsun (cool-temp.)	cool-temperate	72.8 a	3.8	133.3 a	13.4
	mid-temperate	70.4 b	3.5	121.7 b	15.4
	warm-temperate	70.9 b	3.7	121.2 b	19.1
	sub-tropical	73.3 a	1.6	115.1 b	30.6
Chungju (mid-temp.)	cool-temperate	81.2 a	11.2	168.4 a	19.5
	mid-temperate	74.3 b	7.8	156.7 ab	16.6
	warm-temperate	76.0 ab	9.6	153.7 b	15.8
	sub-tropical	76.0 ab	10.5	168.6 a	14.4
Naju (warm-temp.)	cool-temperate	88.8 a	4.1	189.6 a	20.1
	mid-temperate	88.2 a	2.0	189.6 a	21.4
	warm-temperate	88.6 a	3.7	187.4 a	22.0
	sub-tropical	86.7 a	1.4	190.5 a	20.4
Jeju (sub-trop.)	cool-temperate	93.6 a	4.9	277.5 a	9.7
	mid-temperate	91.2 a	3.7	281.8 a	10.7
	warm-temperate	92.4 a	4.5	283.4 a	10.2
	sub-tropical	94.7 a	4.4	286.2 a	7.7

annual mean temperature, the extremely low temperature, annual mean precipitation and growing days with changing the location from sub-tropical to cool-temperate forest zone in Korea.

To help in interpreting the geographic variation in survival rate and height growth at test plantations, the provenances were also arranged into four forest zones (Table 3).

In Jungsun plantation, high survival rate was observed in the provenances originated from cool-temperate zone and sub-tropical zone (Table 3). The high survival rate of provenances from sub-tropical zone was unexpected, because if seed sources are moved too far to the north, trees suffer cold damage and may not perform as well as those from the original source (Wells and Wakeley, 1966; Wright, 1978). This result might be caused by Seogiupo provenance of sub-tropical zone. Although it was belong to sub-tropical zone, it was originated from 1,250 m at Mt. Halla and the temperature of the sampling site is similar to those of cool-temperate zone. According to the estimation by Noh's methods, annual mean temperature, mean temperature (Nov.~Feb.), and extremely low temperature (Dec.~Feb.) of the sampling site were 7.7°C, -2.0°C, and -19.2°C, respectively (Noh, 1988). For height growth, however, the provenances from sub-tropical zone was poor (Table 3). It was suggested that although the provenances from sub-tropical zone showed high survival rate due to the similar temperature condition, the height growth was affected from other climatic conditions of test site such as precipitation, humidity, photoperiod and annual mean growing days (Wright, 1978; Rehfeldt *et al.*, 1999).

In Chungju plantation, the provenances from cool-temperate zone showed high survival rate. The provenances from cool-temperate and sub-tropical zone showed relatively high height growth. In Naju and Jeju plantations, significant difference was not observed among forest zones of provenances. Ching and Hinz (1978) interpreted survival as a proxy variable for site quality, i.e., better quality sites have higher survival and better growth. Therefore, no difference in Naju and Jeju plantation might be caused by the relatively mild climatic conditions of the site.

On the whole, the height growth of the provenances from cool-temperate zone was high in Jungsun plantation, but low in Jeju plantation. The height growth of the provenances from sub-tropical zone was opposite. On the other hand, the provenances from mid-temperate and warm-temperate zone showed average growth performance in four test plantations.

The results of provenance trials have shown that if seed sources are moved slightly northwards, populations outperform local sources. However, if northern seed sources are moved too far south or vice versa, trees heightened sensitivity to disease or suffer cold damage and may not perform well (Wells and Wakeley, 1966; Wright, 1978; Savva *et al.*, 2002).

The CV (coefficient of variation) values were ranged from 1.4% to 11.2% in survival rate and from 7.7% to 22.0% in height growth. There was more variation in height growth than in survival rate. The high variation of

Table 4. Simple correlations between provenance performance and ecological distance of provenances to test plantations (see the text for details).

	Survival rate	Height
Latitude	-0.66**	-0.82**
Longitude	-0.58**	-0.59**
Altitude	-0.13ns	0.04ns
Distance from coastal line	-0.28*	-0.34**
Mean temp.(annual)	0.57**	0.56**
Extremely low temp.(annual)	0.57**	0.57**
Extremely high temp.(annual)	0.45**	0.40**
Mean temp.(Mar.~Oct.)	0.45**	0.38**
Extremely low temp.(Mar.~Oct.)	0.52**	0.47**
Extremely high temp.(Mar.~Oct.)	0.19*	0.07ns
Mean temp.(Nov.~Feb.)	0.58**	0.62**
Extremely low temp.(Nov.~Feb.)	0.58**	0.63**
Extremely high temp.(Nov.~Feb.)	0.59**	0.65**
Extremely high temp.(July~Aug.)	0.02ns	-0.15ns
Extremely low temp.(Dec.~Feb.)	0.59**	0.67**
Mean humidity(Mar.~Oct.)	0.23**	0.39**
Mean humidity(Mar.~May)	0.43**	0.58**
Mean humidity(June~Oct.)	0.11ns	0.28*
Annual mean growing days	0.65**	0.75**

*significant at α=0.05, **significant at α=0.01, n.s.; not significant.

survival rate and height growth was observed in Chungju and Naju plantation, respectively. Although the provenances were arranged into four forest zone for convenience of interpretation, it should be noted that these groups were not homogeneous enough to be termed races. Moreover, the performance of a provenance at a site was related to the performance at its site of origin, and not to the local provenance at the growing site (Persson and Beuker, 1997). Therefore, further study for selection of provenances with high adaptability and growth performance to a given site was needed.

2. Relationships between growth variables and geographic variables

To examine the geographic variables of provenances affecting survival rate and height growth, correlation analysis was conducted with original value of growth variables and ecological distance (Table 4). Survival rate was negatively correlated with latitude and longitude of provenance. The variables such as temperature, humidity, and annual mean growing days were positively correlated with survival rate. Particulary, winter temperature showed relatively high correlation coefficient. It means that provenance from higher latitude or longitude (i.e., lower temperature and shorter annual mean growing days) than that of plantation showed higher survival rate. A similar pattern was observed in height growth, because they had high correlation (r=0.788).

Table 5. Canonical correlations and explained canonical variance percentage of canonical variables between environmental variables of provenance and growth variables.

Pair of Canonical variables	Canonical Correlation (R^2)	Explained Variance(%)	P value*
1st	0.823	94.6	<0.0001
2nd	0.327	5.4	<0.0013

*Likelihood Ratio test with F approximation.

The canonical correlation analysis of the growth variables and geographic variables of provenances yielded two pairs of canonical variables. Two pairs of canonical variables were significantly correlated as shown by the likelihood ratio tests (Table 5). The first pair of canonical variables accounted for nearly 94.6% of the total canonical variation and had the maximal canonical correlation at R^2=0.823; and the second pair has canonical correlation at R^2=0.327 and accounted for an additional 5.4% of the total canonical variation. High correlations imply strong influence of environment of seed source on survival and height growth. The first pairs of canonical variables accounted for most of the total canonical variation. Thus, we focus the examination of the temporal mode of growth and site climate multivariate relationship on the first pairs of canonical variables.

Canonical structure for the environmental variables of seed source revealed that latitude had the strongest correlation with V1, and other variables such as extremely high temperature (Nov.~Feb.), extremely low temperature (Dec.~Feb.), and annual mean growing days also had high correlation with V1. The same mode of correlation of environmental variables with W1 also held (Table 6). The total variation of height growth and survival rate was explained by V1 at 67.4% and 47.1%, respectively. It was suggested that a considerable amount of variation of growth variables was explained by latitude, extremely high temperature (Nov.~Feb.), extremely low temperature (Dec.~Feb.) and annual mean growing days of seed sources.

The relationship between climate of the seed source and growth performance of test site was also discussed in other studies. In provenance experiment of Scots pine, the provenance variation of phenological and wood properties, as well as growth and yield, is predominantly determined by latitude of origin (Persson and Stahl, 1993). Rehfeldt *et al.* (1999) reported that five climatic variables (i.e. mean annual temperature, degree-days < 0°C, mean temperature in the coldest month, ratio of the mean annual temperature to mean annual precipitation, and the summer-winter temperature range) were partic-

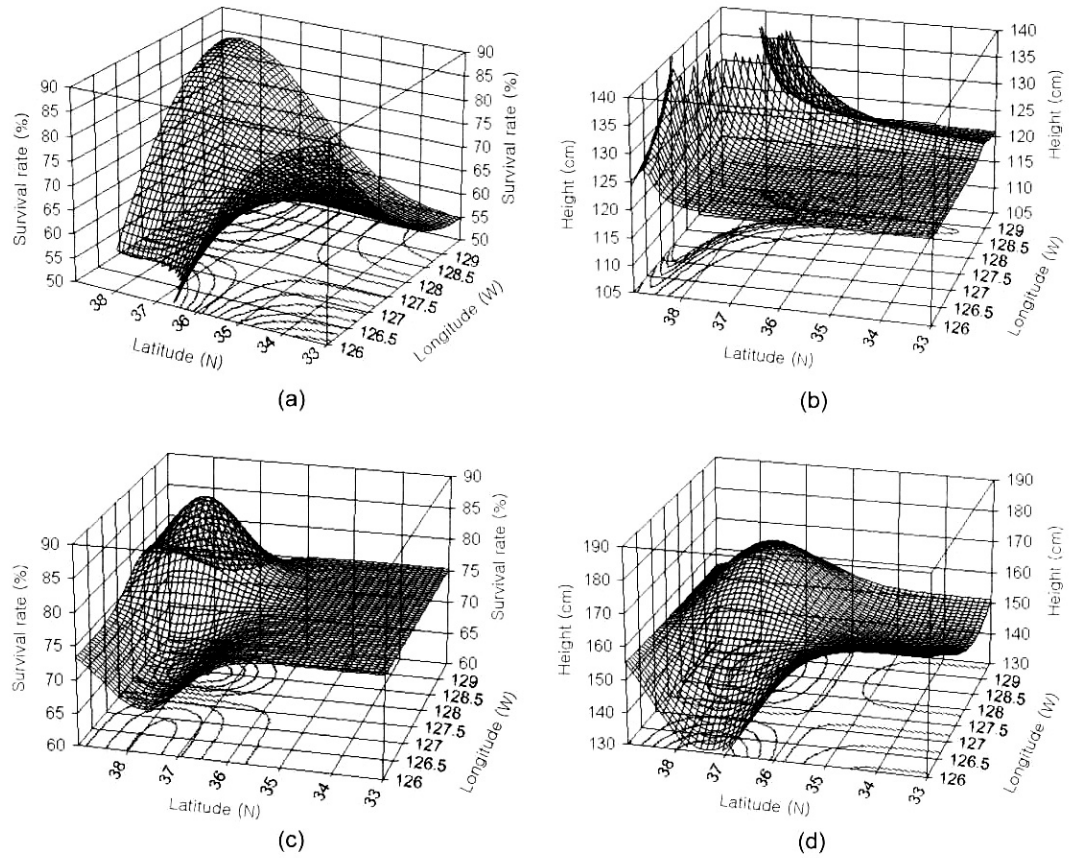

Figure 2. The response surface curve of survival rate and height growth at Jungsun (a, b) and Chungju (c, d) plantations.

ularly effective in predicting height and survival of *Larix* species. Climatic modeling of data from many southern pine seed source studies has shown that the most important factor influencing growth and survival within natural ranges is average yearly minimum temperature at the seed source (Schmidtling, 2001). Xu *et al.* (2000) also reported that winter coldness and length of growing season played an important role during the establishment phase of tree growth.

3. The pattern of geographic variation in survival rate and height growth

As shown in the above analysis, survival rate and height growth were mainly explained by latitudinal difference between plantation and provenance. For convenience of interpretation, the original values of survival rate and height growth of thirty six provenances were plotted against latitude and longitude. The diagrams for Jungsun and Chungju plantation were showed as an example in Figure 2.

In Jungsun plantation, the provenances from the range of 37°~38° in latitude and 128°~129° in longitude showed the higher survival rate and height growth. Although the provenances from the range of 33°~34° in latitude and 126°~127° in longitude were also high survival rate, it had a trivial effect on the interpretation of the result, because it was caused by Seoguipo provenance as mentioned above. Moreover, the provenances from the range of 33°~34° in latitude and 126°~127° in longitude showed the lower height growth. Poor survival rate was observed in the region of lat. 36°~38°/long. 126°~127° and lat. 33°~35°/long. 128°~129°. In Jungsun plantation, the high peak range of provenances in survival rate and height growth was belonged to the cool-temperate zone.

In Chungju plantation, the high peak range of provenances in survival rate and height growth was similar to that of Jungsun plantation. Poor survival and height growth was found in the range of 37°~38° in latitude and 126°~127° in longitude.

In Naju plantation, the high peak in survival rate was found at the range of 35°~36° in latitude and 128°~128° 50' in longitude, which was belonged to the warm-temperate zone. Provenances from other range showed the average survival rate. The high peak in height growth was found at the range of 37°~38° in latitude and 128°~129° in longitude, which was belonged to the cool-temperate and mid-temperate zone. Poor height growth was observed at the range of 33°~36° in latitude and 128°~129° in longitude.

Table 6. Canonical structure of the geographic variables of provenance and growth variables with the two pairs of canonical variables, represented by the correlation coefficients.

Original geographic variables	Geographic canonical variables of provenance		Growth canonical variables	
	V1	V2	W1	W2
Latitude	0.991	-0.087	0.816	-0.029
Longitude	0.735	0.442	0.605	0.145
Altitude	-0.028	0.849	-0.023	0.277
Distance from coastal line	0.413	-0.031	0.339	-0.010
Mean temp.(annual)	-0.701	-0.499	-0.577	-0.163
extremely low temp.(annual)	-0.709	-0.456	-0.584	-0.149
extremely high temp.(annual)	-0.509	-0.589	-0.419	-0.192
Mean temp.(Mar.~Oct.)	-0.481	-0.670	-0.396	-0.219
extremely low temp.(Mar.~Oct.)	-0.594	-0.618	-0.489	-0.202
extremely high temp.(Mar.~Oct.)	-0.106	-0.633	-0.087	-0.207
Mean temp.(Nov.~Feb.)	-0.769	-0.319	-0.633	-0.104
extremely low temp.(Nov.~Feb.)	-0.777	-0.231	-0.639	-0.076
extremely high temp.(Nov.~Feb.)	-0.804	-0.250	-0.662	-0.082
extremely high temp.(July~Aug.)	0.161	-0.747	0.132	-0.244
extremely low temp.(Dec.~Feb.)	-0.823	-0.123	-0.677	-0.040
Mean humidity(Mar.~Oct.)	-0.459	0.447	-0.378	0.146
Mean humidity(Mar.~May)	-0.694	0.273	-0.571	0.089
Mean humidity(June~Oct.)	-0.319	0.600	-0.263	0.196
Annual mean growing days	-0.919	-0.101	-0.756	-0.033
Total redundancy	40.7%	23.1%	27.5%	2.5%
Original growth variables	Growth canonical variables		Geographic canaonical vairables of provenance	
	W1	W2	V1	V2
Height	-0.997	0.077	-0.821	0.025
Survival rate	-0.833	-0.553	-0.686	-0.181
Total redundancy	84.4%	15.6%	57.2%	1.6%

In Jeju plantation, the geographical trend was not found in survival rate of provenances. However, the high survival rate was observed in the range of lat. 33°~34°/ long. 127°~128° and lat. 38°~38° 50'/long. 127°~128°. For height growth, the high peak was found at the range of 33°~35° in latitude and 126°~127° in longitude, which was belonged to the sub-tropical zone. Other provenances showed average growth performance.

There are many arguments on the "local is best" in provenance test (Wright, 1976; Ching and Hinz, 1978; Bresnan *et al.*, 1994; Hamann *et al.*, 2000; Sagta and Nautiyal, 2001). In this study, the local sources had generally better survival rate and height growth. Other researchers also reported that the local sources showed average or above average growth at all plantations (Jeffers and Jensen, 1980; Bresnan *et al.*, 1994). The survival rate and height growth of seed source were significantly correlated with climatic factors and this climatic effect was mainly explained by latitudinal differences (Table 4, 6). It was suggested that survival and height growth of *P. densiflora* were related to similarity of climate and length of growing season between seed origin and test site. Rehfeldt *et al.* (1999) suggested that optimizing the growth and survival rate was dependent on matching provenance and planting site climates for the general temperature regime, the coldness of the winters, the strength of continental effects, and the balance between temperatures and precipitation.

The seed transfer guidelines and outlining of the breeding zones based on climate and geographic variables have been proposed for various tree species(Westfall, 1992; Isik *et al.*, 2000; Schmidtling, 2001). They used several traits such as height, DBH, survival, phenology, branch pattern, stem straightness, wood quality and etc. for delineating seed zone. Therefore, further study was also required to delineate seed zone for *P. densiflora* with several traits above mentioned.

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