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Growth Decline and Abnormal Vertical Distribution of Fine Roots of Pitch Pine in Seoul Metropolitan Area

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首都圈地域에서 리기다소나무 生長 減少와 잔뿌리의 非正常 垂直分布

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ABSTRACT

The annual ring widths of tree and the vertical distribution of fine roots were investigated at 33 sites of pitch pine forests in Seoul, its vicinity and rural areas. The annual ring widths among 16 ~ 20 year-old pitch pines in urban areas were significantly lower than those in rural areas. The annual ring widths for the latest 5 years (1985~1989) for the age class of 11~20, 21~30 and 31~40 year old pines increased in the following order for all the age classes: urban areas< suburbs<rural areas. Amount of fine roots in urban areas were significantly lower than those in rural areas. Fine roots in urban areas were distributed more in litter layer compared with the vertical distribution of those in rural areas. Relative amount of fine root in litter layer decreased along distance from the center of Seoul. There was significant negative correlation between relative amount of fine root in litter layer and annual ring widths. Judging from these results, growth decline of pitch pine in urban areas was caused by growth reduction and abnormal vertical distribution of fine roots.

Key words: Abnormal vertical distribution of fine root, Annual ring, Growth decline, Pitch pine

INTRODUCTION

Damage of plants in polluted areas near industrial complex has been reported for a long time. In contrast, the growth decline of forests occurred at unpolluted areas was called "new forest decline", which had been first noticed at forests in West Germany in early

1980's (Nilsson and Duinker 1987). The symptoms of new forest decline reported for coniferous species are 1) foliage discoloration, 2) irregular foliage loss, 3) precocious foliage shedding, 4) decreased canopy density from foliage loss, 5) reduction in diameter or wood volume growth (Krause *et al.* 1986).

In metropolitan area of Seoul and its vicinity, it have been reported that the soil and atmosphere were heavily polluted by acidic precipitation, ozone, and sulfur dioxide or mixed for a long time (Ministry of Environment 1990). In addition, the discoloration of needle of *Pinus rigida* and shedding of these discoloration needle thereafter were observed in spring in 1989 (Kim 1990) ubiquitously. Also the chlorosis of needle tip, the poor crown density and the reduction in diameter growth of trees were frequently observed. Especially the fine roots of tree having poor crown were observed to distribute more in litter layer than those of tree having rich crown. But the large-scale forest decline observed in central Europe have been not reported in Korea so far.

The purpose of this study is to compare the growth of trees and vertical distribution of fine roots in pitch pine growing in metropolitan area of Seoul, its vicinity and rural areas.

STUDY AREA

The 33 sites of *Pinus rigida* forests were selected for survey during september 1990 to January 1991 in metropolitan area of Seoul, its vicinity and rural areas within 60 km radius from the center of Seoul (Fig. 1). Most of the selected sites were planted with pitch pine in early 1970s by an afforestation campaign. All the sites were thought to be relatively un disturbed for a long time, judging from the fact that saplings, shrubs or young trees of oaks were found in most sites. The sites located at azimuth of 110~290° were selected for study, but those facing north were not included in this study (Table 1). The slopes of study sites were relatively level in the range of 1~7 degrees. All the sites were located relatively at low altitudes of 30~340 m above sea level. The coverages of canopies at all study sites were over 80 % except site 6 (Mt. Achasan 2). Densities of trees within 1 hectare ranged 1,000~2,100 except site 7 (Samsung). Average heights of trees at each site ranged from 6 m to 17.5 m.

The reasons for selecting *Pinus rigida* as study material were as follows: 1) the discoloration of needle of *Pinus rigida* was observed ubiquitously, in Seoul and its vicinity in spring of 1989, but this symptom was not observed frequently for red pine forests, 2) *P. rigida* forests might be easy to compare spatially among sites, for the trees were simultaneously planted in extensive areas, 3) *P. rigida* forests were not affected by pests (e.g. pine gall fly for *Pinus densiflora*) so far, 4) *P. rigida* was reported as a weak species to air pollution (Shin 1991), 5) *P. rigida*, an introduced species, was thought to be sensitive to changes in domestic environment.

To make regional comparisons, we split all samples into 3 geographic regions; 1) urban Seoul which included all sites within a radius of 10 km from the center of Seoul, 2)

Table 1. Site number, distance from the center of Seoul, aspect, altitude, slope, density, height and average age of tree in pitch pine forests

Site number	Location	Distance from the center of Seoul	Aspect (°)	Altitude (m)	Slope (°)	Density of tree (No. /ha)	Height of tree (m)	Average tree age (year)
Urban Area (0~10 km)								
1	Mt. Namsan	2.2	150	220	5	1400	13.0	28
2	Mt. Inwangsan	2.8	170	100	5	1100	8.0	31
3	Mt. Ansan	3.2	80	220	3	1100	8.8	20
4	Jongam	5.2	80	180	2	1600	7.5	26
5	Huksuk	5.6	220	130	6	1300	8.0	24
6	Mt. Baekryensan	6.8	70	240	3	1400	13.5	30
7	Samsung	7.3	60	230	2	800	8.0	20
8	Mt. Achasan-1	9.5	250	160	4	1300	8.5	28
9	Mt. Achasan-2	9.9	230	250	2	1500	6.0	25
Suburban Area (10~20 km)								
10	Shindo	10.4	100	180	5	1400	8.0	28
11	Mt. Nogosan	10.6	150	130	5	1600	6.5	30
12	Hwajon	10.8	90	200	5	1300	7.0	22
13	Mt. Woomyensan	11.2	80	290	6	1200	8.0	18
14	Mt. Kwanaksan	13.2	90	140	2	1400	7.3	26
15	Mt. Daemosan	13.6	120	130	2	1200	9.0	19
16	Kaebong	14.4	100	280	6	1400	8.0	27
17	Mt. Suraksan	15.0	100	200	3	1400	10.0	35
18	Mt. Tobongsan	15.2	200	140	2	1300	10.0	36
19	Shinwhol	15.4	80	160	1	1400	7.5	19
Rural Area (20~60 km)								
20	Mt. Gobongsan	21.0	120	200	3	1700	11.0	20
21	Mt. Yongmasan	27.0	150	200	5	1800	9.5	20
22	Mt. Cheonmasan	27.6	200	110	5	1300	14.0	32
23	Mt. Jukyeopsan	28.6	180	120	3	1800	10.0	22
24	Paju	30.6	75	180	2	2100	9.0	18
25	Hwado	32.0	50	220	2	1300	11.0	26
26	Mt. Chilbosan	34.6	100	180	5	1200	8.0	22
37	Mt. Nogobong	35.0	340	110	3	1500	3.0	18
28	Mt. Taiwhasn	36.0	100	230	1	1400	12.0	18
29	Sagang	41.8	80	200	5	1800	17.5	30
30	Habongam	43.4	180	230	5	1600	9.0	19
31	Sangbongam	43.4	170	200	7	1600	10.0	17
32	Mt. Koryosan	52.0	80	180	4	1600	10.0	20
33	Kanghwa	53.2	30	140	1	1500	12.0	20

suburbs which included those within a radius between 10 km and 20 km from the center of Seoul, and 3) rural areas which included those within a radius between 20 km and 60 km from the center of Seoul (Fig 1).

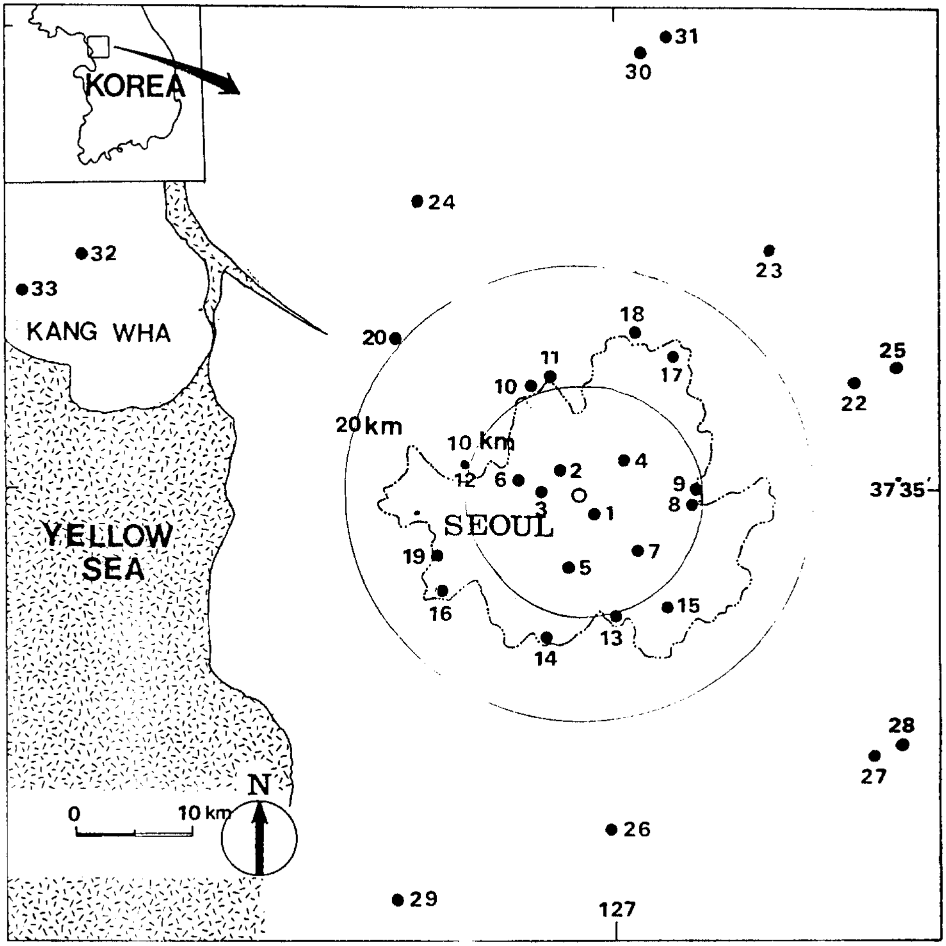

Fig. 1. Map showing 33 sampling sites in and near Seoul metropolitan area. See Table 1. for the name and number of each site.

METHODS

At 33 sites, tree cores were extracted from two sides of each stem with increment borer at 1.3 m (breast height) high aboveground in 100 m^2 quadrats. Fine roots (below 2 mm in diameter of root) were sampled at distance of 60 cm from each stem of 5 trees. All fine roots in litter layer were sampled with litter in 100 cm^2 quadrats with the pruning shear and those in soil layer were sampled at soil depth of 0~5 cm and 5~10 cm with soil core (4.5 cm in diameter and 5 cm in length), respectively. Litter depths were measured randomly over 10 times within quadrat.

Three representative sites, 1) Mt. Acha (site 9) in urban, 2) Mt. Kwanak (site 14) in suburban and 3) Paju (site 24) in rural areas among 33 sites were selected to investigate in detail the horizontal and vertical distribution of fine root of *P. rigida*. Fine roots in litter layer and in soil at depth of 0~5, 5~10, 15~20 and 25~30 cm depth were sampled at intervals of 20 cm as far as 140 cm from each stem by using the method described above. Three different trees were selected for fine root collection in each site during July~August 1991.

The annual ring widths were measured using a vernier caliper and a stereoscope. Fine roots were first separated from litter and soil by using a pair of pincers, then those separated were soaked in water for 24 hr, and finally washed completely by a running water. The washed fine roots were dried at 80℃ dry oven for 72 hr and then were weighed.

To make regional comparisons of annual ring widths for same ages of trees, annual ring widths of which physiological ages were 11~15, 16~20, 21~25 and 26~30 years old were used. Annual ring widths for the latest 5 years (1985~1989) were used to make reginal comparisons.

RESULTS

Comparison of annual ring widths in Seoul, its vicinity and rural areas

Annual ring widths between 11~15 years old in urban, suburban and rural areas were 1.91, 2.18 and 2.61 mm, those between 16~20 years old were 1.58, 1.63 and 2.33 mm, those between 21~25 years old were 1.39, 1.62 and 1.86 mm, and those between 26~30 years old were 1.07, 1.30 and 1.19 mm, respectively (Table 2). Growth of annual rings for all age stages in urban areas was significantly lower than those in rural areas. Annual ring widths between 16 and 20 years old and for latest 5 years (1985~1989) significantly increased along distance from the center of Seoul (Fig. 2). There were significant (positive) correlations between annual ring widths and the distance from the center of Seoul for all age stages. Annual ring widths for the latest 5 years (1985~1989) of each after classifying the age class of 11~20, 21~30 and 31~40 years old were in the following order for all age classes: urban<suburban<rural areas (Fig. 3). When annual ring widths in rural areas were expressed as 100%, those for age classes of 11~20, 21~30 and 31~40 years old were 77, 66 and 60% in urban area, and 90, 95 and 92% in suburban areas, reopectively, as compared with those in rural areas. Recent growths of annual rings for all age classes in urban areas were significantly lower than those in rural areas.

Horizontal and vertical distribution of fine roots

Fine roots in soil of 0~5 cm depth were horizontally uniformly distributed as far as 120 cm from each stem at Mt. Achasan (urban), Mt. Kwanaksan (suburban) and Paju (rural) (Table 3). Horizontal distributions of fine roots in soil of 5~10, 10~15 and 25~30 cm depth were the same as those of 0~5 cm depth for the 3 different areas. As fine roots enter deeply into the ground, fire root biomass greatly decrease. Total amount of fine roots from ground to 30 cm depth except for those in litter layer was calculated from the

Table 2. Average tree age, annual ring width along age classes and annual ring width for the latest 5 years (from 1985 to 1989) in pitch pine forests. Numerals in parentheses indicate standard deviations

Site number	Tree age Mean	Tree age Range	Annual ring width (mm) 11~15	16~20	21~25	26~30	1985~1989
Urban Area (0~10 km)							
1	27.6(2.6)	25~35	2.61(0.73)	1.78(0.67)	1.32(0.47)	1.12(0.43)	1.04(0.60)
2	31.0(3.1)	26~36	1.36(0.49)	1.17(0.55)	0.89(0.64)	0.67(0.31)	0.75(0.38)
3	19.8(3.4)	16~24	2.78(0.50)	3.28(0.35)	3.09(0.82)		3.47(1.09)
4	25.6(7.1)	15~33	1.52(0.38)	1.18(0.34)	0.64(0.31)	0.87(0.36)	1.33(1.04)
5	24.0(1.1)	22~26	2.15(0.68)	2.67(0.61)	2.17(0.74)	2.25(0.84)	2.45(0.45)
6	30.0(3.0)	23~34	2.10(0.64)	1.59(0.58)	1.48(0.52)	0.87(0.30)	0.90(0.46)
7	20.4(0.5)	20~21	1.98(0.19)	0.84(0.21)			0.85(0.22)
8	28.3(2.1)	25~32	1.36(0.39)	1.06(0.42)	0.63(0.33)	0.87(0.36)	0.88(0.26)
9	24.9(4.9)	20~34	1.34(0.41)	0.66(0.21)	0.86(0.38)	0.86(0.25)	0.72(0.25)
Mean	25.7(3.7)		1.91(0.52)	1.58(0.82)	1.39(0.80)	1.07(0.50)	1.38(0.90)
Suburban Area (10~20 km)							
10	27.8(6.0)	20~37	1.56(0.44)	1.36(0.57)	1.15(0.52)	1.21(0.34)	1.27(0.51)
11	30.1(4.4)	23~39	1.24(0.35)	1.08(0.31)	0.86(0.24)	0.70(0.31)	0.93(0.36)
12	21.7(4.8)	15~31	2.12(0.56)	2.01(1.11)	2.37(0.84)	1.85(0.68)	2.41(0.93)
13	18.4(2.6)	16~23	2.59(0.75)	1.73(0.81)	2.13(0.64)		2.39(0.86)
14	26.1(2.7)	22~31	3.11(0.82)	1.89(0.44)	1.74(0.54)	1.72(0.47)	1.78(0.36)
15	18.6(2.0)	15~24	2.96(0.76)	2.36(0.57)	2.02(0.34)		2.60(0.74)
16	27.3(11.1)	14~45	2.73(0.65)	2.07(1.23)	2.40(1.06)	1.34(0.56)	2.02(1.47)
17	35.3(3.7)	28~39	1.27(0.29)	1.16(0.48)	1.05(0.41)	1.17(0.34)	1.22(0.57)
18	36.2(1.8)	33~39	1.65(0.55)	0.96(0.30)	0.85(0.32)	0.72(0.33)	0.67(0.30)
19	18.7(4.7)	15~29	2.53(0.79)	1.65(0.45)	1.64(0.57)	1.69(0.36)	1.59(1.04)
Mean	26.0(6.3)		2.18(0.67)	1.63(0.45)	1.62(0.58)	1.30(0.41)	1.69(0.63)
Rural Area (10~60 km)							
20	20.1(2.2)	16~25	2.17(0.65)	2.03(0.43)	2.04(0.48)		2.33(0.52)
21	19.6(1.6)	17~23	2.51(0.44)	2.34(0.35)	2.29(0.35)		2.40(0.45)
22	32.0(2.9)	27~38	2.38(0.58)	1.79(0.64)	1.23(0.32)	0.74(0.22)	0.81(0.53)
23	22.0(6.5)	15~37	4.88(1.70)	3.67(1.55)	2.04(0.25)	1.26(0.35)	5.56(1.58)
24	18.2(1.3)	16~20	3.19(0.93)	3.45(1.10)			3.45(1.10)
25	26.3(3.4)	19~31	2.33(0.65)	1.84(0.48)	1.74(0.54)	1.85(0.84)	1.65(0.77)
26	22.1(4.7)	16~26	1.73(0.57)	1.75(0.47)	1.51(0.62)		1.54(0.50)
27	17.8(1.8)	15~20	2.14(0.62)	2.04(0.56)			2.17(0.64)
28	18.1(6.4)	15~35	2.48(0.76)	2.22(0.45)	1.43(0.00)	1.35(0.00)	2.45(1.18)
29	29.8(5.7)	21~38	1.62(0.11)	1.41(0.48)	0.91(0.24)	0.73(0.35)	1.18(0.50)
30	19.4(1.8)	17~23	2.16(0.64)	1.84(0.50)	1.92(0.62)		2.02(0.70)
31	16.5(1.1)	15~18	3.23(1.00)	2.40(0.77)			2.93(1.13)
32	20.2(3.4)	16~27	2.56(0.40)	2.43(0.37)	2.85(0.67)		2.72(0.56)
33	19.8(2.5)	16~24	3.16(0.72)	3.45(0.99)	2.54(0.86)		3.39(0.68)
Mean	21.6(4.5)		2.61(0.79)	2.33(0.68)	1.86(0.55)	1.19(0.42)	2.47(1.13)

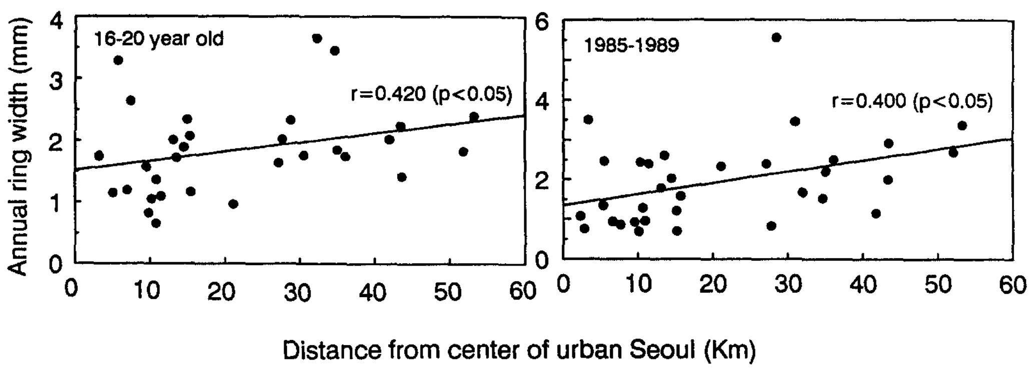

Fig. 2. Changes of average width of annual rings between 16 and 20 years old of pitch pine (left) and for the latest 5 years from 1985 to 1989 (right) along distance from the center of Seoul.

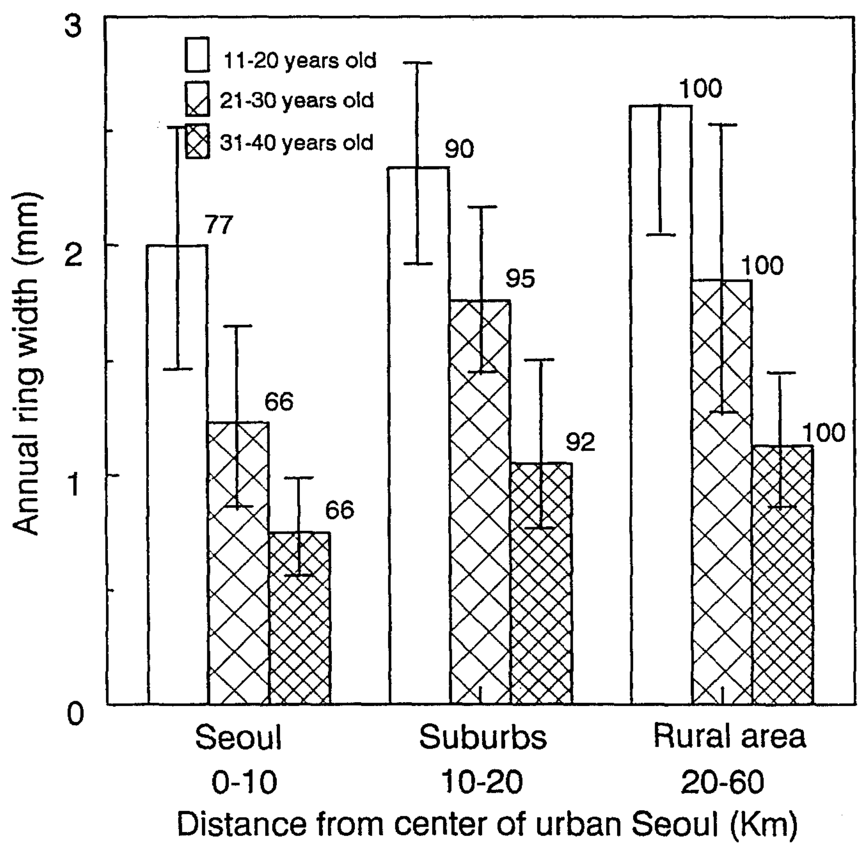

Fig. 3. Comparisons of average annual ring widths of pitch pine grown for the latest 5 years from 1985 to 1989 in trees with different ages, 11~20 year-old, 21~30 year-old and 31~40 year-old, along distances from the center of Seoul.

Table 3. Amount of fine roots of pitch pine distributed vertically and horizontally at Mt. Acha, Mt. Kwanak and Paju, Kyounggi-do. Numearals in parentheses indicate standard deviations

Depth of soil (cm)	Dry mass of fine roots (kg/ha) Distance from stem (cm) 0	10	20	30	40	50	70	90	120	Mean (kg/ha)
	Mt. Acha (Urban area)									
Litter	381.0	866.7	887.3	693.7	423.3	281.3	244.0	281.3	157.7	468.5
layer	(212.2)	(235.7)	(613.1)	(308.3)	(296.8)	(102.3)	(161.7)	(171.3)	(73.2)	(279.5)
0~5	930.3	790.9	964.5	646.2	337.6	445.6	626.9	586.4	333.7	628.9
	(485.6)	(344.1)	(730.8)	(461.4)	(118.8)	(308.9)	(429.6)	(420.7)	(258.2)	(233.9)
5~10	216.0	418.6	565.2	339.7	354.9	272.0	653.2	251.4	381.9	383.7
	(68.4)	(122.3)	(328.4)	(249.1)	(215.7)	(79.5)	(326.0)	(69.6)	(138.0)	(144.8)
10~15	194.8	299.0	272.0	436.0	412.8	201.5	135.0	148.5	283.6	264.8
	(56.4)	(9.8)	(125.3)	(201.2)	(75.4)	(90.4)	(61.7)	(52.7)	(78.1)	(107.2)
25~30	115.0	120.7	209.9	223.4	190.7	53.1	82.4	123.0	148.6	140.8
	(11.1)	(28.4)	(175.0)	(121.5)	(51.4)	(52.9)	(44.9)	(46.8)	(72.4)	(57.7)
	Mt. Kwanak (Suburban area)									
Litter	114.0	356.0	228.0	393.9	253.3	217.0	609.7	259.0	265.3	299.6
layer	(89.6)	(187.2)	(91.0)	(66.3)	(151.7)	(185.9)	(464.5)	(151.0)	(133.0)	(141.2)
0~5	294.6	758.1	973.0	567.1	812.1	1072.1	561.9	1062.9	994.9	788.5
	(312.3)	(363.6)	(350.9)	(367.0)	(448.0)	(59.5)	(411.8)	(617.2)	(719.7)	(268.8)
5~10	195.7	358.8	368.4	314.4	408.3	449.5	513.1	160.7	405.1	352.7
	(69.0)	(183.1)	(242.1)	(122.5)	(205.2)	(271.5)	(97.1)	(203.7)	(196.5)	(114.1)
10~15	113.7	158.8	132.1	237.3	142.7	175.5	210.9	247.1	372.3	198.9
	(163.3)	(32.7)	(76.9)	(118.1)	(48.3)	(131.3)	(94.8)	(113.7)	(123.3)	(79.9)
25~30	196.8	46.3	77.5	207.3	139.0	233.4	65.8	196.8	106.1	141.0
	(59.0)	(40.9)	(39.3)	(115.8)	(16.8)	(19.7)	(58.9)	(82.0)	(57.2)	(69.9)
	Paju, Kyounggi-do (Rural area; control)									
Litter	17.0	65.5	45.7	18.7	59.3	8.3	15.3	104.3	83.0	46.3
layer	(19.9)	(77.0)	(48.6)	(5.3)	(40.9)	(5.9)	(10.8)	(96.1)	(93.5)	(34.0)
0~5	524.7	914.3	718.6	432.5	450.7	787.0	307.9	448.1	758.1	593.5
	(314.9)	(439.6)	(271.0)	(244.4)	(135.1)	(146.5)	(394.9)	(278.4)	(156.6)	(265.2)
5~10	345.3	546.3	564.5	480.3	640.4	561.3	742.7	611.5	509.3	555.7
	(238.6)	(335.0)	(466.8)	(223.6)	(253.8)	(301.6)	(283.8)	(385.2)	(176.7)	(110.4)
10~15	314.2	343.4	534.3	351.1	212.2	164.0	233.4	310.6	270.1	303.7
	(159.0)	(311.7)	(358.4)	(275.1)	(148.3)	(122.5)	(265.7)	(262.3)	(112.7)	(106.7)
25~30	191.6	165.9	30.9	100.3	40.5	88.7	92.6	98.4	65.6	97.2
	(104.4)	(206.0)	(13.6)	(76.4)	(45.6)	(68.9)	(66.2)	(36.9)	(33.5)	(52.8)

equations below:

$$V = e^{(-D \cdot 206.1+886.4)} \ (r^2=0.993)$$

$$V = e^{(-D \cdot 278.9+981.8)} \ (r^2=0.916)$$

$$V = -D \cdot 20.7+646.7(r^2=0.928)$$

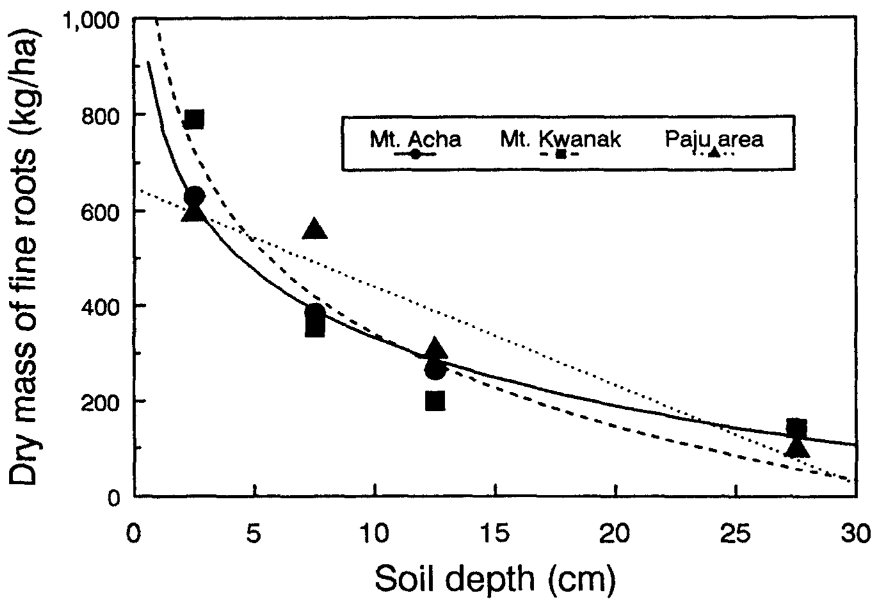

Fig. 4. Vertical distribution of fine roots of pitch pine at Mt. Acha, Mt. Kwanak and Paju, Kyounggi-do.

V: Amount of fine roots at D cm depth in soil (kg /ha),

D: Soil depth(cm)

Total amount of fine roots from ground to 30 cm below ground were 1,825, 1,721 and 1,757 kg /ha at Mt. Acha (urban area), Mt. Kwanak (suburban area) and Paju (rural area). The proportion of the amount of fine roots in 10 cm depth to those in 30 cm depth were 55.4% at Mt. Acha, 66.3% at Mt. Kwanak and 65.3% at Paju, respectively.

These results indicated that horizontal distributions were the same for all the 3 areas, but amount of fine roots in litter layer differed among the areas. The amount of fine roots in litter in urban Seoul were higher than that in Paju.

Comparison of amount of fine roots among different areas

Average amount of fine roots in litter layer, soil of 0~5 cm depth and soil of 5~10 cm depth were 201, 292 and 128 kg /ha in urban areas, 220, 593 and 160 kg /ha in suburbsan areas, and 83, 644 and 291 kg /ha in rural araes, respectively (Fig. 5). Total amount of fine roots in the litter layer and in soils 0~10cm depth were 621 kg /ha in urban areas, 973 kg /ha in suburbs and 1,018 kg /ha in rural araes, respectively. Total amount of fine roots in urban areas were lower than those in suburban or rural areas.

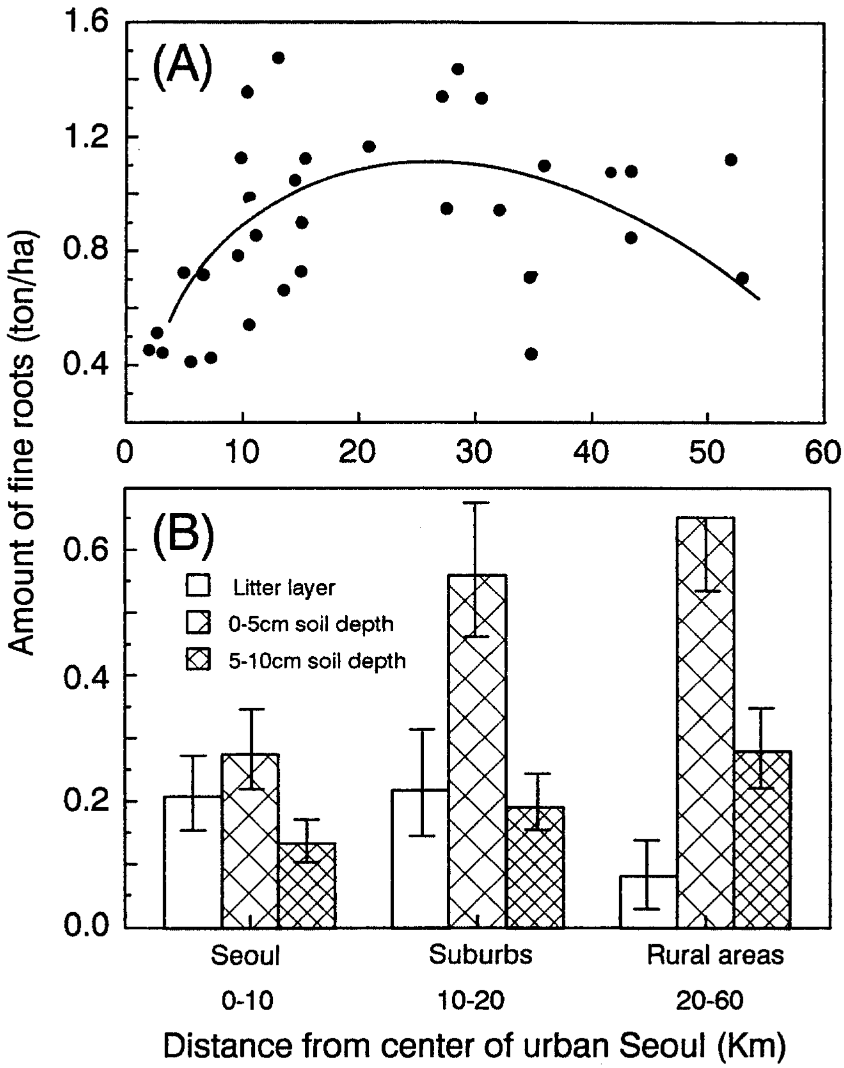

Fig. 5. Changes of total amount of fine roots of pitch pine along distance from the center of Seoul (A) and regional comparison of them grown in litter layer, top soil and subsoil (B).

Comparison of vertical distribution of fine roots among different areas

As total amount of fine roots existing between litter layer and soil of 0~10cm depth were expressed as 100%, the proportion of fine roots in litter layer, soil of 0~5 cm depth and soil of 5~10 cm depth was given in Fig. 6. Relative amount of fine root in litter layer decreased along distance from the center of Seoul with statistically significant correlation (Fig. 3). In contrast, relative amount of fine roots in soil of 5~10 cm depth increased along distance from the center of Seoul. The proportion of fine roots in litter layer, soil of

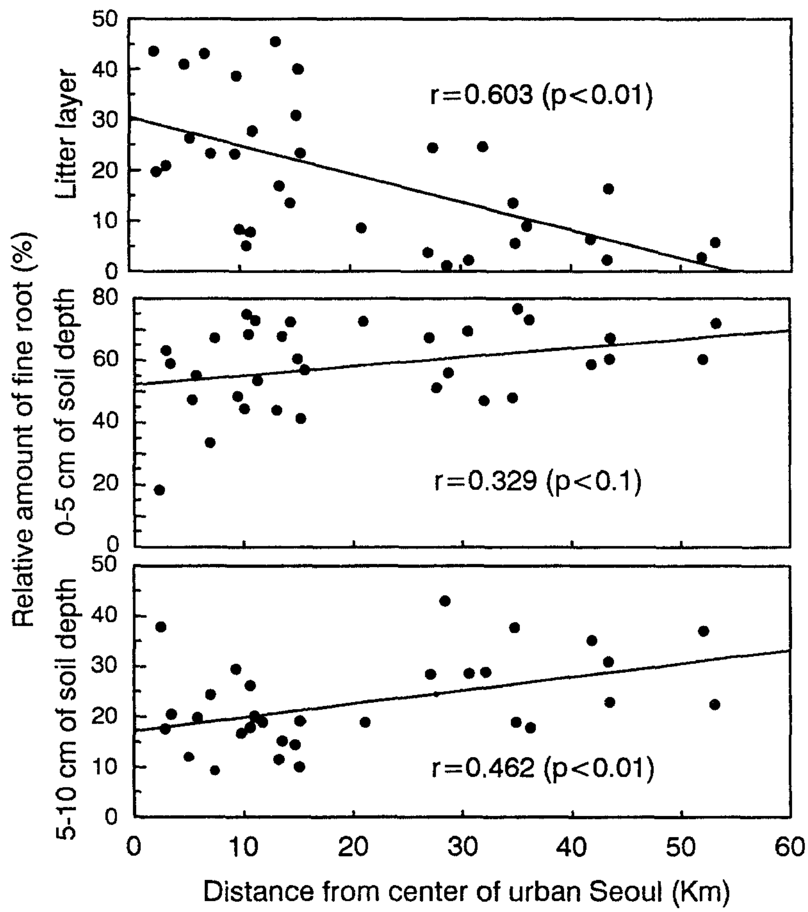

Fig. 6. Changes of relative amount of fine roots of pitch pine grown in litter layer, top soil (0~5 cm depth) and subsoil (5~10 depth) along distance from the center of Seoul.

0~5 cm depth and soil of 5~10 cm depth was 30.9, 48.3, 20.8 % in urban, 21.7, 61.2, 17.1% in subruban, and 9.0, 62.8 and 28.2 % in rural areas, respectively. Fine roots in urban areas were distributed relatively more in litter layer than in soil layer compared with vertical distribution of fine roots in rural areas.

Relationship between amount of fine roots in litter and litter depth

Amount of fine roots in litter layer increased as litter depth increased in all areas. In urban Seoul, there was statistically significant positive correlation between the amount of fine roots in litter layer and the litter depths, and in suburbs, there was a positive correlation between the former and the latter although it was not statistically significant (Table 4). In rural areas, the correlation between the former and the latter was weak. This result indicates that fine roots in urban Seoul must penetrate into litter layer, but not always in rural areas.

Table 4. Correlation coefficient between litter depth and dry mass of fine roots in litter layer along the distance from the center of Seoul

Area	Distance from the center of Seoul(km)	Correlation coefficients Litter depth - Dry mass of root
Urban area	0 ~ 10	+ 0.68*
Suburban area	10 ~ 20	+ 0.54 (n.s.)
Rural area	20 ~ 60	+ 0.21 (n.s.)

* : p > 0.05
n.s : not significant

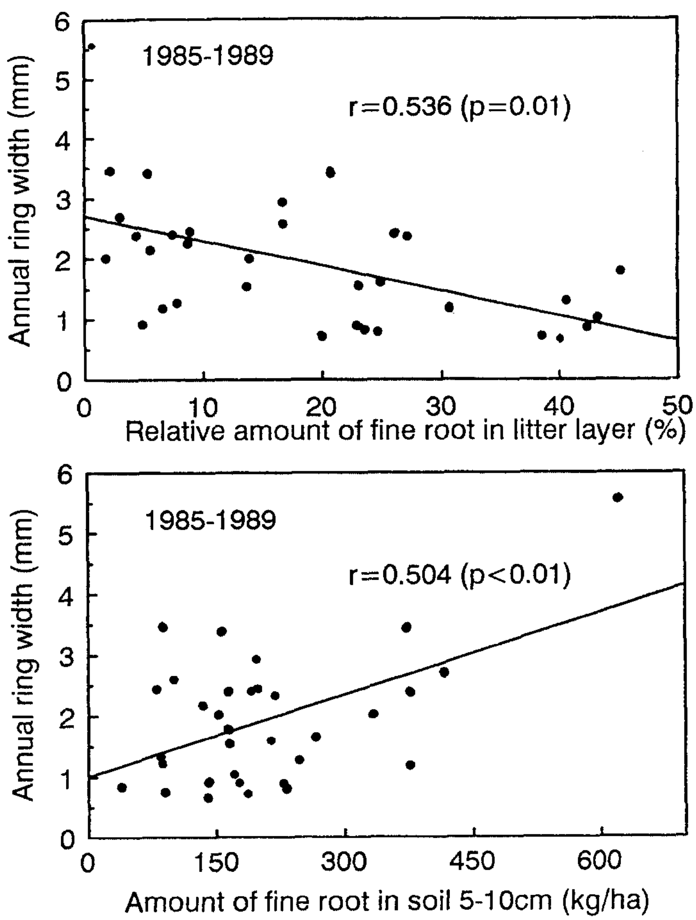

Fig. 7. Relationship between annual ring widths of pitch pine and relative amount of fine root in litter layer (above) or fine root in soil of 5~10 cm depth (below). Annual ring widths were obtained from annual rings for the latest 5 years from 1985 to 1989.

Relationship between fine roots and annual ring widths

There was a positive correlation (r= +0.307) between total amount of fine roots and annual ring widths for the latest 5 years (1985~1989), but there was a strong negative correlation between relative amount of fine roots in litter layer and annual ring widths (Fig 7). However there was a strong positive correlation between relative amount of fine roots in soil of 5~10 cm depth and annual ring widths (Fig 7). These results indicate that growth of pitch pine in urban Seoul decreases as the amount of fine roots increases in litter layer.

DISCUSSION

Decline of tree growth in Seoul and its vicinity

Although the growth of tree rings varied from tree to tree, site to site, mean growth of pitch pine for all age classes or intervals decreased in Seoul and its vicinity compared with those in rural areas. In addition to pitch pine, the growth declines of red pine and mongolian oak in Seoul were reported by Office of Forestry (1986~1988). Chung *et al.* (1991) reported that the vitalities of red pine in Seoul were worse than those in control area (Pyungchang, Kangweondo), but those of mongolian oak were not. Although the growth decline of pine in Seoul and its vicinity can be due to several factors, the acidified soil and air pollutants in these areas might be responsaible for the decline of tree growth.

Abnormal vertical distribution of fine roots

Characteristics of distribution of fine roots at three areas in this study are as follows (Fig. 5 and Fig. 6):

1) Urban Seoul: amount of fine roots in deep soil layer decrease, but those in litter and top soil layer increase, total amount of fine roots decrease

2) Suburbs: amount of fine roots in deep soil layer do not change, but those in litter and top soil layer increase, total amount of fine roots increase

3) Rural areas: amount of fine roots in deep soil is high, and those in litter and top soil layer is low, total amount of fine roots do not change.

In urban Seoul, abnormal vertical distribution of fine roots was thought to be caused by soil stressor (Al or Mn) which inhibited the growth of fine roots in soil layer. Therefore, as soil was acidified, fine roots were thought to be superficially distributed (Matzner *et al.* 1985, Schneider and Zech 1990/1991). However, the increase in the amount of fine roots in suburbs were thought to occur because of energy translocation from leaves to fine roots to cope with soil stressors.

Abnormal distributions of fine roots in areas showing forest decline were reported by only a few authors. Matzner *et al.* (1986) reported that much of dead or living fine roots were distributed in top soil layer. Meyer *et al.* (1988) also identified the reduction of growth of fine roots and VAM in acid soil. Most of the areas showing abnormal characteristics of fine roots had such characteristics of acid soil as low pH, deficiency of basic cations and high content of Al. Ulrich (1990) proposed a hypothesis that the superficially rooting trees in acid soil suffer more and more site-specific stressors. The abnormal vertical distribution and the decrease of fine roots in Seoul areas suggested that fine roots were suffered by many stressors existing in acid soil i.e., cation deficiency and high content of Al in soil layer made the fine roots escape to litter or top soil layer. Therefore, growth of trees having superficial rooting was thought to decrease by frequent infection with pathogens and insects and by frequent experience of drought stress (Ulrich 1990).

적 요

수도권과 그 주변의 33 장소의 리기다소나무 숲에서 연륜생장과 잔뿌리의 수직분포를 조사하였다. 생리적 연령이 16년과 20년 사이의 연륜의 생장은 전원지보다 도심지에서 불량하였다. 그리고 최근 5년간 (1985~1989)의 연륜생장은 연령 11년~20년, 연령 21년~30년 및 연령 31년~40년 그룹 모두에서 도심지에서 거리가 멀어짐에 따라 양호하였다. 리기다소나무 잔뿌리의 양은 도심지, 주변지 및 전원지 모두에서 토양의 깊이가 깊어짐에 따라 지수함수적으로 감소하였고, 그 양은 전원지에 비해 도심지에서 매우 적었다. 그리고 전원지의 잔뿌리의 수직분포와 비교해 볼 때, 도심지에서 잔뿌리는 토양층보다 낙엽층에 많이 분포하였다. 그리고 낙엽층 속의 잔뿌리의 상대적 양은 도심으로부터 멀어짐에 따라 감소하였다. 연륜 생장과 낙엽층 속의 잔뿌리 양과는 유의한 음의 상관이 있었다. 이들 결과로부터 도심지에서 리기다소나무 생장감소는 잔뿌리 생장감소와 잔뿌리의 비정상적인 수직분포에 원인이 있는 것으로 판단되었다.

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