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Effects of Cone Number and Thinning on Nutrient Content in Needles of Korean Pine (*Pinus koraiensis*)

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Abstract : We investigated on the distribution of nutrient contents (N, P and K) in current and one-year old needles of Korean pine, *Pinus koraiensis*, to understand the physiological effects of alternate bearing. One experimental set was designed with three types of cone number (one, three and five) under natural state and cone number of another one was controlled by thinning. Test samples were separated to collect into three fractions; current needles on the shoot and one-year old needles above and under the cone. On the branch without cone, N, P and K concentrations in needles on the shoot were higher than those in needles of one-year old branch. At natural state, needle P concentration was the lowest in needles on the five-cone branch in August. Macronutrient concentrations were the lowest in needles above the cone, which was remarkably observed in needle K concentration. Under cone thinning, N, P and K concentrations were the highest in needles on one-cone branch and the lowest in needles on five-cone branch. Needle nutrient concentrations were the lowest in needles above the cone, which was remarkably observed in the needle on five-cone branch. In conclusion, the current needles of the shoot and cones are a strong sink of nutrient like N, P and K, and the increase of cone number influences nutrient removal from needles.

Key words : *Korean pine, alternate bearing, cone number, cone thinning, macronutrient*

Introduction

Alternate bearing-the alternation of high and low crop years-is widespread among forest trees as well as commercially important fruit tree species, such as olive, citrus species, pistachio and apples etc. (Weinbaum *et al.*, 1994; Roussos *et al.*, 2004). A heavy yield is followed usually by an extremely low one and *vice-versa*. In general, there is a regular biennial pattern, with an "on year" (heavy yield) followed by an "off-year" (low or no yield). Sometimes, however, two or more "on" or "off" years occur in sequence in response to genetic, climatic, cultural or pathological conditions (Proietti, 2000).

During an "on-year", the many growing fruits reduce the production of new shoots, which provide buds that are apt for floral induction. Therefore the number of flower is drastically reduced. Due to an excessive consumption of assimilate reserves during a heavy yield, the flowers and the percent of fruit set are usually lower than after an "off-year". In contrast, the strong shoot growth and abundant assimilate availability in the "off-year" favour the formation of many flowers the following year (Proietti, 2000).

Alternate fruit bearing occurs under both extensive and intensive growing conditions, but the degree of alternation can be reduced by establishing a very delicate balance between vegetative and reproductive activities by rational cultivation practices. While several specific interactions between fruit load and vegetative activity and characteristics of fruit have already been studied in other species (Priestly, 1977; Stutte and Martin, 1986; Stephan *et al.*, 1999), further study of the effect of fruit load on tree physiology is needed in order to define strategies that could reduce alternate bearing (Proietti, 2000; Ulger *et al.*, 2004).

Fruit thinning is a representative control technique which can overcome alternate bearing and also reduce the number of under-size fruit for commercial marketing (Untiedt and Blanke, 2001). In addition, thinning allows each remaining fruit to develop to its maximum size, with little reduction of tree vigor. Less-crowded fruit receive more sunlight, so fruit color and flavor may be improved. Reducing the fruit load through proper pruning and fruit thinning, especially near the ends of branches, lessens the chances of limb breakage. Fruit thinning can

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also reduce the spread of some diseases. For example, if the fruits are touching each other, brown rot can quickly spread from one fruit to another just before harvest (Ingels *et al*., 2001).

Korean pine, *Pinus koraiensis* Sieb. et Zucc., is an evergreen plant species and grows in the Amur and maritime provinces of Russia in Korea and China, and in a few spots on the Japanese islands of Honshu and Shikoku (Mirov, 1967; Vidakovic, 1991). The species was introduced into Europe in 1846, where its altitudinal distribution generally ranges from 600 to 1000 m, while in Korea it occurs from 600 to 1500 m elevation (Vidakovic, 1991). Korean pine is an ornamental, hardy tree, but slow growing. It starts to produce seed at the age of 15 years, but abundant seed crops are produced after its 30th year or later. In addition to high economic value of its seeds, wood from the tree has long been used for fine quality furniture in north-eastern Asia, especially in Korea, where the species was extensively planted throughout the country in the last several decades (Korea Forest Service, 1999).

Korean pine, unfortunately, has strong alternate bearing, which causes some physiological disorder like size, poor quality of seed, ripening delay or some mechanical effect like branch breaking and disturb the sustainable production of seed. Therefore we are necessary to understand on the effect of alternate bearing of Korean pine and to reduce the negative effects for a sustainable production of pine nut using cone or flower thinning.

The objectives of this study were to evaluate the effects of alternate bearing in Korean pine on (1) annual nutrient demand and removal in needle and (2) nutrient contents and distribution. This information could establish the importance of reserves in supplying annual nutrient demands, and reveal the influence of cropping on the size of nutrient reserve pools within the tree during the alternate bearing cycle.

Materials and Methods

The study site is situated at Chuncheon Branch (N 37° 55' 255", E 127° 43' 520") of Forest Seed Research Center, Korea Forest Research Institute. The clone bank of Korean pine, *P. koraiensis*, was constructed in 1995. Mean temperature, mean relative humidity and annual total precipitation of Chuncheon area in 2007 were 11.7°C, 74% and 13,749 mm, respectively.

To analyze the effect of cone number for the changes of nutrient concentrations in the needles, we selected 54 branches with three types of cone number (one, three and five) at natural state of the study site. In addition, we selected 54 branches with more than five cones at the same site, and then controlled artificially the cone number of the branches (one, three and five).

Needle samples were collected from three branches including three types of cone number at approximately monthly intervals from April to September in 2007. Test samples were separated to collect into three fractions; current needles on the shoot and one-year old needles above and under the cone. The separated needles were dried at 70°C for 48h, ground, and stored in an oven at 60°C until analysis.

Nitrogen was determined by elemental analyzer (FLASHEA 1112 series). For other element determinations, nitric acid (70%, 15 mL) and hydrogen peroxide (30%, 5 mL) were added to 0.5 g of dried, ground plant sample in a digestion vessel. Samples were digested using the microwave digestion system, cooled after addition of distilled water, and filtered prior to analysis. Potassium concentration in the digested tissue was measured by atomic absorption spectrophotometer (AA-6701F, Shimadzu, Tokyo, Japan). Total P was colorimetry using the method described by Murphy and Riley (1962).

Results

1. Distribution on the branches without cone

Macronutrient (N, P and K) concentrations were significantly different between current and one-year old needles on the branches without cone of Korean pine in April ($p \leq 0.05$). N concentration was higher in current needles than in one-year old needles, which continued to May (Figure 1). P concentration, however, was lower in current needles than in one-year old needles in April. In July, P concentration was also significantly different between current and one-year old needles, and it was higher in current needles than in one-year old needles. Potassium showed significantly higher concentration in current needles than in one-year old needles from April to June ($p \leq 0.05$).

N concentration in current needles was highest in April and began to drop in May to reach a minimum in June, and then increased again in July. However, there was no seasonal change of N concentration in one-year old needles. P concentration in current needles was lowest in April and tended to increase gradually to September. P concentration in one-year old needles was highest in April and lowest in May, and then increased in June. K concentration in current needles was highest in April and began to drop in May to reach a minimum in August. However, K concentration in one-year old needles was lowest in April and then increased gradually from May to reach a maximum in September.

2. Effects of cone number at natural state

There was little or no difference in N concentration

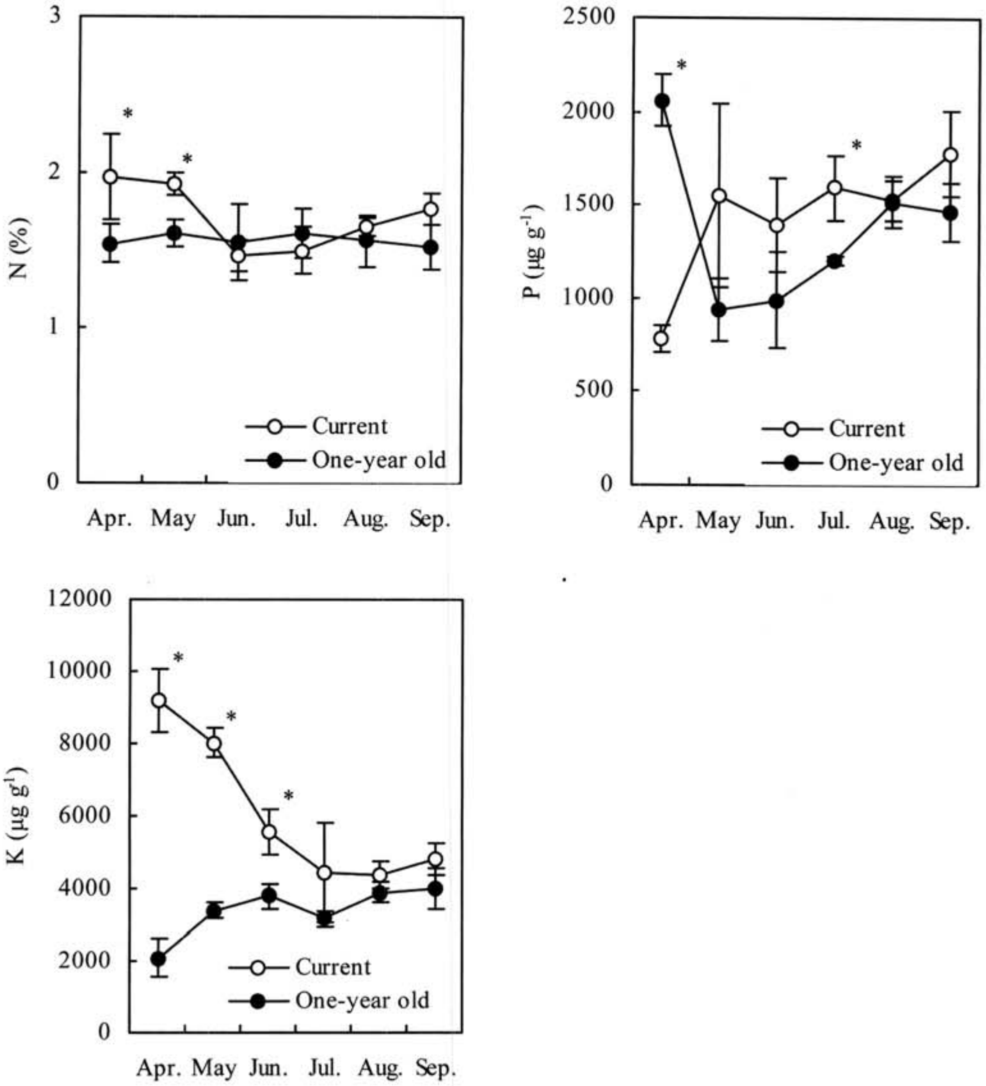

Figure 1. Seasonal trends of nitrogen, phosphorus and potassium concentrations in current and one-year old needles on the branches without cone of Korean pine. Each bar is mean of three replicates±SD, * indicates significant differences ($p \leq 0.05$) according to Duncan's multiple range test.

among cone numbers in needles of Korean pine from April to June (Table 1). In July and August, however, N concentrations were significantly different among cone numbers ($p \leq 0.05$) and their concentrations were highest in needles of three-cone branches in July and one-cone branches in August. N concentration was significantly different among needle positions from April to May and from August to September ($p \leq 0.05$). N concentration was highest in needles on shoot and there was no significant difference in N concentration between needles above and under the cones ($p \leq 0.05$).

N concentration of needles on shoot began to drop in May, reaching a minimum value in June (Table 1). Subsequently, these needles showed an increase in N concentration. N concentration of needles above the cone of one-year old branch also began to drop in May, reaching a minimum value in July and, subsequently, these needles showed an increase in N concentration.

In contrast, N concentration of needles under the cone of one-year old branch began to increase in May. These values in one-cone branch were almost constant until September but a new drop in N concentration in three-cone branch was observed in June.

P concentration in Korean pine needles showed significant difference among cone numbers from June to August ($p \leq 0.05$) and it was highest in needles on three-cone branch in July. The significant differences among needle positions were observed in needles on three- and five-cone branches from April to July ($p \leq 0.05$). It was highest in needles on shoot and lowest in needles above the cone.

P concentration of needles on shoot began to drop strongly in May, reaching a minimum in May (one-cone branch), June (three-cone branch) or August (five-cone

Table 1. Seasonal trends of nitrogen, phosphorus and potassium concentrations in current needles on shoot and one-year old needles above and under the cone of one-, three- and five-cone branches of Korean pine under natural state.

(A) Nitrogen (%)

Cone number	Needle position	April	May	June	July	August	September
1	Shoot	2.12±0.27^{a}	1.83±0.10^{a}	1.40±0.07^{a}	1.50±0.17^{a}	1.73±0.01^{a}	1.80±0.14^{a}
	Above	1.63±0.37^{b}	1.40±0.06^{b}	1.45±0.12^{a}	1.46±0.07^{a}	1.52±0.04^{b}	1.53±0.15^{a}
	Under	1.35±0.07^{b}	1.53±0.15^{b}	1.53±0.14^{a}	1.60±0.12^{a}	1.62±0.15^{ab}	1.65±0.21^{a}
	Mean	1.70±0.41	1.58±0.21	1.46±0.11	1.52±0.13	1.63±0.12	1.67±0.19
3	Shoot	2.10±0.18^{a}	2.04±0.07^{a}	1.38±0.08^{a}	1.88±0.07^{a}	1.50±0.14^{a}	1.91±0.18^{a}
	Above	1.37±0.23^{b}	1.66±0.30^{a}	1.45±0.07^{a}	1.54±0.10^{b}	1.37±0.08^{a}	1.29±0.04^{b}
	Under	1.29±0.11^{b}	1.68±0.26^{a}	1.55±0.14^{a}	1.58±0.21^{ab}	1.30±0.06^{a}	1.38±0.13^{b}
	Mean	1.59±0.41	1.81±0.27	1.46±0.12	1.67±0.20	1.39±0.12	1.58±0.32
5	Shoot	2.03±0.18^{a}	2.04±0.28^{a}	1.42±0.07^{a}	1.51±0.27^{a}	1.58±0.03^{a}	1.78±0.16^{a}
	Above	1.43±0.08^{b}	1.29±0.06^{b}	1.29±0.10^{a}	1.16±0.01^{a}	1.33±0.03^{b}	1.55±0.18^{ab}
	Under	1.26±0.17^{b}	1.32±0.06^{b}	1.34±0.30^{a}	1.23±0.16^{a}	1.51±0.10^{a}	1.24±0.04^{b}
	Mean	1.57±0.37	1.55±0.39	1.35±0.17	1.34±0.24	1.47±0.13	1.56±0.27
Pr > F	Cone (C)	ns	*	ns	**	***	ns
	Position (P)	***	***	ns	ns	***	***
	C × P	ns	ns	ns	ns	ns	ns

(B) Phosphorus (μg g^{-1})

Cone number	Needle position	April	May	June	July	August	September
1	Shoot	1931±442^{a}	1441±203^{a}	1457±430^{a}	1489±275^{a}	1484±154^{a}	1713±254^{a}
	Above	910±202^{b}	983±355^{a}	1007±104^{a}	946±166^{a}	1423±245^{a}	1526±526^{a}
	Under	810±303^{b}	977±156^{a}	1223±130^{a}	1128±340^{a}	1334±139^{a}	1906±701^{a}
	Mean	1217±608	1133±318	1229±302	1186±333	1414±174	1715±485
3	Shoot	2055±270^{a}	1634±49^{a}	1280±246^{a}	2280±254^{a}	1410±220^{b}	1871±468^{a}
	Above	665±152^{b}	983±193^{b}	376±61^{b}	1450±234^{b}	1304±59^{b}	1298±122^{a}
	Under	819±151^{b}	901±123^{b}	843±349^{ab}	1396±132^{b}	1800±99^{a}	1457±121^{a}
	Mean	1180±675	1196±378	890±441	1709±467	1505±258	1577±387
5	Shoot	2075±169^{a}	1575±427^{a}	1784±255^{a}	1641±266^{a}	1364±494^{a}	1921±251^{a}
	Above	652±63^{c}	766±244^{b}	813±376^{b}	419±283^{b}	917±254^{a}	1262±393^{b}
	Under	1031±230^{b}	904±225^{b}	980±330^{b}	1294±230^{a}	1077±159^{a}	1170±266^{b}
	Mean	1253±647	1082±465	1192±530	1118±590	1119±351	1451±445
Pr > F	Cone (C)	ns	ns	*	***	**	ns
	Position (P)	***	***	***	***	ns	*
	C × P	ns	ns	ns	*	ns	ns

(C) Potassium (μg g^{-1})

Cone number	Needle position	April	May	June	July	August	September
1	Shoot	7510±767^{a}	7905±630^{a}	4897±1324^{a}	4323±268^{a}	3936±188^{a}	4931±445^{a}
	Above	2327±335^{c}	3098±818^{b}	3333±445^{a}	3431±926^{a}	3001±67^{b}	4075±479^{a}
	Under	3464±440^{b}	3607±941^{b}	3893±390^{a}	3672±292^{a}	3176±16^{b}	4156±1004^{a}
	Mean	4434±2375	4870±2391	4042±999	3809±643	3371±442	4388±725
3	Shoot	9128±435^{a}	8460±541^{a}	5189±484^{a}	4639±385^{a}	4374±137^{a}	4840±805^{a}
	Above	1447±638^{c}	2007±60^{b}	2402±240^{c}	2560±187^{c}	3815±236^{a}	3684±37^{b}
	Under	2643±553^{b}	2930±634^{b}	3580±179^{b}	3253±271^{b}	4553±732^{a}	4229±505^{ab}
	Mean	4406±3559	4773±3109	3889±1217	3484±951	4247±514	4302±710
5	Shoot	9584±1109^{a}	8933±1528^{a}	6105±354^{a}	3889±561^{a}	5282±903^{a}	4215±352^{a}
	Above	1485±629^{c}	2093±837^{b}	2641±262^{c}	2609±645^{a}	3477±248^{b}	2920±316^{b}
	Under	3302±815^{b}	2989±870^{b}	3959±127^{b}	3985±1219^{a}	4409±259^{ab}	3268±219^{b}
	Mean	4790±3709	4672±3330	4236±1532	3495±998	4389±920	3493±670
Pr > F	Cone (C)	ns	ns	ns	ns	***	**
	Position (P)	***	***	***	***	***	**
	C × P	***	ns	ns	ns	ns	ns

All the values are means of three replicates±SD; Values with the different letter indicate significant differences ($p \leq 0.05$) according to Duncan's test. *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$ and ns: non-significance

Table 2. Seasonal trends of nitrogen, phosphorus and potassium concentrations in current needles on shoot and one-year old needles above and under the cone of one-, three- and five-cone branches of Korean pine under cone thinning.

(A) Nitrogen (%)

Cone number	Needle position	May	June	July	August	September
1	Shoot	1.93 ± 0.35^{a}	1.49 ± 0.01^{b}	1.68 ± 0.11^{a}	1.50 ± 0.10^{a}	1.77 ± 0.17^{a}
	Above	1.60 ± 0.02^{a}	1.56 ± 0.06^{b}	1.39 ± 0.16^{b}	1.21 ± 0.01^{b}	1.27 ± 0.08^{b}
	Under	1.55 ± 0.09^{a}	1.75 ± 0.10^{a}	1.54 ± 0.06^{ab}	1.28 ± 0.20^{ab}	1.35 ± 0.10^{b}
	Mean	1.71±0.27	1.60±0.13	1.54±0.16	1.33±0.17	1.46±0.26
3	Shoot	1.91 ± 0.18^{a}	1.43 ± 0.23^{a}	1.52 ± 0.15^{a}	1.42 ± 0.21^{a}	1.54 ± 0.07^{a}
	Above	1.33 ± 0.16^{b}	1.28 ± 0.11^{a}	1.34 ± 0.13^{a}	1.30 ± 0.16^{a}	1.14 ± 0.08^{b}
	Under	1.35 ± 0.26^{b}	1.59 ± 0.14^{a}	1.26 ± 0.26^{a}	1.16 ± 0.12^{a}	1.21 ± 0.12^{b}
	Mean	1.53±0.34	1.43±0.19	1.38±0.21	1.31±0.19	1.30±0.20
5	Shoot	1.88 ± 0.05^{a}	1.34 ± 0.01^{a}	1.55 ± 0.17^{a}	1.55 ± 0.15^{a}	1.65 ± 0.09^{a}
	Above	1.20 ± 0.13^{b}	1.09 ± 0.04^{c}	1.28 ± 0.01^{a}	1.24 ± 0.09^{a}	1.25 ± 0.09^{b}
	Under	1.22 ± 0.23^{b}	1.23 ± 0.03^{b}	1.43 ± 0.11^{a}	1.36 ± 0.25^{a}	1.35 ± 0.13^{b}
	Mean	1.43±0.36	1.23±0.10	1.46±0.15	1.40±0.21	1.44±0.20
Pr > F	Cone (C)	ns	***	ns	ns	*
	Position (P)	***	**	*	*	***
	C × P	ns	*	ns	ns	ns

(B) Phosphorus ($\mu g\ g^{-1}$)

Cone number	Needle position	May	June	July	August	September
1	Shoot	1595 ± 407^{a}	1302 ± 162^{ab}	1387 ± 15^{a}	1474 ± 546^{a}	1910 ± 373^{a}
	Above	1285 ± 353^{a}	1008 ± 306^{b}	1275 ± 235^{a}	1149 ± 388^{a}	1911 ± 539^{a}
	Under	1095 ± 82^{a}	1545 ± 102^{a}	1833 ± 492^{a}	1840 ± 74^{a}	1732 ± 397^{a}
	Mean	1330±349	1255±267	1498±374	1488±583	1851±394
3	Shoot	1603 ± 248^{a}	1503 ± 190^{a}	1476 ± 80^{a}	1454 ± 799^{a}	1827 ± 154^{a}
	Above	936 ± 207^{b}	505 ± 103^{b}	706 ± 103^{b}	1260 ± 347^{a}	1224 ± 215^{b}
	Under	1167 ± 130^{b}	1206 ± 104^{a}	1213 ± 460^{ab}	1520 ± 680^{a}	1612 ± 369^{ab}
	Mean	1235±341	1142±434	1132±415	1431±587	1554±349
5	Shoot	1439 ± 132^{a}	1428 ± 28^{a}	1852 ± 351^{a}	1532 ± 175^{a}	1660 ± 230^{a}
	Above	798 ± 82^{c}	555 ± 212^{c}	806 ± 10^{b}	962 ± 335^{a}	1014 ± 132^{b}
	Under	991 ± 14^{b}	971 ± 230^{b}	1639 ± 309^{ab}	1381 ± 338^{a}	1440 ± 79^{a}
	Mean	1076±295	1038±396	1611±459	1333±339	1416±302
Pr > F	Cone (C)	ns	*	*	ns	*
	Position (P)	***	***	**	ns	ns
	C × P	ns	*	ns	ns	ns

(C) Potassium ($\mu g\ g^{-1}$)

Cone number	Needle position	May	June	July	August	September
1	Shoot	9927 ± 686^{a}	4919 ± 637^{a}	4259 ± 166^{a}	4979 ± 763^{a}	5622 ± 931^{a}
	Above	3646 ± 603^{b}	4039 ± 528^{a}	3808 ± 449^{a}	4001 ± 2277^{a}	4147 ± 285^{b}
	Under	4806 ± 466^{b}	4441 ± 67^{a}	4364 ± 376^{a}	4107 ± 1118^{a}	5116 ± 581^{a}
	Mean	6437±2972	4520±542	4143±398	4363±1404	4962±862
3	Shoot	9455 ± 1064^{a}	5516 ± 712^{a}	5117 ± 1382^{a}	5175 ± 1357^{a}	4640 ± 182^{a}
	Above	2846 ± 590^{b}	2988 ± 328^{b}	2134 ± 779^{b}	3134 ± 1511^{a}	3577 ± 909^{a}
	Under	4249 ± 452^{b}	4470 ± 440^{a}	3369 ± 902^{b}	3965 ± 1139^{a}	4236 ± 195^{a}
	Mean	5516±3084	4492±1146	3540±1441	4211±1287	4151±664
5	Shoot	8260 ± 1385^{a}	5334 ± 443^{a}	5116 ± 102^{a}	4528 ± 684^{a}	5118 ± 106^{a}
	Above	2869 ± 2033^{b}	2245 ± 190^{b}	3014 ± 39^{b}	3444 ± 91^{a}	3626 ± 91^{c}
	Under	3743 ± 2259^{b}	3291 ± 814^{b}	4706 ± 781^{a}	4724 ± 937^{a}	4424 ± 199^{b}
	Mean	4957±3011	3624±1440	4279±1042	4331±833	4485±632
Pr > F	Cone (C)	ns	**	*	ns	*
	Position (P)	***	***	***	ns	***
	C × P	ns	*	*	ns	ns

All the values are means of three replicates±SD; Values with the different letter indicate significant differences ($p \leq 0.05$) according to Duncan's test. *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$ and ns: non-significance branch) and, subsequently, showed a slight increase until September (Table 1). P concentration of needles both above and under the cone of one-year old branch, however, increased in May to reach a maximum in September.

Needle K concentration showed significant difference among cone numbers in August and September ($p \leq 0.05$). K concentration was highest in needles on five-cone branch in August and one-cone branch in September. From April to September, there was significant difference among needle positions ($p \leq 0.05$) and K concentration was highest in needles on shoot and lowest in needles above the cone.

K concentration of needles on shoot began to drop in May, reaching a minimum in August (one- and three-cone branches) or July (five-cone branch) and, subsequently, showed a slight increase in September (Table 1). K concentration of needles above the cone of one-year old branch, however, increased in May to reach a maximum in September (one-cone branch) or in August (three- and five- cone branches). On one-cone branch, K concentration of needles under the cone showed a slight increase from April to June, and then began to drop in July and August and increased again to reach a maximum in September. In case of three-cone branch, K concentration increased until June and then showed a slight decrease in July, but it reached a maximum in August. K concentration of needles under the cone of five-cone branch was a minimum in May and a maximum in August.

3. Effects of cone number under cone thinning

The significant difference of N concentration among cone numbers was observed in June (Table 2). N concentration was highest in needles of one-cone branch and lowest in needles of five-cone branch. There was a significant difference among needle positions from May to September ($p \leq 0.05$). The highest N concentrations were observed in needles on shoot of one-cone branch from July to September, three-cone branch in May and September and five-cone branch in May, June and September. On the contrary, the lowest N concentrations were observed in needles above the cone at the same period.

Needle N concentration on shoot was highest in May and lowest in June. N concentration in needles above the cone of one- and three-cone branches tended to decrease from June (Table 2). The lowest N concentrations of one-, three- and five-cone branches were observed in August, September and June, respectively. In needles under the cone, N concentration increased slightly in June, and then decreased in July (one- and three-cone branches) or in August (five-cone branch).

P concentration didn't show a significant difference among cone numbers, but the difference among needle positions was significantly observed from May to June ($p \leq 0.05$). On three- and five-cone branches, P concentrations were highest in needles on shoot and lowest in needles above the cone.

P concentration in needles on shoot of one-cone branch was lowest in June, and then increased in July to reach a maximum in September (Table 2). In addition, P concentration in needles above the cone was lowest in June and highest in September. In needle under the cone, P concentration began to increase in June, reaching a maximum in August. On three-cone branch, P concentration in needles on shoot began to drop in June to reach a minimum in August, and then increased in September. In needles above the cone, the lowest P concentration was observed in June and the highest value in August. P concentration in needles under the cone increased linearly from June to September. On five-cone branch, P concentration didn't show a constant pattern, and the lowest P concentrations were observed in June.

K concentration showed a significant difference among cone numbers in June ($p \leq 0.05$) and K concentration was highest in needles on one-cone branch and highest in needles on five-cone branch (Table 2). There were the significant differences among needle positions in K concentration from May to September, except August (Table 2, $p \leq 0.05$). K concentrations were highest in needles on shoot and lowest in needles above the cone. K concentration in needles on shoot of one-cone branch decreased in June to reach a minimum in July, and then increased in August and September. Needle K concentration of three-cone branch began to drop in June, reaching a minimum in September and that of five-cone branch decreased to August and showed a slight increase in September. In needles above the cone, K concentration tended to increase from June to September. In needles under the cone of one-cone branch, K concentration began to drop in June to reach a minimum in August, and K concentration of three-cone branch was highest in June and lowest in July. K concentration of five-cone branch was, however, lowest in June and highest in August.

Discussion

Seasonal change of N concentration was more obvious in the current needle than in one-year old needle (Figure 1). In addition, the direction of seasonal change in N concentration in current needle was in agreement with those reported for other tree species. In our study, needle N concentration of the shoot decreased during the growing season. Ryugo (1988) and Shear and Faust (1980) reported that leaf N concentration in deciduous fruit trees decreased during the growing season until leaf fall. The decrease of N concentration during the growing season was observed more easily in the needle of shoot and above the cone of five-cone branch at natural state (Table 1). These results indicate that the decrease of N concentration could be due to N consumption by cones during the 'on' year, and it depends on the cone number. However we could not find the similar results in the branches that cone number was controlled artificially.

Moreno and Garca-Martnez (1984) reported that N in citrus accumulated in younger leaves during the season. Leaf N concentration in olive decreased until August and then increased in younger leaves, as in citrus. In the needle of Korean pine, N concentration was higher in the young needle of shoot than those of one-year old branch. The higher N concentration of younger leaves also has been reported for other evergreen species (Broschat, 1997). These results mean that the young needles on the shoot are a strong sink of nitrogen.

Brown *et al.* (1995) reported that the greater N accumulation in the 'off' year was observed in perennial parts of pistachio trees. In general, following the 'on' year, leaf N content was significantly lower than that obtained following the 'off' year. This difference could be due to N consumption by fruits during the 'on' year (Fernndez-Escobar *et al.*, 1999). Therefore pine cone demands the larger N during the 'on' year and leaf N consumption depends on the cone number.

Phosphorus concentration was the highest in the current needle of shoot and the lowest in the needle above the cone. The tendency could observe more easily in the needle of three- and five-cone branches both at natural state and under cone thinning (Table 1, Table 2). The decrease of P concentration in the needle above the cone of three- and five-cone branches could be due to P consumption by cones. Fernndez-Escobar *et al.* (1999) reported that leaf P concentration was higher in younger leaves in both the 'off' and 'on' year.

The seasonal change in needle P concentration was not in agreement with those reported for other tree fruit species. Needle P concentration of Korean pine did not decrease in all branches during the growing season. On the contrary, it showed the tendency of the increase during the growing season. The tendency wasn't also affected by the cone number.

Many studies have reported the reduction of leaf P concentration throughout the growing season in deciduous trees (Ryugo, 1988; Shear and Faust, 1980), citrus (Embleton *et al.*, 1973) and avocado (Embleton and Jones, 1966). Fernndez-Escobar *et al.* (1999) observed the same trends in olive trees, and also an increase in leaf P concentration during the autumn in both years. This tendency has not been reported consistently in other evergreen trees, although fluctuations in leaf P concentration were observed by Bingham (1961) in avocado and by Fahmy and Nasrallah (1959) in olive. However, the data reported by the latter authors are in contrast with the results presented here. They found the lowest leaf P concentration values in April and May and the highest in January in one year and in August the next year, whereas we always found a minimum in May or June and a maximum in April, which mean an accumulation of P in leaves during the winter (Brown *et al.*, 1995).

Needle K concentration was the highest in the current needle of shoot and the lowest in the one-year old needle above the cone like P concentration in the current needle. We could also observe more obviously the results in the needle of three- and five-cone branches both at natural state and under cone thinning during the beginning of the growing season (Table 1, Table 2). Like N and P concentrations, the decrease of K concentration in the needle above the cone of three- and five-cone branches could be due to K consumption by cones during the 'on' year. Fernndez-Escobar *et al.* (1999) reported that leaf K concentration was significantly higher in the current-season leaves of both the 'off' and 'on' year than in the one-year-old leaves.

Potassium concentration of current season needle gradually decreased from the beginning of the season to August. Many results demonstrated that leaf K concentration declined in most tree crops as the season progresses (Ryugo, 1988; Shear and Faust, 1980). In addition, a similar pattern has been reported for prunes (Weinbaum *et al.* 1994) and figs (Brown, 1994), both species with a large fruit K demand. Fernndez-Escobar *et al.* (1999) suggested that the high leaf K accumulation following the 'off' year and the rapid decline after March of the 'on' year were due to a large K demand by the reproductive structures of olive.

Unlike the previous results, K concentration in one-year old needle above and under the cone of Korean pine increased gradually during growing season both at natural state and under cone thinning.

The initial event that triggers alternate bearing may involve external factors (frost, lack of pollination, disease, etc.) which generally start the cyclic alternate behavior by eliminating one year's crop. The perpetuation of this cycle is attributed to the lack of an efficient self-thinning mechanism; the fruit overload produced during an "on-year" is the most universally recognized cause of alternate bearing (Monselise and Goldschmidt, 1982). The developing fruit is a strong sink that requires a continuous supply of building materials (Proietti *et al.*, 1999), like our results. It competes successfully with shoot growth for both newly assimilated materials and a reserve previously accumulated assimilates in different tree tissues. Most assimilates for fruit developing are supplied by the leaves on the same shoot where the fruit is attached (Rallo and Suarez, 1989; Proietti and Tombesi, 1996). When assimilate supply is reduced, the fruit can also use substances from other nearby parts. Previous studies (Balasubrahmanyam *et al.*, 1978; Monselise *et al.*, 1983) suggest that nutrient storage pools are reduced following an 'on' year. In agreement with this observation we found that the increase of cone number demanded significantly more N, P and K which probably reflects the decreased demand for these elements when the crop load is light.

In conclusion, the current needle of the shoot and cones are a strong sink of nutrient such as N, P and K, and the increase of cone number influences nutrient removal from needles.

Literature Cited

1. Balasubrahmanyam, V.R., Eifert, J. and Dofasi, L. 1978. Nutrient reserves in grapevine canes as influenced by cropping levels. Vitis 17: 23-29.
2. Bingham, F.T. 1961. Seasonal trends in nutrient composition of Hass avocado trees. Proceedings of the American Society for Horticultural Science 78: 149-160.
3. Broschat, T.K. 1997. Nutrient distribution, dynamics, and sampling in coconut and Canary Island date palms. Journal of the American Society for Horticultural Science 122: 884-890.
4. Brown, P.H. 1994. Seasonal variations in fig (*Ficus carica* L.) leaf nutrient concentrations. HortScience 29: 871-873.
5. Brown, P.H., Weinbaum, S.A. and Picchioni, G.A. 1995. Alternate bearing influences annual nutrient consumption and the total nutrient content of mature pistachio trees. Trees 9: 158-164.
6. Embleton, T.W. and Jones, W.W. 1966. Avocado and mango. pp. 51-76. In: Childers, N.F. (Ed.) Fruit Nutrition, Horticultural Publications. Rutgers University, NJ.
7. Embleton, T.W., Jones, W.W., Labanauskas, C.K. and Reuther, W. 1973. Leaf analysis as a diagnostic tool and guide to fertilization. pp. 183-210. In: Reuther, W. (Ed.), The Citrus Industry, vol. III, University of California, Berkeley. CA.
8. Fahmy, I. and Nasrallah, S. 1959. Changes in macronutrient elements of Souri olive leaves in alternate bearing years. Proceedings of the American Society for Horticultural Science 74: 304-307.
9. Fernndez-Escobar, R., Moreno, R. and Garca-Creus, M. 1999. Seasonal changes of mineral nutrients in olive leaves during the alternate-bearing cycle. Scientia Horticulture 82: 25-45.
10. Ingels, C., Geisel, P.M., Unruh, C.L. and Lawson, P.M. 2001. Fruit trees: thinning young fruit. ANR publication 8047 pp. 1-4.
11. Korea Forest Service. 1999. Forestry Statistics. Korea (in Korean).
12. Mirov, N.T. 1967. The Genu *Pinus*. Ronald, New York.
13. Monselise, S.P. and Goldschmidt, E.E. 1982. Alternate bearing in fruit trees. Horticultural Reviews 5: 128-173.
14. Monselise, S.P., Goldschmidt, E.E., Golomb, A. and Rolf, R. 1983. Alternate bearing in citrus: long-term effects of a single girdling treatment on individual 'Michal' tangerine branches. Journal of the American Society for Horticultural Science 108: 373-376.
15. Moreno, J. and Garca-Martnez, J.L. 1984. Nitrogen accumulation and mobilization in Citrus leaves throughout the annual cycle. Physiologia Plantarum 61: 429-434.
16. Murphy, J. and Riley, J.P. 1962. A modified single solutions method for the determination of phosphate in natural waters. Analytica Chimica Acta 27: 31-36.
17. Priestly, G.A. 1977. The annual turnover resources in young olive trees. Journal of Horticultural Science 52: 105-112.
18. Proietti, P. 2000. Effect of fruiting on leaf gas exchange in olive (*Olea europaea* L.). Photosynthetica 38: 397-402.
19. Proietti, P., Famiami, F. and Tombesi, A. 1999. Gas exchange in olive fruit. Photosynthetica 36: 423-432.
20. Proietti, P. and Tombesi, A. 1996. Translocation of assimilates and source-sink influences on productive characteristics of the olive tree. Advances in Horticultural Science 10: 11-14.
21. Rallo, L. and Suarez, M.P. 1989. Seasonal distribution of dry matter within the olive fruit-bearing limb. Advances in Horticultural Science 3: 55-59.
22. Roussos, P.A. and Pontikis, C.A. 2004. The role of free polyamines in the alternate-bearing of pistachio (*Pistacia vera* cv. Pontikis). Trees 18: 61-69.
23. Ryugo, K. 1988. Fruit Culture, Its Science and Art. Wiley, New York.
24. Shear, C.B. and Faust, M. 1980. Nutritional ranges in deciduous tree fruits and nuts. Horticultural Reviews 23: 142-163.
25. Stephan, M., Bangerth, F. and Schneider, G. 1999. Quantification of endogenous gibberellins in exudates from fruit of *Malus domestica*. Plant Growth Regulation 28: 55-58.
26. Stutte, G.W. and Martin G.C. 1986. Effect of light intensity and carbohydrate reserves on flowering in olive. Journal of the American Society for Horticultural Science 11: 27-31.
27. Ulger, S., Sonmez, S., Karkacier, M. Ertoy, N., Akdesir, O. and Aksu, M. 2004. Determination of endogenous hormones, sugar and mineral nutrition levels during the

induction, initiation and differentiation stage and their effects on flower formation in olive. Plant Growth Regulation 42: 89-95.

28. Untiedt, R. and Blanke, M. 2001. Effects of fruit thinning agents on apple tree canopy photosynthesis and dark respiration. Plant Growth Regulation 35: 1-9.
29. Vidakovic, M. 1991. Conifers: Morphology and Variation. Crafickizavod Hrvatske, Croatia.
30. Weinbaum, S.A., Niederholzer, F.J.A., Ponchner, S.W., Rosecrance, R.C., Carlson, R.M., Whittlesey, A.C. and Muraoka, T.T. 1994. Nutrient uptake by cropping and defruited field-grown 'French' prune trees. Journal of the American Society for Horticultural Science 119: 925-930.

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