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Effective Crown Form of Changbai Larch (*Larix olgensis H.*) Plantation in Changbai Mountain[1]

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長白落葉松(*Larix olgensis H.*) 人工林의 有效 樹冠形에 관한 研究[1]

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ABSTRACT

Based on stem analysis as well as branch analysis data of each tree from 8 plots of circle clear-cutting and 1 biomass plot in Changbai Mountain area, located in Northeast of China, the effective crown form of Changbai larch(*Larix olgensis H.*) plantation were studied by using the approach of crown curve. The results indicated that the cross-section forms of effective crown were stable and showed approximate circle for different tree size. Because the effective crown was on upper position of the canopy and its form reflects crown architecture under non-competition condition, the architecture is mainly affected by species hereditary feature. Therefore, for the specified species the effective crown form was thought to be relatively stable. The effective crown form of tree was neither related to the tree size within stand nor to the stand condition for different stand. The total effective crown curve of larch plantation could be characterized by using mean effective crown taper.

Key words ; Larix olgensis H., *branch analysis, effective crown form, crown curve*

要 約

中國 北東部에 소재한 長白山 지역에서 원형으로 개벌한 8개의 표준지와 1개의 biomass(生物質量) 標準地 내에 존재하는 각 個別木에 대해 가지를 포함한 樹幹을 분석한 자료로 樹冠曲線에 대한 방법을 이용하여 長白落葉松(*Larix olgensis H.*) 조림지에 있어 有效樹冠形에 대한 연구를 실시하였다. 얻어진 결과에 의하면 有效樹冠의 橫斷面形態는 여러 立地에서 모두 일정하게 원형에 가까운 것으로 나타났다.

有效樹冠은 林冠의 상부에 존재해 있고 그 형태는 非競爭 조건하에서의 樹冠構造를 반영하는 것이기 때문에, 그 구조는 주로 각 種의 遺傳的 특성에 의해 가장 큰 영향을 받는다. 따라서 특정한 種들의 有效樹冠形은 비교적 일정한 것으로 판명되었다. 林木의 有效樹冠形은 같은 임분내의 임목의 크기와 관계가 없고 여러 林分들의 다양한 林分의 조건과도 관계가 없는 것으로 나타났다. 長白落葉松 人工造林地의 總 有效 樹冠曲線은 평균 有效樹冠 梢殺度를 이용하여 그 특성을 파악할 수 있다.

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INTRODUCTION

Above ground of tree is composed of stem, branches, and leaves. Crown especially effective crown regards as the main place of photosynthesis and its size mainly affects activity and productivity of tree growth. Studying effective crown structure has significance to discuss tree growth and stand management. Developing effective crown structure and dynamics models have a number of use, including :

(1) To reflect growth activity and competition effects of tree development, some of crown variables can be used to develop competition indices(Mitchell, 1975 ; Biging and Wensel, 1990 ; Biging and Dobbertin, 1992 ; Li, 1995a) ;
(2) The crown size directly influences tree's assimilation and it is one of basic variable for predicting increment of tree(Sprinz and Burkhart, 1987) ;
(3) To evaluate effects of the silvicultural treatments. Since various silvicultural treatments directly affect crown dimensions and development, if the dynamics of crown could be quantitatively simulated, it would provide a means to better understand and predict the effects of silvicultural treatments on tree and stand attributes and to determine a reliable silvicultural practices(Shimizu, 1989 ; Mizunaga, 1992 ; Li, 1995a) ;
(4) The crown size reflects photosynthetic area, translocation distance of organism, and the efficientcy of photosynthesis. The crown variables are available to interpret the result of tree growth.

Although the tree crown plays an important role as above, there are some reasons why, the models of crown structure haven't been developed well in past as follows : (i) the crown form is not symmetric with respect to the vertical axis of tree due to the competition between trees within the stand ; (ii) it is difficult to measure the crown form due to variation and large measurement errors ; (iii) it is tedious to collect the crown data in field.

This study based on Cangbai larch(*Larix olgensis H.*) plantation of Changbai Mountain region, Northeast China, the tree and stand effective crown form were studied by using the approach of branch analysis of circle clear cutting.

The models of effective crown structure is expected to be used to further simulating tree and stand effective crown dynamics and developing the stand growth and management models. It may provides better base for optimum crown structure and rational management of Cangbai larch plantation.

MATERIALS AND METHODS

Data collection

Data used in this study were collected from Songjianghe Forestry Bureau in Western part of Changbai Mountain, Northeast of China. The region located in Fusong County of Jilin Province, China(127° 12′-127° 50′E, 41° 44′-42° 21′N).

Data were collected from a biomass sample plot

Table 1. Summary of stand variables for each sample plot

Plot No.	Stand age (A)	Mean D.B.H. (cm)	Mean height (m)	Dominant height (m)	Site index (SI)	Tree No. (N/ha)	Stand volume (m³/ha)	Plot area (ha)	Subsample plot area of circle branch analysis(m²)	No. of stem for branch analysis
L-1	11	8.8	7.90	10.00	17.6	1740	65	0.100	----	7
L-2	25	11.6	13.10	15.80	13.7	2674	180	0.089	132.730	32
L-3	11	6.0	7.00	9.30	16.4	6520	106	0.025	38.485	24
L-4	21	12.7	13.00	16.50	16.5	2029	167	0.070	132.730	34
L-5	26	17.4	16.20	18.40	15.6	1025	166	0.120	201.060	25
L-6	22	12.2	11.10	13.35	12.5	2000	152	0.060	95.033	23
L-7	25	11.6	12.40	14.60	12.7	2650	179	0.060	113.100	30
L-8	14	9.2	8.95	10.40	14.0	2667	109	0.063	63.620	26
L-9	17	11.5	11.10	13.92	16.6	2189	144	0.090	95.033	23

(L-1) and eight plots of branch analysis of circle clear cutting. All nine sample plots were grown well and unthinned.

Every tree in each plot were marked for the coordinate of x and y, and species, DBH, total height(H), height to live crown(HB) and crown-width(CW) were recorded. Subsample plots of circular branch analysis were set up by mean stand height as diameter in each sample plot. Each tree selected for stem analysis and branch analysis within the circular sample plots were all fallen. Table 1 gives information of stand variables for each plot in detail.

Quantitative description of crown structure

After falling each tree within subsample plots

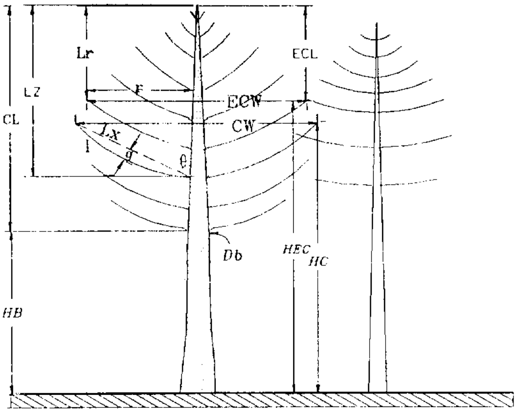

Fig. 1. Descriptive factors of crown structure

Lr : Crown depth
r : Crown radius of any height within crown
l : Branch length
Lx : Chord length
Lr : Crown depth from axes
Lz : Branch depth from axes
θ : Brand angle toward the stem
g : Arch height of branch
H : Total height
HB : Height to crown base
Db : Stem diameter at live crown base
HEC : Height of effective crown
HC : Attaching height
CL : Crown length CL=H-HB
CR : Crown ratio(%), CR=CL/H*100
ECL : Effective crown length ECL=H-HEC ;
CW : Crown width
ECW : Effective crown width
ECSA : Effective crown surface area
ECV : Effective crown volume

for branch analysis, discs were taken at breast height(1.3m), stump, and then after one meter intervals above the stump with Smalian's method. The tree crown also bucked at one meter interval. Each section within tree crown is called "Layer". Every branch within the crown layer was numbered and crown variables were measured to describe the crown structure(see Fig. 1).

Definition of effective crown

The distribution of branch and leaf biomass is different for each layer of canopy in a stand. For upper crown of tree, the photosynthetic efficiency is relatively high, because the leaves fully receive radiation. Reversally, for branches on the lower position of crown, the photosynthetic effect is low which is caused by shade of upper crown and adjacent trees. Therefore, effective crown and non effective crown can be divided by stand mean attaching height(HC).

Crown which is above the limited height of canopy layer of maximum branches and leaves vertical distribution density and directly affects tree growth, especially stem growth is defined as effective crown. The other part of crown except for the effective crown is defined as non-effective crown. The effective crown could be determined by the height of effective crown(HEC) that was computed by using the method of stem analysis and biomass distribution of branches and leaves.

For Cangbai larch larch plantation, the stand mean height of effective crown(HEC) was basically stable within a stand(at about 2/3 position of total crown) and about the same as position of stand mean attaching height(HC)(Li, 1995a). The HEC was positively related to stand age, site, and stand density for different stand(Li, 1995b).

Effective crown form

The effective crown form is often studied from form of cross-section and vertical-section form separately. Cross-section form of effective crown is always defined horizontal shape at any height h(HEC≤h≤H) within effective crown and ordinarily supported the concept of circle(Mitchell, 1975 ; Inose, 1982 ; Han, 1985). Reviewing the research methods on vertical crown form, we can divide them into three kinds : (i) the crown taper (Kajihara, 1975 ; Inose, 1982 ; Mizunaga, 1992) ; (ii) the analysis of leaf biomass(Satoo and Imoto, 1979 ; Fujimori et al., 1984) ; and (iii) the regression equation(Cole and Jensen, 1982). In this paper, the crown taper method were employed.

Crown taper is often described by crown depth (Lr) and crown radius(r). Lr is easy to measure directly, but r need to be transformed from branch angle(θ) and chord length(Lx) :

$$r = L_x \sin\theta \quad \cdots\cdots (1)$$

For larch as an intolerant species, the natural pruning is obvious in a closed stand. The tree crown width increased along with the increase of crown depth, and the crown profile mainly appears parabolic especially the surface of effective crown. The effective crown taper is expressed as power function :

$$L_r = \alpha\ r^{\beta} \quad \cdots\cdots (2)$$

$\alpha, \beta > 0$

where α : the interception parameter
β : the shape parameter that determine the shape of crown profile

Total geometric effective crown volume (ECV) and surface area(ECSA)

This work has some analogies to conventional tree volume. Total geometric effective crown surface area on the interval HEC≤h≤H can be estimated when the information on crown taper is available.

〈i〉 Effective crown volume equation

From equation (2) we obtain

$$r = a\ L_r^{b} \quad \cdots\cdots (3)$$

a,b>0

where $a = \alpha^{-\frac{1}{\beta}}$ $b = \frac{1}{\beta}$

Let's denote ECA(h) as cross sectional area of effective crown at height h on the interval HEC ≤h≤H, a cross section area expression can be developed by expressing the crown volume above height h as the integral of the crown area from the tip to the base of the effective crown(HEC) as follows ;

$$ECV(h) = \int_H^h ECA(h)dh = \int_0^{L_r} \pi r^2 dL_r \quad \cdots\cdots (4)$$
$$= \int_0^{L_r} \pi a^2 L_r^{2b} dL_r = \pi \frac{a^2}{2b+1} L_r^{2b+1}$$

From equation (4), each effective crown layer volume can be calculated.

〈ii〉 Effective crown surface area equation

A model for cumulative effective crown surface area formula can be defined using following formula :

$$ECSA(h) = 2\pi \int_0^{L_r} L_r \left[1 + \left(\frac{dL_r}{dr}\right)^2\right]^{\frac{1}{2}} dr \quad \cdots\cdots (5)$$

For equation (4) and (5), we can obtain total geometric effective crown volume(ECV) and surface area(ECSA) with assuming that crown depth equals effective crown length. Equation (5) can be solved by iteration procedure using Romberg numerical integration.

RESULTS AND DISCUSSION

Cross-section form of effective crown

Using the branch analysis data of every sample plot, each layer cross-section form of effective crown were drawn for each tree in the stand. As example, Fig. 2 showed the cross-section form of the lowest layer(10-11m) of effective crown for dominant tree, suppressed tree, and five classes tree in size of L-4 plot 1 highest tree and 1 lowest tree in the subsample plot were selected to refer as the dominant tree and the suppressed tree. The other 5 trees were selected with hartig's classical mean sample tree method, which the 5 classes possessed same basal area were divided by series of tree size and 1 mean sample tree was selected for each class.

From Fig. 2, the cross-section forms of effective crown were stable and approximate circle for different tree size.

Effective crown curve

The crown taper of every tree were fitted for each subsample plot of branch analysis using equation (3). In procedure, eight longest branches were taken at each layer of every tree to repre-

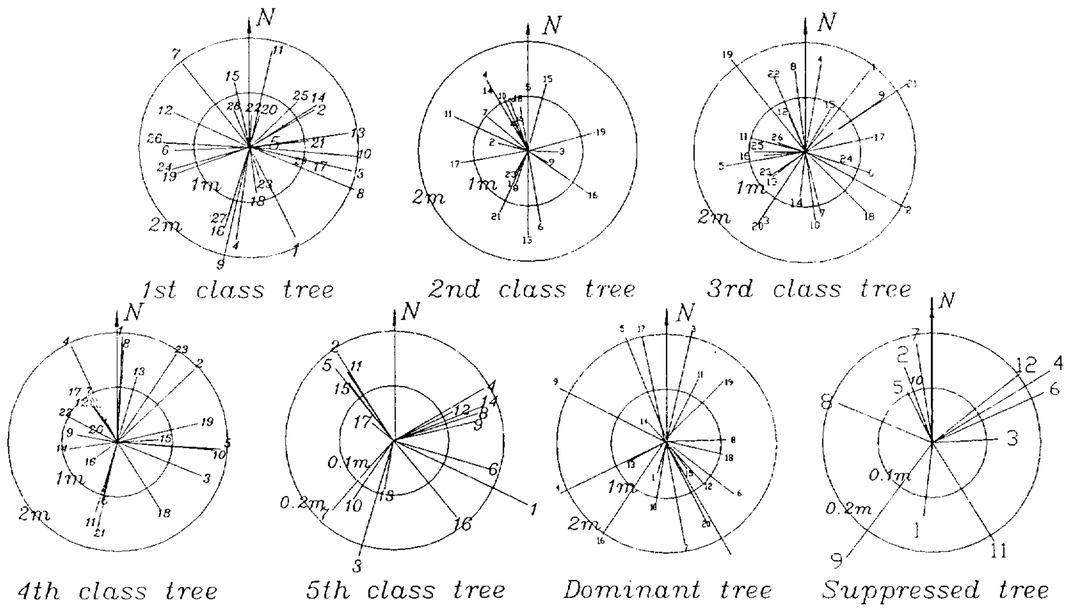

Fig. 2. Cross-section form of effective crown for 7 biomass trees in plot L-4

sent the outside effective crown surface profile (two longest branches for each quadrant separately). The parameter of effective crown taper and its fitted statistics of every tree for each subsample plot of branch analysis were computed. The value of the interception parameter a for the individuals tree's crown taper ranged from 0.4 to 0.6, and the value of the shape parameter ranged from 0.7 to 0.9. Two parameters had a minimal variance in the same stand(standard error was less than 0.12 for a and less than 0.26 for b except for L-7 plot).

This indicated that the effective crown form was relatively stable in the same stand. Fit index R^2 was about 0.7 for every stand. To get a further analysis how the effective crown form varies from tree size within stand, the results of simple relation analysis between parameter a and b of effective crown taper with the diameter at the breast height(DBH) and total height(H) were presented in table 2.

From table 2 it was known that the related coefficients(absolute value) between parameters with tree size(DBH or H) were all less than 0.5 and the volume among the most plots were less than 0.3. The significant test of coefficients at the 5% level showed that all of the values in table 2 were not-significant. This indicated that the effective crown form is relatively stable and independent with tree size within the stand.

Table 2. Related coefficient between parameters of effective crown taper with DBH and H for each plot

plot	Number of stems	D.B.H.		Height	
		a	b	a	b
L-1	7	0.01	0.26	0.32	0.16
L-2	31	0.05	0.16	-0.02	0.09
L-3	23	0.49	0.01	0.28	0.14
L-4	31	-0.24	0.45	-0.14	0.30
L-5	25	-0.18	0.35	0.08	-0.25
L-6	22	0.36	0.13	0.32	-0.26
L-7	27	-0.20	-0.16	-0.43	-0.48
L-8	26	0.24	0.32	0.15	0.07
L-9	23	-0.17	0.29	-0.04	-0.04

Stand mean taper of effective crown

Since the effective crown form of tree was not related to the tree size within stand, we combined all branch analysis for trees within stand and fitted stand mean taper of effective crown for each plot. The results were presented in table 3.

Table 3. Results of fitting mean taper of effective crown for each stand

Plot	Numbers of Stems	Numbers of branches	Parameters a	Parameters b	R^2
L-1	7	166	.449708	.769608	.7800607
L-2	32	681	.530434	.742388	.7254844
L-3	24	291	.469325	.880693	.7064886
L-4	34	845	.470946	.858161	.7190749
L-5	25	854	.453586	.866793	.6993801
L-6	23	606	.382766	.847994	.7947943
L-7	30	691	.444358	.829533	.6651213
L-8	26	465	.477476	.845755	.6555411
L-9	23	475	.486151	.826436	.7257680

Table 4. F-test results of mean effective crown taper for each stand

Plot	Mean error		Absolute mean error		System error		Precision		Calculated F-value		Critical F-value		Significant	
	ECSA	ECV	ECSA	ECV	ECSA	ECV	ECSA	ECV	ECSA	ECV	ECSA	ECV	ECSA	ECV
L-1	1.41	1.19	2.60	2.61	-7.67	-9.90	73.54	72.24	3.22	5.92	6.04	6.04	no	no
L-2	0.91	0.27	2.39	2.18	-0.98	-2.76	92.95	87.01	0.07	0.10	3.33	3.33	no	no
L-3	0.17	0.12	1.28	0.79	-1.83	-3.44	91.19	84.18	0.12	0.10	3.47	3.47	no	no
L-4	0.36	0.40	3.35	3.12	-1.65	-3.37	92.15	86.05	0.62	0.54	3.33	3.33	no	no
L-5	0.25	0.25	4.63	5.25	-0.77	-1.21	92.22	85.66	0.64	0.71	3.42	3.42	no	no
L-6	0.08	0.10	1.46	1.13	-0.49	-1.36	94.84	90.31	0.13	0.07	3.49	3.49	no	no
L-7	0.51	0.29	2.83	2.17	-2.90	-3.47	90.90	84.35	0.26	0.81	3.39	3.39	no	no
L-8	0.17	0.23	2.09	1.73	-1.00	-2.80	92.52	86.28	0.10	0.10	3.42	3.40	no	no
L-9	0.12	0.31	2.51	2.31	-0.62	-2.89	91.82	85.21	1.67	0.08	3.49	3.47	no	no

Table 5. Simple regression analysis between parameters of stand mean of effective crown with stand condition for each plot

Parameter	Stand age (A)	Site index(SI)	Stems number per hectare(N/ha)	Stand Density Index (SDI)
a	-0.0319	0.2248	0.1833	0.2459
b	-0.0587	0.0150	0.2926	0.1191

To verify the validity of stand mean effective crown taper for different stand, the analysis of predicting errors and confidence elliptic F-test at significant level of 5% were conducted which measured individual tree effective crown volume (ECV) and effective crown surface(ECSA) as observed value, and that computed ECV and ECSA from mean effective crown taper of the stand in table 3 as predicted value. The test results were presented in table 4.

Table 4 indicated that system errors of ECSA in every plot were all less than 2% and ECV were less than 5% except for plot L-1(sample number too little, only 7 stems). The results of F-test further proved conclusion that effective crown taper for each tree within stand was similar for larch plantation and also indicated that individual tree's effective crown form could be described with mean crown taper in the same stand.

So, how does the effective crown form change with stand condition? After analyzing relation between the interception parameter a and the shape parameter b of mean taper of effective crown(in table 3) with stand conditions, it was found that the parameter a and b were very stable and were not correlated with stand age, site, and stand density(the relation coefficients were all less than 0.3)(See Table 5).

The results indicated that the effective crown form were stable and were not correlated to tree size within stand and stand condition of different stand for larch plantation, because the effective crown is on upper position of the canopy and the form reflects crown architecture under non-competition condition and the architecture is mainly affected by species hereditary feature.

Therefore, for the determined species the effective crown form was thought to be relatively stable and didn't correlate with competitive state of tree for a specified species.

Total effective crown curve of larch plantation

Since the effective crown form of tree was not related to the tree size within stand and to the stand condition for different stand, all data of the branch analysis tree for each stand were combined and total effective crown curve(total average curve) of larch plantation was fitted(see eq. 9 and Fig. 3).

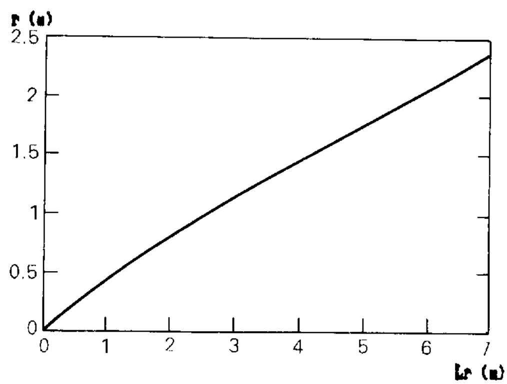

Fig. 3. Total effective crown curve of Changbai larch plantation

To verify the validity of the total effective crown curve of Changbai larch plantation, the analysis of predicting errors and confidence elliptic F-test at significant level of 5% were conducted that measured individual tree ECV and ECSA using equation (4) and (5) as observed value, and that computed ECV and ECSA from equation (9) as predicted value. The test results are presented in table 6.

$$r = 0.46302086 L_r^{0.83483794} \quad \text{(9)}$$

n=5074, SSE=392.45465,
Sy.x=0.27792, R^2=0.706768

Table 6 indicated that system errors of ECSA for every plot were all less than 6% and ECV were less than 12% except plot L-1 and L-6. The results of F-test were not significant at level of 5% except plot L-6. All of this proved conclusion that the total effective crown curve of larch plantation was stable and could be simulated by equation (9).

Using the models it is possible to simulating the tree and stand effective crown dynamics in different stand conditions for larch plantation by combining HEC predicting model(Li, 1995a). The results of this work can provide the basis for further studying stand growth and management models.

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Table 6. F-test results of the total effective crown curve for larch plantation

Plot	Mean error		Absolute mean error		System error		Precision		Calculated F-value		Critical F-value		Significant	
	ECSA	ECV	ECSA	ECV	ECSA	ECV	ECSA	ECV	ECSA	ECV	ECSA	ECV	ECSA	ECV
L-1	-0.34	0.21	2.44	2.23	1.85	-2.18	80.69	81.25	0.87	1.74	6.04	6.04	no	no
L-2	1.37	1.11	2.63	2.32	-6.03	-11.3	92.48	86.33	2.11	1.63	3.33	3.33	no	no
L-3	0.55	0.39	1.32	0.80	-5.96	-11.5	90.65	83.02	1.54	1.80	3.47	3.47	no	no
L-4	1.29	1.34	3.38	3.13	-5.95	-11.3	92.00	86.66	1.31	1.44	3.33	3.33	no	no
L-5	0.87	1.09	4.58	5.16	-2.70	-5.39	92.27	85.81	0.50	0.49	3.42	3.42	no	no
L-6	-3.32	-2.79	3.33	2.80	20.74	40.23	87.70	74.68	47.54	58.73	3.49	3.49	yes	yes
L-7	-0.37	-0.50	2.91	2.23	2.13	6.00	92.38	84.64	1.55	0.34	3.39	3.39	no	no
L-8	0.89	0.86	2.03	1.68	-5.18	-10.5	92.38	85.45	1.55	1.62	3.40	3.40	no	no
L-9	1.08	1.13	2.49	2.30	-5.21	-10.3	92.05	84.42	1.14	1.22	3.47	3.47	no	no

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LITERATURE CITED

1. Biging, G.S. and M. Dobbertin. 1992. A comparison of distance-dependent competition measures for height and basal area growth of individual conifer trees. For. Sci. 38(3) : 695-720.
2. Biging, G.S. and L.G. Wensel. 1990. Estimation of crown form for six conifer species of northern California. Can. J. For. Res. 20(8) : 1137-1142.
3. Cole, D.M. and C.E. Jensen. 1982. Models for describing vertical crown development of lodgepole pine stands. USDA For. Serv. Res. Pap. INT-292. 10p.
4. Fujimori, T., Y. Kanazawa., Y. Kiyono, K. Kamo and I. Iimori. 1984. Crown development and stem growth in relation to stand density in even-aged pure stands. (I) stand structure of young cryptomeria japonica. J. Jap. For. Soc. 66(4) : 132-140.
5. Han, X. 1985. Studies on branch growth of Latin. J. Beijing Forestry College 6(3) : 50-59.(In Chinese)
6. Inose, M. 1982. A tree growth model based on crown competition in Todomatsu(Abies sachalinensis) (I) The relationship between crown development and volume increment. Bull. For. Prod. Res. Inst. No. 138 : 103-127.(In Japanese)
7. Kajihara, M. 1975. Studies on the morphology and dimensions of tree crown in evenaged stand of Sugi (I) Crown form. J. Jap. For. Soc. 57(12) : 425-431.(In Japanese)
8. Koop, H. 1990. Forest Dynamics. Springer-Verlug, Netherlands. 229pp.
9. Li, Fengri. 1995a. A simulation system of stand dynamics for *larix olgensis H.* Ph.D. Dissertatio Beijing Forestry Univ. 203pp.(In Chinese)
10. Li, Fengri. 1995b. Models for crown structure of larch plantation. J. Northeast For. Univ. 6(1) : 6-11.
11. Mitchell, I.J. 1975. Dynamics and Simulated yield of Douglas-fir. For. Sci. Monogr. No. 17. 39p.
12. Mizunaga, H. 1992. Prediction of thinning effect by canopy model (I) Canopy surface structure dynamics after thinning. J. Jap. For. Soc. 74(4) : 314-324.(In Japanese)
13. Satoo, T. and H. Imoto. 1979. Modelling crown canopy of an even-aged stand of cryptomeria japonica from measurement leaf mass : A new approach to the morphology of forest crown. J. Jap. For. Soc. 61(4) : 127-134.
14. Shimizu, A. 1989. Estimation of the change in the number of stems in non-controlled forests based on the crown model. J. Jap. For. Soc. 71(5) : 181-186. (In Japanese)
15. Sprinz, P.T. and H.E. Burkhart. 1987. Relationships between tree crown, stem, and stand characteristics in unthinned loblolly pine plantations. Can. J. For. Res. 17 : 534-538.