O.D.C. 532:228.7:174.7 p.g.

CROWN DEVELOPMENT IN WHITE SPRUCE PLANTATIONS

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FORESTRY BRANCH, DEPARTMENT OF FISHERIES AND FORESTRY
Publication No. 1249
Extrait en français

Published under the authority of the
Minister of Fisheries and Forestry
Ottawa, 1969

THE QUEEN'S PRINTER
OTTAWA, 1969

Catalogue No. Fo. 47-1249

ABSTRACT

Observations of branch development and needle distribution within the crown are presented for 43 white spruce ranging in age from 13 to 41 years and representing planted spacings of 3 x 3, 4 x 4, 5 x 5, 6 x 6, and 7 x 7 feet. The relations of total oven-dry foliage weight to various measures of the stem and crown are expressed in a series of regression equations. Stem diameter at the base of the live crown and an expression combining diameter at breast height with crown length seem to be the two most useful estimators of foliage weight. Variables of height, age, spacing, and crown class had little or no effect on the relationships.

EXTRAIT

Rapport sur la distribution des aiguilles et sur le développement des branches formant la cime de 43 Épinettes blanches (*Picea glauca*) âgées de 13 à 41 ans qui avaient été plantées à tous les 3 x 3, 4 x 4, 5 x 5, 6 x 6 et 7 x 7 pieds. Représentation, au moyen de courbes de régression, des rapports entre le poids anhydre du feuillage et le diamètre du fût, etc. Les deux critères les plus fiables pour estimer le poids du feuillage s'avèrent, *primo*, le diamètre du bout supérieur du fût, *secundo*, une fonction comprenant le d.h.p. et la longueur de la cime. La hauteur de l'arbre, son âge, l'espacement, la classe de cime n'avaient pas de connexion avec le poids des aiguilles.

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INTRODUCTION

A knowledge of total leaf weight is required for assessing a tree's complete dry-matter production and relating wood formation to unit quantity of foliage. Foliage weights on standing trees can only be obtained indirectly, by using previously established relationships with some directly measured dimension of the crown or stem. The study reported here deals with attempts to determine such relationships for plantation white spruce (*Picea glauca* (Moench) Voss).

Few investigations have been made of the crown morphology of this species. Fraser *et al.* (1964) analyzed in detail a single open-grown tree, determining the age composition and weight of the needles and branches. Clark (1961) dissected the branches of three open-grown white spruce about 25 feet tall and used the length of foliated shoots by ages as estimates of the relative amounts of foliage. A second objective of the current study, therefore, was to collect information on branch and needle distribution for a variety of crowns and to determine how these were influenced by tree size and stand condition.

METHODS

Seven plantations established on old fields at the Petawawa Forest Experiment Station were chosen for study. The age range was 13 to 41 years from planting, and spacings were 3 x 3, 4 x 4, 5 x 5, 6 x 6, and 7 x 7 feet. All plantations had closed canopies, or at least the crown bases had started to recede (in the case of the youngest stand, Plantation 112).

Forty-three trees were collected for the primary sample (i.e. all but trees nos. 49 and 50, Table 1); each was undamaged and had four healthy competitors growing around it without intervening gaps. Where possible, two trees in each crown class (dominant, codominant, intermediate, and suppressed) were sampled in each plantation. Conditions within a plantation

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TABLE 1. BASIC TREE DATA

Tree No.	Plantation No.	Years Planted	Average Spacing (feet)	Crown Class	Height (feet)	D.b.h. (inches)	Diam Base Crown (inches)	Crown Length (feet)	Crown Width (feet)
32	20	40	7.1	D	57.6	9.75	7.33	30.4	16.8
34	21	40	6.9	D	48.3	6.79	5.20	23.5	12.1
43	21	40	6.9	C	37.2	6.14	4.46	17.2	12.4
44	21	40	6.8	C	40.1	6.57	3.44	13.5	10.2
40	21	40	7.1	I	31.3	4.70	2.83	8.8	7.9
42	21	40	7.0	I	27.1	4.39	2.27	8.9	8.0
41	21	40	7.3	S	20.3	2.94	1.42	5.1	6.6
33	20	40	7.2	S	18.3	2.20	1.12	5.2	6.5
12	24	35	6.7	S	17.5	1.61	0.87	3.6	4.9
6	29	31	6.8	D	39.4	6.46	5.26	21.4	11.8
8	29	31	6.3	D	38.2	5.73	4.20	20.8	8.8
3	29	31	5.7	C	33.8	5.03	3.69	15.1	8.5
2	29	31	5.8	I	30.0	4.29	2.95	13.5	6.4
4	29	31	6.0	S	18.3	2.28	-	3.7	4.7
7	29	31	5.8	S	26.2	2.83	1.49	8.3	7.0
16	14	41	4.8	D	52.6	6.88	3.95	16.6	10.0
21	14	41	5.4	D	45.4	6.00	3.88	17.7	8.3
18	14	41	5.1	C	50.5	5.94	3.27	16.8	10.0
22	14	41	5.2	C	55.1	5.88	2.38	11.5	6.9
19	14	41	5.3	I	44.5	4.60	1.92	8.5	6.2
20	14	41	5.5	I	32.7	4.25	2.50	10.7	8.5
17	14	41	5.0	S	29.6	3.45	0.83	3.2	5.2
23	14	41	5.0	S	27.3	2.56	0.42	1.1	5.1
11	24	35	4.9	D	48.9	6.22	4.38	19.2	12.1
14	24	35	5.1	D	48.1	5.39	3.51	17.6	9.2
9	24	35	4.7	C	40.5	5.19	4.51	14.9	10.4
15	24	35	5.3	C	36.4	4.76	2.41	10.2	6.8
10	24	35	4.7	I	37.5	5.16	2.13	9.0	6.7
13	24	35	5.1	I	32.2	3.21	1.59	7.5	4.9
1	29	31	5.4	C	35.1	4.76	3.32	15.9	8.5
5	29	31	5.4	I	29.4	3.45	2.09	10.6	8.5
48	67	32	4.3	D	37.5	5.93	3.96	16.3	9.7
46	67	32	4.2	C	33.9	5.02	-	10.9	11.3
45	67	32	4.2	I	27.4	3.31	1.89	8.4	4.2
47	67	32	4.0	S	12.3	1.58	0.70	2.8	4.6
24	112	13	3.0	D	11.3	2.02	2.68	10.2	4.4
30	112	13	3.0	D	12.7	1.97	2.94	12.5	4.2
27	112	13	3.0	C	9.5	1.44	1.93	8.4	4.8
28	112	13	2.9	C	10.1	1.75	2.32	9.6	4.0
26	112	13	3.1	I	6.6	0.83	1.52	5.6	3.9
29	112	13	3.0	I	7.0	0.78	1.53	6.3	2.8
25	112	13	3.0	S	2.4	-	0.57	1.6	1.4
31	112	13	3.1	S	3.5	-	0.84	3.1	2.3
49	14	41	4.7	C	56.2	8.23	-	23.3	-
50	21	40	6.7	C	36.7	5.57	-	14.5	-

were not always uniform, and some stands provided sample trees which reflected differences in site quality and represented more than one spacing. For each sample tree observations were made of:

Crown class
Stem-to-stem distance to the four nearest competitors
Height to the first dead branch
Height to the first live branch
Height to the first wholly live whorl
Total height
Diameter of the stem at breast height (=d.b.h.)
Diameter of the stem at the base of the live crown (i.e. at the first wholly live whorl)
Average maximum diameter of the crown (measured along the plantation row and at right angles to it)

The number, and the diameter at the base, of all main branches, by annual whorls, were recorded on about one-third of the sample trees.

The foliage-bearing portions of the crowns were transported to the workshop and dissected. For each annual whorl, the stem, main branch, and internodal branch components were separated and placed in labelled kraft paper bags and air-dried for 4 to 6 weeks. Needles were then detached by vigorous shaking of the bags, assisted by hand picking. Large twigs and pieces of bark were discarded, and final cleaning of the needles was accomplished by sieving out small particles of extraneous material with 1/8-inch mesh screens.

All air-dry foliage was weighed -- to the nearest gram for large quantities. Samples of approximately 100 grams were then oven-dried at 100 C for 24 hours and weighed to 0.1 gram. Where needle-lots were less than 100 grams, air-dry weights were taken to 0.1 gram, and the whole amount was oven-dried. A different procedure was followed for six of the trees, whose air-dry foliage was further dried in a Moore cone kiln to a moisture content of 2.1% and subsamples were later oven-dried as already described.

The identity of all needle-lots was maintained, and the total oven-dry weight of foliage was calculated according to point of origin on the tree and summed for the entire crown. Branch data and foliage distribution within the crown were summarized by spacing, age, and crown class to provide data for morphological descriptions.

Stem and crown measurement data were coded, and an IBM 1620 computer was used to determine, and test the significance of, relations between total oven-dry weight of foliage and various measures of the stem and crown. These measures had either been found effective estimators of foliage weight for other species (Loomis *et al.*, 1966; Stiell, 1962; Storey *et al.*, 1955) or seemed likely to be useful for the purpose. For each relationship the effects of tree height, age, spacing, and crown class were tested through the addition of these independent variables by the stepwise regression process.

RESULTS AND DISCUSSION

Branch Development

Two types of branches are consistently formed in white spruce. The main branches develop annually from the lateral buds at the apex of the leader and form regular whorls or nodes. Data from the main branches in different parts of the crown are summarized in Table 2. Internodal branches, usually much smaller than the foregoing, are produced from buds distributed along the leader. In addition, epicormic branches may develop from dormant buds on the stem or on other branches. No diameter measurements or counts of internodals or epicormics were made in the primary sample, although the foliage production of both was recorded.

Main Branches

The crown is considered in three sections:

(1) The Dead Crown, which contains no living branches, extends from ground level to a height that varies directly with stand age and density. The numbers of whorls in the sample tree dead crowns ranged from 14 to 26, averaging from 3.0 to 4.7 main branches per whorl, or about 77 branches per tree. Dead branches on all trees persisted in a remarkably sound condition right to the base of the stem -- i.e. for up to 26 years.

(2) The Partially Live Crown is a transitional zone between the dead and the live crowns that is usually composed of only a few whorls and contains both living and dead branches. It can be absent. In the sample trees, partially live crowns had a maximum of 12 whorls but averaged 3, and these whorls averaged 1.2 live branches. Branch basal diameters tended to be largest in the partially live crown.

(3) The Live Crown is taken to begin at the first wholly live whorl and extends to the apex of the tree. Occasional dead branches are included, but this is the main green portion of the crown, as the name implies. In fact it forms the entire crown until canopy closure and shading induce the sequence of annual mortality of the lower branches. In the youngest plantation, the live crown occupied up to 98% of tree height. In a given stand, higher crown classes usually had higher live-crown ratios: e.g. a ratio of only 4% was found in a suppressed tree in the oldest 5' x 5' plantation, where the dominants had ratios of more than 30%. For trees of the same height and age, wider spacings usually resulted in higher live-crown ratios; young age seemed to offset close spacing in this respect.

The range in the number of live whorls was 4 to 23, and the average 12. Numbers were slightly higher for plantations at 7 x 7 feet but otherwise showed little difference according to spacing. Dominants usually had the most live whorls (average 14), and the suppressed trees the least (average 10).

The number of live main branches varied between 11 and 74, with an average of 37. This was equivalent to about three branches per whorl, although the actual numbers ranged from one to six. Within a spacing, there was no consistent difference in main-branch numbers between crown classes, although the smallest numbers were found in suppressed trees. Between spacings, there was no consistent difference in numbers for a given tree height. Age did not have a noticeable effect on numbers.

Basal diameters of main branches varied from 0.1 inch in the youngest whorls, or top five whorls in the case of suppressed trees, to 1.2 inches near the base of the live crowns of dominants. Diameters tended to be smaller on the average in the live crown than elsewhere in the tree, partly owing to the occurrence of the youngest branches. Spacing had no apparent effect on main-branch diameter, at least for spacings of 5 x 5 and 7 x 7 feet, where most of the observations were taken.

Internodal Branches

Observations on size and numbers of internodals were confined to two trees felled especially for the purpose. Both were codominants, one growing at a spacing of 5 x 5 feet and one at 7 x 7 feet (trees nos. 49 and 50, respectively, Table 1).

Internodal branches had an average diameter of 0.2 inches on each tree and a diameter range of from 0.1 inch to 1.1 inches. On both trees the internodals were more than three times as numerous as the main branches and added about 35% to the total branch basal area.

These internodals included 71 live epicormic branches on tree no. 49, and 47 on tree no. 50. These were well distributed throughout the partially live crown and the lower two-thirds of the live crown and were mostly 1 or 2 years old. Numerous dead branches of like size and appearance were present and were probably derived in the same way. A similar pattern of small branches was also observed in the primary sample. How many of the larger internodals were of epicormic origin could not be determined without sectioning. Epicormic branches are usually regarded as appearing in response to crown damage or stand opening, and Berry (1967) has described an example of such behavior in white spruce. However, epicormics have been reported to occur on *Abies concolor* (Cosens, 1952) and *Picea sitchensis* (Herman, 1964) growing under undisturbed conditions. It now appears that white spruce may maintain a population of epicormics within the live portion of the crown and, while most are ephemerals, some will perhaps develop into large and long-lived branches even without a change in the tree's environment.

TABLE 2. MAIN-BRANCH SIZE, NUMBER, AND LOCATION WITHIN CROWN

Tree No.	Live Crown			Partially Live Crown		
	Number Whorls	Number Branches	Avg Branch Diameter (inches)	Number Whorls	Number Branches	Avg Branch Diameter (inches)
32	23	74		3		
34	13	40	0.64	4	18	0.59
43	18	73	0.44	6	16	0.59
44	12	34		4		
40	16	38	0.37	3	6	0.65
42	13	30		1	4	
41	22	53		1	2	
33	17	49	0.22	0	0	0
12	10	35	0.19	1	2	0.30
6	13	49		3	12	
8	13	52		1	3	
3	12	37		2	5	
2	12	38		5		
4	7	11		1	5	
7	9	17		2		
16	14	42	0.58	4	13	0.74
21	12	30		3		
18	12	43	0.51	1	5	0.50
22	9	25		6	23	
19	13	30	0.31	3	11	0.51
20	10	29		7	18	
17	4	13	0.16	12	43	0.33
23	4	11		11	38	
11	12	38	0.71	3	14	0.86
14	12	42	0.49	4		
9	12	31	0.54	3	7	0.46
15	13	34	0.39	1	2	0.50
10	9	26	0.34	2	7	0.36
13	9	36	0.27	3	14	0.34
1	11	38		3	9	
5	12	26		2		
48	14	48		1	4	
46	10	34		4	16	
45	13	47		2	7	
47	13	34		2	5	
24	10	46		2		
30	12	42	0.44	1		
27	10	43		1	3	
28	13	49	0.35	1		
26	9	34	0.33	2		
29	9	31		1	0	
25	6	24	0.14	5	6	0.12
31	8	17		2		

TABLE 2. MAIN-BRANCH SIZE, NUMBER, AND LOCATION WITHIN CROWN (continued)

Dead Crown			Totals				
Number Whorls	Number Branches	Avg Branch Diameter (inches)	Number Whorls	Number Branches	Avg Branch Diameter (inches)	Branch Basal Area (square feet)	Tree No.
							32
23	81	0.57	40	139	0.59	0.264	34
20	83	0.54	44	172	0.50	0.235	43
							44
24	74	0.52	43	118	0.48	0.148	40
							42
							41
25	84	0.37	42	133	0.31	0.070	33
19	74	0.29	30	111	0.26	0.041	12
							6
							8
							3
							2
							4
							7
19	78	0.59	37	133	0.60	0.261	16
							21
24	99	0.46	37	147	0.48	0.185	18
							22
24	89	0.47	40	130	0.43	0.131	19
							20
19	61	0.51	35	117	0.40	0.102	17
							23
19	79	0.49	34	131	0.59	0.249	11
19	66	0.64					14
14	66	0.51	29	104	0.52	0.153	9
17	71	0.55	31	107	0.50	0.146	15
26	77	0.56	37	110	0.49	0.144	10
20	70	0.56	32	120	0.44	0.127	13
							1
							5
							48
							46
							45
							47
							24
							30
							27
							28
							26
							29
							25
							31

Synopsis

Branch data for the whole crown may be summed up as follows. The total of live and dead branches on a tree will almost invariably depend on the number of whorls, which will in turn depend on age. The range encountered on the sample trees was from about 30 main branches in the 13-year-old plantation to 172 on a 40-year-old codominant. Except in the former stand, all trees had more than 100 main branches. The inclusion of the internodal branches could increase these totals four-fold. The aggregate basal area of the main branches was at a maximum (0.264 square feet) on a 50-foot dominant, whereas a 17-foot suppressed tree in the same stand had a total branch basal area of only 0.041 square feet; the addition of internodals would raise these values by about one-third.

Foliage Production

The main branches usually bore about two-thirds of the foliage (range 37 to 99%). Spacing did not appear to affect the proportion. Within stands, the highest proportion of needles borne on main branches tended to be on suppressed trees.

Virtually all remaining foliage was formed by internodal branches. However, a minute quantity of foliage (a maximum of 1.4% of the crown total) grew directly on the main stem. As many as the 10 top internodes were needle-bearing, but the average was 5 (4 for suppressed trees). Spacing did not appear to influence this distribution pattern.

The weight of foliage contained by individual whorls increased gradually from the top downwards, in nearly all cases reaching a maximum in the lower third or quarter of the live crown. The heaviest whorl was usually the same one in which cumulative foliage weight reached 50% of the total. On the average (although the range was considerable), this was the ninth whorl from the top, regardless of crown class. The proportion borne by the heaviest whorl was usually greater in suppressed trees, where it averaged 30% of the total foliage weight as compared with about 20% in the other crown classes.

Total oven-dry weights for the whole crowns varied from 43 grams on a suppressed tree in the 13-year-old stand to 25 kilos on the largest 40-year dominant. For trees of a given height, crown weights in the 5' x 5' stand seemed to be lighter. The 3' x 3', 13-year stand seemed to have crowns that were much heavier for their size. At other spacings, trees of the same height seemed to have crowns of similar weight. Within stands, dominants had the heaviest crowns, suppressed trees the lightest.

TABLE 3. FOLIAGE WEIGHT AND DISTRIBUTION

Tree No.	Total Oven-dry Foliage Weight (grams)	Number of Needle-bearing Stem Internodes	% Foliage Borne on			Whorl of Greatest Weight (No. from apex)
			Stem Internodes	Internodal Branches	Main Branches	
32	25,173	6	0	43.1	56.9	16
34	12,088	4	0	47.4	52.6	11
43	8,191	5	0.1	39.9	60.0	12
44	7,386	5	0.1	55.4	44.5	8
40	2,434	8	0.2	46.9	52.9	9
42	1,627	5	0.2	57.9	41.9	8
41	506	10	0.7	26.5	72.8	14
33	442	6	0.1	4.3	95.5	14
12	166	4	0.1	1.2	98.7	9
6	10,788	3	0	30.8	69.2	10
8	8,166	5	0.1	25.6	74.3	9
3	3,372	6	0.2	33.6	66.2	8
2	1,870	4	0.1	51.6	48.3	11
4	331	3	0.4	62.3	37.3	8
7	821	4	0.4	58.5	41.1	9
16	6,009	4	0.1	30.6	69.3	9
21	6,603	4	0.2	54.7	45.1	8
18	4,086	7	0.3	26.9	72.8	10
22	2,632	1	0	37.9	62.1	9
19	1,861	4	0.1	58.8	41.1	12
20	1,855	4	0.2	53.5	46.3	7
17	193	0	0	8.6	91.4	8
23	167	0	0	5.7	94.3	10
11	10,489	3	0	45.0	55.0	9
14	4,932	5	0.1	52.4	47.5	9
9	6,476	4	0	57.7	42.3	9
15	1,524	5	0.2	49.6	50.2	9
10	1,783	5	0	47.6	52.4	8
13	745	6	0.3	14.5	85.2	9
1	4,691	5	0.2	42.0	57.8	9
5	1,377	5	0.5	55.1	44.4	9
48	5,734	7	0.1	27.7	72.2	10
46	4,404	7	0.2	28.7	71.1	9
45	914	7	0.4	23.8	75.8	9
47	61	4	1.2	7.2	91.6	13
24	2,472	6	0.3	40.9	58.8	7
30	2,342	6	0.5	36.5	63.0	8
27	1,071	4	0.1	30.5	69.4	7
28	1,499	5	0.3	34.5	65.2	8
26	836	5	0.5	39.1	60.4	7
29	651	5	0.7	35.2	64.1	7
25	43	3	1.2	23.9	74.9	5
31	185	3	1.4	37.1	61.5	6

TABLE 4. RELATION OF OVEN-DRY-FOLIAGE WEIGHT IN GRAMS (=W) TO VARIOUS STEM AND CROWN MEASURES

X Variable	Regression	No.	R^2	Standard Error of Estimate as % of $\bar{W}$
D.b.h. in inches = D	$W = 2912.35 - 2096.55D + 449.74D^2$	(1)	.89	40.7
Diameter of stem at base of live crown in inches = DBC	$W = 410.39 - 688.37DBC + 550.53DBC^2$	(2)	.97	23.1
Basal area of stem at base of live crown in square feet = BA	$W = -535.48 + 83314.12BA$	(3)	.96	24.3
(Length in feet) x (width in feet) of live crown = CA	$W = -1000.39 + 46.77CA$	(4)	.95	27.4
Volume of live crown considered as paraboloid = (0.393) x (crown length in feet) x (crown width in feet)^2 = CV	$W = 574.13 + 7.82CV$	(5)	.95	27.6
(D.b.h. in inches) x (live-crown length in feet) = DL	$W = -162.88 + 55.01DL + 0.108DL^2$	(6)	.95	27.4
(D.b.h. in inches) x (distance in feet from first live branch to stem apex) = DS	$W = -110.91 + 38.09DS + 0.107DS^2$	(7)	.94	31.0
(D.b.h. in inches) x (live-crown length in feet/total height in feet) x (100) = DR	$W = -173.32 + 56.32DR + 8.41DR^2$	(8)	.93	32.6

Foliage Weight Estimates

Good correlations were found between oven-dry weight of foliage and most of the crown and stem measures tested (Table 4). The addition of other variables (age, spacing, height) rarely increased the value of R^2 by more than 0.01. Relationships did not vary with crown class except for crown area and for the product of d.b.h. and distance from first live branch to stem apex. Even in these cases the results from pooled data were satisfactory.

Stem diameter at the base of the live crown seems to give the best estimate of foliage weight (Equation 2, Table 4). This parameter, used directly or converted to its basal area equivalent (Equation 3), would be suitable where optical calipers or other instruments for measuring the upper stem were available, or else where the tree could be felled.

In other situations, the most practical estimator is the product of d.b.h. and live-crown length (Equation 6). Both of these values are readily determined, unlike crown width, for example, which is difficult to measure accurately in some closed stands.

D.b.h. alone gives the least satisfactory results (Equation 1). Not only is the spread of data considerable, but the relationship becomes an inverse one for small diameters.

It should be emphasized that values of stem growth and crown size should be determined independently when relationships between these variables are being investigated. In these circumstances it would not be appropriate to estimate foliage weight from some measure of the stem.

ACKNOWLEDGMENT

Thanks are due Mrs. A. Blair, Biometrics Research Services, Department of Fisheries and Forestry, for performing the regression analyses.

REFERENCES

Berry, A.B. 1967. Epicormic branching in pruned white spruce. Bi-Mon. Res. Notes 23:7.

Clark, J. 1961. Photosynthesis and respiration in white spruce and balsam fir. State Univ. Coll. Forest., at Syracuse Univ., Tech. Publication 85.

Cosens, R.D. 1952. Epicormic branching on pruned white fir. J. Forest. 50:939-940.

Fraser, D.A., L. Belanger, D. McGuire, and Z. Zdrazil. 1964. Total growth of the aerial parts of a white spruce tree at Chalk River, Ontario, Canada. Can. J. Bot. 42:159-179.

Herman, F.R. 1964. Epicormic branching of Sitka spruce. US Forest Serv. Res. Pap. PNW-18.

Loomis, R.M., R.E. Phares, and J.S. Crosby. 1966. Estimating foliage and branchwood quantities in shortleaf pine. Forest Sci. 12:30-39.

Stiell, W.M. 1962. Crown structure in plantation red pine. Can. Dep. Forest., Forest Res. Br., Tech. Note 122.

Storey, T.G., W.L. Fons, and F.M. Sauer. 1955. Crown characteristics of several coniferous tree species. US Forest Serv., Div. Fire Res., Calif. Forest Range Exp. Sta., Interim Tech. Rep. AFSWP-416.

1249-2-69-2M