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Studies of Selection of Frost-Hardy Cryptomeria I.

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1. Introduction

Every winter, 5 to 12 year cryptomerias growing in southern Hokkaido invariably suffer frost damage to some extent. This area is near the northern economical limit of growing cryptomeria. The minimum and average temperatures in this area are about -17^0 C and -5^0 C, respectively. In this area, the snow cover differs considerably with the year and locality. During the winter of 1964-65, the snow depth ranged rom 10 to 20 cm in flat lands. The soil continues to freeze from early Deoember to late March and the depth of frozen soil is about 15 cm in midwinter. When the snow cover exceeds 30 to 50 cm from early winter, the soil generally remains unfrozen, but the cryptomeria stems at 5 to 10 cm below the snow surface usually remains in a frozen state for a considerable length of time.

Investigations of the damage of cryptomeria over several years revealed that most of the cryptomerias growing on the lee side of wind breaks and in low lands were generally undamaged, but those in wind-swept areas or on raised ground were seriously damaged during winter. In addition, the leaves and small twigs on the northwest side of tree; suffered serious damage. It may be added that even in a considerably damaged trees, the lower parts of the stem and the roots usually remained undamaged.

Frost damage of young cryptomeria in Japan Proper is usually observed on the south side of the stem 10 to 15 cm above ground. However, frost damage seldom occurs in Matsumae district.

From these results, it may be surmized that wintering young cryptomerias in frozen soil and wind-swept areas are damaged by ~desiccationdue to an unbalance of water in leaves, small twigs and terminal buds resulting from freezing of soil or stem for a considerable length of time. It may also be surmized that dry winds are one of the main factors contributing to damage in the wintering young trees in frozen soil.

As result of investigations of damage during winter continued for several years, it was also observed that even in the same meteorogical and topographical conditions, the degree of damage differs remarkably among trees, even among trees in the same stands or groves, and that there seems to be some relation between the degree of winter damage and tree-type of cryptomeria.

To obtain more information and to establish a method of selecting hardier trees, cryptomeria grown in Matsumae district in southern Hokkaido was classified into 3 groups and the degrees of ~desiccationresistance and frost-hardiness in these tree-types were studied under varying conditions for 3 years.

The authers wish to thanks Mr. MIZUGUCHI, K., Chief of Matsumae District Forestry Office for his constant encouragement and Mr.

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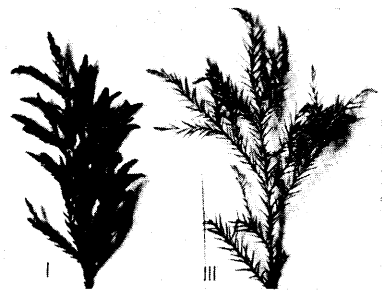

Figure 1. — Leaf-type.

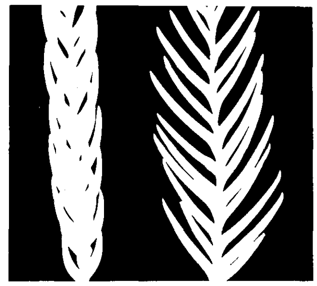

Figure 2. — Leaf-type.

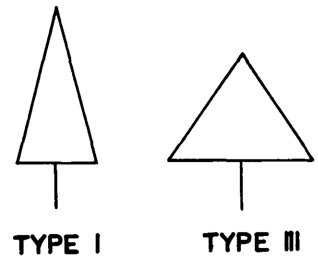

Figure 3. — Crown-type.

Suzuki, I., Maeda, T., and the late Mr. Saito, K. for technical assistance.

2. Material and Methods

(1) Classification of tree-type:

The majority of cryptomerias *(Cryptomeria japonica,* D. Don) grown in Matsumae district were introduced from the Akita prefecture. These cryptomerias were classified into 3 tree-types with reference to leaf form *(Figs. 1, 2),* the shape of crown *(Fig. 3),* bark surface, face of stem and pattern of shooting out branches.

As shown in *Figs. 1 and 2,* in the cryptomeria of type I, the green twigs are covered closely with short and thick needle leaves, while, in type III, they are covered sparsely with long and thin needle leaves. Type II was an intermediate between type I and III. The majority of cryptomerias (about 95%) grown in southern Hokkaido belong to types II and III.

(2) Sampling of green twigs:

For the present experiment, only five to ten year cryptomerias grown in artificial plantations were used. In preliminary experiments, a considerable difference in the frost-hardiness among twigs taken from different parts of the same tree were observed; twigs from the north side of a tree were usually more frost-hardy than those from the south side. Therefore, in all experiments only one-year-old green twigs of the branch growing on the north side from the widest part of a crown were used.

(3) Method of desiccation test:

Several twigs (15 to 20 cm in length) of cryptomeria were desiccated in a polyethylene bag containing dried silicagel of twice the weight of the twigs, for about 20 days at about 15^0 C. This method was tried first by Imai to select hardy cryptomerias. At one or two days intervals, some twig segments were removed and the water content and intactness were observed. The degree of desiccation resistance was represented by the duration for which twigs can withstand desiccation without injury.

It was demonstrated that a parallelism in hardy cells exists between desiccation resistance and frost-hardiness (Siminovitch 1952, Sakai 1959). In this experiment, the same correlation was also seen in cryptomeria twigs. However, in the desiccation test used here, it was impossible to test a large number of twigs under the same conditions in a limited number of days. Therefore, in the paper, a freezing test was used as the method for selecting hardier trees.

(4) Methods of freezing and thawing:

Samples were sent to Sapporo and were frozen in the cold room of the Institute of Low Temperature Science at the Hokkaido University. Several twigs (15 to 20 cm in length) wet with water were placed in a polyethylene bag and were cooled in a cold chamber at -5^0 C. After one hour, they were inoculated with frost and were then gradually transfered at hourly intervals to other cold chambers set at various temperatures from -5 to -30^0 C graded at 5 or 2.5^0 C intervals. After the twigs were cooled to the desired temperatures, they were kept at the temperatures for 16 hours, and then thawed in air at 0^0 C.

(5) Method of survival:

Frozen and thawed twigs were sent back to the Matsumae Forest Office and were planted in water to test the intactness of a twig segment as a whole. Browning of needle leaves was taken as a sign of injury. The extent of damage was determined within a few days after thawing in autumn and after about one month or later in winter. The degree of frost damage was classified into 4 grades on the basis of the extent of browning. The degree of frost-hardiness in a twig was represented by the lowest temperature at which it could withstand freezing without injury.

(6) Measurement of osmotic concentration:

To investigate the osmotic concentration of leaf cells, young twigs were always collected at 10 o'clock, and several thin sections were sliced from the leaf epidermal cells using a sharp razor blade. By the usual plasmolytic method, the osmotic concentration of the cells was determined in a balanced salt solution. Osmotic concentration was indicated as the equivalent of molar solution of sodium chloride.

3. Results

(1) Relation between tree-type and the degree of damage in natural conditions:

To clarify whether the degree of winter damage differs among the tree-type of cryptomeria, a damage survey was made at three different artificial plantations in the middle of June in 1963, using about 1800 young cryptomerias of nine or ten years of age. The number of cryptomeria of type I growing in the same plantation was too small to make an exact statistical investigation on damage.

Therefore, the total number of types I and II was compared with type III. In this investigation, the degree of damage was classified into 5 grades on the basis of the extent of browning of a tree; 0 (normal), 1 (slight), 2 (median), 3 (serious), 4 (killed). As shown in *Table 1,* it was found that cryptomeria of types I and II suffered much less frost damage than type III in every plantation.

Many cryptomerias and pines were seriously damaged during the winter of 1964-65. Approximately the same results were also obtained in the investigations made in many different plantations in June of 1965.

Table 1. — Relation between Tree-Type and Degree of Damage in 3 Different Artificial Plantations (1963).

Place	Tree Type	Degree of Damage				
		Normal	Slight	Medial	Serious	Total
Komata	I + II	123 (71.0)	30 (17.0)	13 (7.4)	8 (4.6)	174 (100)
	III	184 (41.6)	96 (21.7)	80 (18.1)	82 (18.6)	442 (100)
	Total	307	126	93	90	616
	Chi Square Test $\chi^2 = 47.2$ $v = 3$ $P < 0.001$					
Moyama	I + II	47 (77.1)	10 (16.4)	3 (4.9)	1 (1.6)	61 (100)
	III	129 (42.3)	73 (23.9)	24 (7.9)	79 (25.9)	305 (100)
	Total	176	83	27	80	366
	Chi Square Test $\chi^2 = 29.0$ $v = 3$ $P < 0.001$					
Futagoe	I + II	81 (51.6)	40 (25.5)	25 (15.9)	11 (7.0)	157 (100)
	III	103 (14.9)	83 (12.0)	62 (9.0)	442 (64.1)	690 (100)
	Total	184	123	87	453	847
	Chi Square Test $\chi^2 = 179.2$ $v = 3$ $P < 0.001$					

(2) Relation between tree-type and degree of frost-hardiness:

To investigate the degree of frost-hardiness in different types, 27 trees (type I and II) of 10 years age and the neighboring trees (type III) of the same age were selected at random from the same artificial plantation. Five twigs were taken from every tree in midwinter and then were frozen at -20^0 C for 20 hours. As shown in *Fig. 4,* twigs collected from trees of types I and II were much hardier than type III.

(3) Seasonal variations of frost-hardiness of types I and III:

Seasonal variations in the frost-hardiness of types I and III were investigated from November to April. The results obtained are summarized in *Fig. 5.* Cryptomeria twigs became frost-hardy for the first time in the middle of October. Frost-hardiness of types I and III gradually increased as the environmental temperature lowered, and their frost-hardiness reached its maximum in early January. After

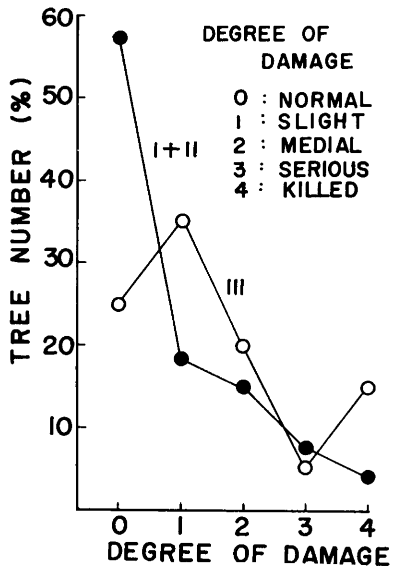

Figure 4. — Relation between tree-type and frost-hardiness.

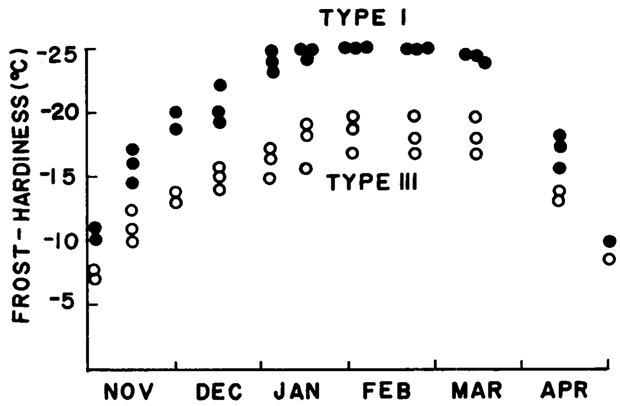

Figure 5. — Seasonal variations of types I and III in frost-hardiness

this, these levels remained nearly constant until early March and then decreased up to the middle of April. Twigs of type I always showed a higher degree of frost-hardiness than type III. In late January, twigs of type I could withstand freezing as low as -25^0 C for 16 hours, while twigs of type III could not survived freezing even at -18^0 C.

(4) Osmotic concentrations of types I and III:

Osmotic concentration of leaf epidermal cells taken from types I and III was investigated in November and December. In every experiment, the osmotic concentration of leaf cells of type I was much greater than that of type III *(Table 2).*

Table 2. — Osmotic Concentration of leaf cells.

	Type I	Type III
November	0.40 ± 0.05*)	0.33 ± 0.02
December	0.60 ± 0.02	0.45 ± 0.02

*) Osmotic concentration is indicated as the equivalent of molar solution of sodium chloride.

(5) Desiccation resistance of twigs of types I and III:

To determine the degree of desiccation resistance in twigs of types I and III, three twigs (15 to 20 cm length) were desiccated in a polyethylene bag containing dried silicagel of twice the weight of the twigs for 20 days at about 15^0 C. Some twig segments were removed and examined at one or two days intervals, and their water content and their intactness were investigated. As shown in *Fig. 6,* twigs of type I could withstand desiccation in a polyethylene bag even for 17 to 22 days without injury, while twigs of type III were destroyed after desiccation of only 7 to 10 days.

(6) Relation between frost-hardiness and desiccation resistance:

To clarify the relation between frost-hardiness and desiccation resistance, freezing and desiccation tests were simultaneously made using 20 twigs taken from each 10 trees (10-year-old) of types I and III. Results obtained are summarized in *Fig. 7.* From this, it seems apparent that there is a parallel correlation between frost-hardiness and desiccation resistance.

(7) Selection of the hardiest trees:

From the results obtained, it seems apparent that cryptomeria of type I is much hardier than type III. Therefore, in

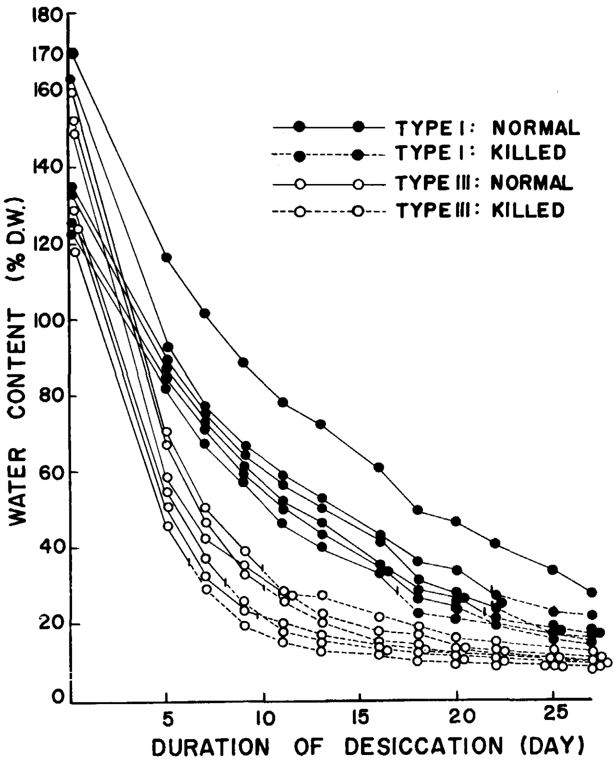

Figure 6. — Desiccation resistance of types I and III.

an initial attempt to select the hardier cryptomerias, about 750 trees of typical type I from 5 to 12 years were selected on the basis of their leaf form, crown type and pattern of out shooting branches, from artificial plantations of 770 hectars and numbered. Considerable efforts were required to check 750 trees individually in wide plantation in mountain areas covered with snow and then to collect twigs from designated places in each tree using a ladder for a few days.

About 3700 twigs from selected trees, five twigs to every tree, were frozen at -17^0 C in October 25 and at -23^0 C in November 30. A further selection from 122 trees in which almost all of twigs were undamaged by the two freezing tests, was made in January 20. Finally, 63 trees were selected as the hardiest ones by a third freezing test at -28^0 C.

Using about 60,000 scions taken from the selected hardiest 63 mother trees, their rooting ability was investigated in vinyl houses. As a result of this experiment, 42 frost hardy mother trees with high rooting ability were finally selected.

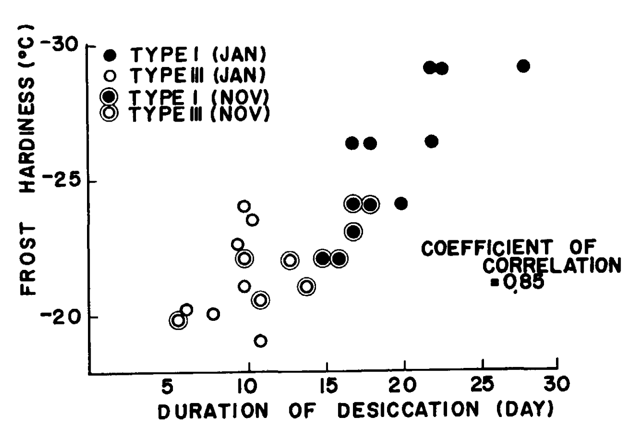

Figure 7. — Relation between frost-hardiness and drought resistance.

4. Discussion

(1) Desiccation and frost damage of cryptomeria in Japan:

Cryptomeria is the most important native forest tree in Japan, but it is a much tender tree than larch, Marie's fir and Ezo spruce. Cryptomeria is grown all over Japan except for middle and northern Hokkaido.

In the northern slopes of mountain areas higher than approximately 400 m above sea level in Japan Proper, especially in east Japan, the soil usually freezes throughout the winter and the depth of frozen soil comes to about 10 to 15 cm. Besides, in the Pacific seaboard areas of Japan, the air is a dry state, and dry strongish northwesterly winds sweep through during the winter. In these conditions, the wintering young cryptomerias on the frozen soil on northern slopes, especially in wind swept areas, are damaged seriously by desiccation due to an unbalance of water in leaves, small twigs and terminal stems (Sakai *et al.* 1963). While, young trees on the southern slope are usually undamaged, even in wind swept areas, because the soil on the slope remains unfrozen during winter (Okanoue 1960).

In cold districts, in which the average environmental temperature in January is below -4^0 C, the soil usually freezes all winter even in flat lands and on southern slopes. However, when the snow cover exceeds about 50 to 60 cm, the soil generally remains unfrozen. Under these conditions, the stems of cryptomeria at about 5 to 10 cm below the snow surface usually freeze for a long time, which makes water movement from the root to the higher stems difficult, and causes damage in the wintering trees above the snow surface.

Bark and xylem tissues at 10 to 15 cm above the ground on the south side of the stem are exposed to a remarkable fluctuation of temperature, and this area of stems is most sensitive to frost injury. Such injury is often observed in young cryptomeria growing in low and damp lands in rather warm districts.

One of the greatest difficulties in growing cryptomeria in Japan is to protect desiccation and frost damage during winter. Therefore, studies for selecting hardier cryptomeria and for protecting young cryptomeria from frost and desiccation damage have been undertaken by many workers in various districts throughout Japan.

(2) A method of selecting hardier cryptomeria:

There are many local varieties of cryptomeria in Japan, and the degree of frost-hardiness differs considerably among them. And since propagation by cutting is rather easy in cryptomeria, it is not difficult to select hardier cryptomeria and to propagate them.

As a result of the selection tried here, a relation between tree-type, especially leaf-type and frost-hardiness became so clear that hardier trees might be selected chiefely by leaf-type. The hardier trees selected have twigs covered compactly with short and thick needles and also they are characteristic in the short node of the stem and the compact growth as observed in many hardy varieties of fruit trees and other forest trees.

Leaf-type of cryptomeria varies, to some degree, with age and the conditions of growing places, especially in ridges and valleys, but it may be essentially considered as a character determined hereditarily. If many cutting seedlings taken from the same mother tree are planted under different conditions, this problem may be clarified more.

One of the most important unsolved problems on hand is to determine whether the cuttings taken from finally selected trees have nearly the same high ability to withstand freezing and desiccation as the mother trees and whether almost all of the seedlings of type I are much hardier those from type III.

To push the studies of selecting hardy cryptomeria further, it is necessary to make clear the following fundamental and unsolved problems: (1) comparison of frost-hardiness between the seedlings raised from the seeds and the cuttings from the same tree respectively, (2) effect of growing conditions on frost-hardiness, (3) relation between frost-hardiness and age, (4) comparison of the degree of frost-hardiness between the selected hardy cryptomeria and other hardy local varieties of cryptomeria; which have been regarded as hardy ones on the basis of investigations of damage in other districts in Japan, such as *Masuyamasugi* (Nagano prefecture), *Tonosugi* (Iwate prefecture), *Obiakasugi* (Kyushu), etc.

Cryptomeria of type I shows as slow and steady growth in young age. About 10 to 20 years later, its growth rate usually becomes higher than type III. Growth patterns of types I and III are to be investigated in detail, using many trees of many ages.

(3) Some problems concerning the selection of frost hardy plants:

Growing twigs are neither frost hardy nor able to increase their frost-hardiness, even when subjected to low temperatures. Soon after the growth of twig ceases, these twigs became frost hardy for the first time without being subjected to low temperature (Sakai 1955). As long as they are kept at higher temperatures (15 to 20^{0} C), their frost-hardiness cannot further increase over a definite level, but when subjected for several days to a temperature of 0^{0} C, the twigs considerably increase their frost-hardiness (Sakai, 1955, 1956). Soon after the growth of a tree ceases, considerable changes took place in the cells of a twig: remarkable decrease of both water content and the activity of cambium cells and increase of both starch content and osmotic concentration. It has been also confirmed that there is an intimate correlation in autumn twigs between the increase of frost-hardiness and the degree of maturation (Sakai 1955). Therefore, to select hardier trees, the determination of some indicators representing the degree of maturation of a twig, such as time of growth-cease, starch content, water content, osmotic concentration, activity of cambium cells, formation of cork layer on twig bark (Sakai 1955), electric resistance of twig bark (Wilner 1961, Sakai 1964 a), etc. can be used instead of the freezing test.

The difference of frost-hardiness among varieties in many plants has been generally explained by the length of the growth period: Varieties in which growth ceases earlier has a greater frost-hardiness than others. However, as shown in *Fig. 8*, there are two different patterns in the process of frost-hardening (Sakai 1959 b). In type A, the difference of frost-hardiness among varieties as observed

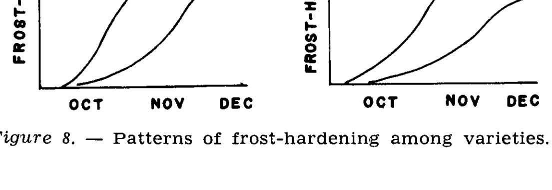

Figure 8. — Patterns of frost-hardening among varieties.

in autumn can hardly be found in winter. In this type, the difference of frost-hardiness among varieties can be found only in the rate of increase in frost-hardiness from autumn to winter. Therefore, in the species belonging to this type, a test for selecting hardier trees must be made in autumn. On the other hand, in cryptomeria which belongs to type B, as shown in *Fig. 5*, a test for selecting hardier trees can be made in any times from autumn to winter.

It was found that in twigs which could withstand continuous freezing without injury, the temperature most effective in producing maximum frost-hardiness was about -3^{0} C, irrespective of the environmental temperature at which they were growing (Sakai 1964 b). Willow *(Salix sachalinensis)* growing in Sapporo[3]) could even survive immersion in liquid nitrogen (-196^{0} C) in winter. However, the same willow growing in Tokyo can only withstand freezing at -30^{0} C in midwinter. Besides, the tender willow *(Salix Sieboldiana)* growing in Kumamoto[3]) in Kyushu, in the southern part of Japan, can only withstand freezing at -13^{0} C even in midwinter. However, when winter twigs from the willow were sent to Sopporo by air and then artificially hardened at -3^{0} C for 14 days, they could withstand freezing at -70^{0} C. Recently, twigs from willows growing in Singapore, Cairo and Lahore were sent to Sapporo where they were planted and allowed to grow for about one year. The following winter, these twigs could withstand freezing at -30^{0} C for a day. From these facts obtained by Sakai (1965), it seems apparent that even the willows growing in warm and hot climates have the heredital ability to withstand deep freezing, but they cannot fully exhibit these characteristics because they have never been exposed to temperatures low enough to develop them under natural conditions. Therefore, in the erperiments for determining the maximum ability to withstand freezing of plants growing in warm and hot climates and for selecting hardier trees using the wintering twigs in different climates, it is indispensable to previously expose plants and twigs to temperatures low enough to develop their frost-hardiness fully.

The survivors in severe environments such as in northern and high altitude regions, and those in plantations in which almost all of the trees were seriously damaged, have been selected as hardier trees. It is, however, necessary to analyze whether the reason of existence of these survivors was due to their high ability to withstand freezing or to some favorable topographical and micrometeorological factors in plantations in which they were growing.

Recently, the degree of frost-hardiness of cryptomeria grown in artificial plantations in northern and middle Hokkaido, which are much colder than the Matsumae district were investigated. However, no hardier trees than those selected in the Matsumae district could be discovered (Sakai *et al.* 1965).

The twigs of *Obiakasugi* grown in Kumamoto could withstand freezing at -22^{0} to -23^{0} C in midwinter. This is five degrees higher than any other local varieties growing in western Japan. This fact also indicates that cryptomerias growing in warm climates are not always tender, as pointed out concerning the willows in tropics.

Summary

To select hardier cryptomerias from artificial plantations of 770 hectars in southern Hokkaido, some experiments

[3]) Average temperatures in January in Sapporo and Kumamoto were about —6 and 5^{0} C.

were made. As a result of investigations in various artificial plantations of cryptomeria, it was found that in natural conditions cryptomeria of types I and II suffered less frost damage than tree-type III.

Twigs of different tree-types collected at random in midwinter were frozen at -20^0 C for 20 hours to determine the degree of frost-hardiness. Twigs from trees of types I and II were much hardier than type III. Besides, in the seasonal variations during the period from November to May, both frost-hardiness and osmotic concentration were much greater in the twigs of type I than type III. Twigs from trees of type I were also much greater than type III in desiccation resistance.

From these results, 750 trees of typical type I, ranging from 5 to 12 years were selected with reference to tree-type from artificial plantations of 770 hectars and marked. Finally, 46 trees with the highest frost-hardiness and high cutting ability among 750 trees were selected by 3 freezing tests and one cutting test.

Résumé

Titre de l'article: *Sélection de Cryptomeria résistant au froid. I.*

On a réalisé certaines expériences en vue de sélectionner, dans des plantations artificielles de 770 hectares, au sud d'Hokkaido, des *Cryptomeria* résistant au froid. On a trouvé, d'après les études faites dans diverses plantations artificielles, que les *Cryptomeria* de types I et II souffrent moins des dégâts du froid que les arbres de type III.

Des rameaux d'arbres de divers types récoltés au hasard au milieu de l'hiver ont été soumis à un froid de -20^0 C pendant 20 heures, en vue de déterminer le degré de résistance. Cette expérience a confirmé que les arbres de types I et II étaient plus résistants que ceux de type III. En outre, de novembre à mai, la résistance au froid et la pression osmotique étaient ensemble plus élevées dans les rameaux de type I que dans ceux de type III. De plus, les rameaux des arbres de type I résistent beaucoup mieux à la dessiccation que ceux de type III.

D'après ces résultats, 750 arbres du type I, de 5 à 12 ans, ont été sélectionnés et marqués dans cette plantation de 770 hectares. Finalement, on a retenu, parmi ces 750 arbres, 46 arbres qui, d'après trois tests de résistance au froid et un essai de bouturage, montrent la meilleure résistance et la meilleure aptitude au bouturage.

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Scaffolding for Work in Tree Crowns

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More and more attention is given to the development of tools in forestry which enable the ascension and climbing in crowns of high trees notably at the collection of forest tree fruits. A summarizing report carried out by FAO gives a total survey of these tools used in various parts in the world (Matusz 1964).

Forest research indicates more complicated problems because of more difficulties and challenging work output, more challenging than the usual collection of fruits. The work in crowns is mostly repeated on the same tree for several times and it is often necessary to erect various aids and apparatuses in the crown or in precincts. The present tools are not fully suited for the climbing of trees, mainly for the reason that they enable only access to the stem and not to all parts of crown, notably to its surface and top. In our conditions the tree net used for large American trees is unsuitable (Seal, Matthews, Wheeler 1962). Also the use of transportable ladders and extension platforms is mostly limited only on the lowest trees (up to 20 m.) and on localities with suitable terrain conditions (accessible ways).

For this reason, the controlled pollination in forest tree breeding or physiological and microclimatical investigations use mostly complicated tower constructions. Towers are as a rule of wooden material (Rohmeder-Schönbach 1959); recently also metal tubes applied in the system of building scaffolding are used. Besides that there exist also brick box constructions; for instance, Fraser (1957) describes a light portable tower from alluminium composed of individual frame parts.

These constructions enable work in tree crown space in several stories (according to the allocation of working platforms) and secure the maximal accension to the crown and the work safety. But their common drawback is a large consumption of material notably at the erection on large trees (high cost value) and high labouriousness (at the transport to the place of destination, at the construction and dismantling). This conduces high costs of these devices and makes the broader use in forest research impossible.

A new type of a simple mounted pollination tower for high trees was designed by my countryman Chira (1963).