Mechanism of Desiccation Damage of Forest Trees in Winter*

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Received November 1967

Abstract

To clarify the mechanism of desiccation damage of forest trees wintering on frozen soil and in wind-swept areas, some experiments were made using Ezo spruces and cryptomerias.

The results obtained are as follows: 1. The Ezo spruces growing in wind-swept areas were seriously damaged, while those in the lee of wind break were normal. 2. In seriously damaged spruces, the leaves, small twigs and upper stems died, but these basal stems and roots were usually remain undamaged. 3. In damaged spruces, the water content of leaves and small twigs was considerably smaller than that of normal ones, while that of stems and roots was almost the same as in normal ones. 4. During winter, the leaves and twigs of the spruce could withstand even freezing at −30°C.

These results obtained lead to the conclusion that the young spruces wintering in frozen soil and wind-swept areas are damaged by desiccation due to an unbalance of water in leaves, small twigs and upper stems which comes from the freezing of soil or stems for a long time.

It was also determined that the freezing points of xylem in the basal stem and root were −0.52 and −0.25°C respectively. Actually, it was confirmed that when a limited part of the basal stem was kept frozen at temperatures below −0.55°C, the water ascent in the stem was completely blocked.

I. Introduction

In the Pacific seaboard areas of Japan, dry strong north-westerly winds sweep the area throughout the winter. And even in Japan proper in the

* Contribution No. 892 from the Institute of Low Temperature Science.

northern slopes of mountain areas higher than 400 m above the sea level or thereabouts, especially in middle and east Japan, the soil usually freezes throughout the winter and the depth of frozen soil comes to 10 to 30 cm. Under these conditions, wintering conifers suffer desiccation damage during the winter. The frost and desiccation damages constitute the greatest limiting factor for growing forest trees in Japan. Therefore, many studies[1-3] on the protection of young forest trees from desiccation damage have been made by many workers in Japan. And in spite of the fact that the same situation is found in many foreign countries, especially in Sweden[4], Germany[5,6], Austria[7,8], etc., fundamental studies on desiccation damage in winter especially under natural conditions are very few in contrast to the amount of works done on frost damage.

For these reasons, to clarify the mechanism of desiccation damage of forest trees in winter, some experiments were made using young cryptomerias and Ezo spruces.

II. Materials and Methods

Materials

As experimental materials, 6-year-old Ezo spruces (*Picea Glehnii* Mast.) and 4-year-old cryptomerias (*Cryptomeria japonica* D. Don) were used.

Methods

The leaves of Ezo spruce change their colour from dark green to brown according to the degree of damage even in winter, unlike many other conifers. Therefore, the time at which damage occurs and the degree of damage are easily determined from the leaf colour. The degree of damage of Ezo spruce was classified into the following 5 grades on the basis of the change of colour: normal, slight, medial, serious (unrecoverable) and dead. The temperatures of cryptomerias wintering were determined by a thermister and were recorded. In the laboratory, the temperatures in various tissues of a young tree were determined by 0.2 mm copper-constantan thermocouples and were recorded by a high sensitive recorder.

To determine the specific temperature at which water ascent in the stem was blocked, a potted cryptomeria was placed in a chamber held at about 10°C, and a part of the stem 5 to 10 cm above the ground surface was locally kept at various temperatures with a thermoelectric apparatus (Fig. 1). Thereafter, the part of the stem above the chilled part was enclosed in a double polyethylene bag, in which two cotton bags containing 2 kg dried silica gel were placed (Fig. 2).

Fig. 1. Thermoelectric apparatus for cooling locally a part on a stem. A, stem part cooled locally (5 cm in length); F, cooling fin of thermoelectric apparatus; O, a lead-wire to a thermocouple; S, needle-type thermister for temperature control

This thermoelectric apparatus is composed of one pair. A part of the stem (A) was fixed between each component before cooling

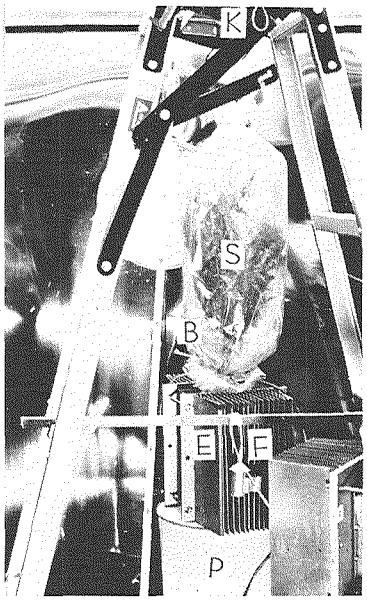

Fig. 2. Artificial inducement of desiccation damage in 4-year-old cryptomerias. B, a double polyethylene bag containing 2 kg of dried silica gel; E, thermoelectric apparatus by which a part of the stem at 5 to 10 cm above the ground surface is locally kept at −0.55 to −0.60°C in a frozen state; F, fin of thermoelectric apparatus; K, footstool from which polyethylene bag and two cotton bags containing 2 kg of the dried silica gel are hung; P, pot; S, cryptomeria

III. Desiccation damage of forest trees in Japan

First, various desiccation damages occuring under different conditions in Japan will be explained. In a map of Japan presented in Fig. 3, the places where desiccation damage usually occurs in conifers are indicated.

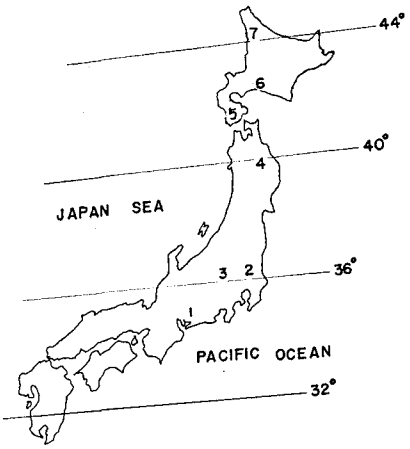

Fig. 3. Numerals in this map show the sites in which desiccation damage in conifers in winter usually occurs. 1, Tsukute; 2, Satomi; 3, Ikaho; 4, Takizawa; 5, Matsumae; 6, Tomakomai; 7, Toikanbetsu

The desiccation damage of cryptomerias grown on wind-swept northern slopes in northern mountain areas of Aichi Prefecture is shown in Fig. 4-1. The cryptomerias on the northern slopes, especially on the upper part on the slopes are usually seriously damaged. In contrast, in the southern and eastern slopes, desiccation damage is hardly observed, and the soil remains unfrozen during winter unlike on the northern slopes.

Desiccation damages in cryptomerias grown on the wind-swept northern slopes in northern Kanto district are shown in Fig. 4-2, 3. Young cryptomerias wintering on the northern and north-western slopes in this district invariably suffer desiccation damage to some extent, while the desiccation damage is also hardly observed in southern slopes. Therefore, on the northern and north-western slopes, cryptomerias can hardly be grown. In this district, minimum temperature usually falls to about $-15°C$, and the depth of frozen soil on the northern slopes generally comes to about 10 to 20 cm, while the soil on the southern and eastern slopes remains unfrozen even in midwinter.

In the winter of 1962–63, in the Pacific seaboard areas of Japan severe cold weather and a dry state prevailed throughout the winter. Therefore,

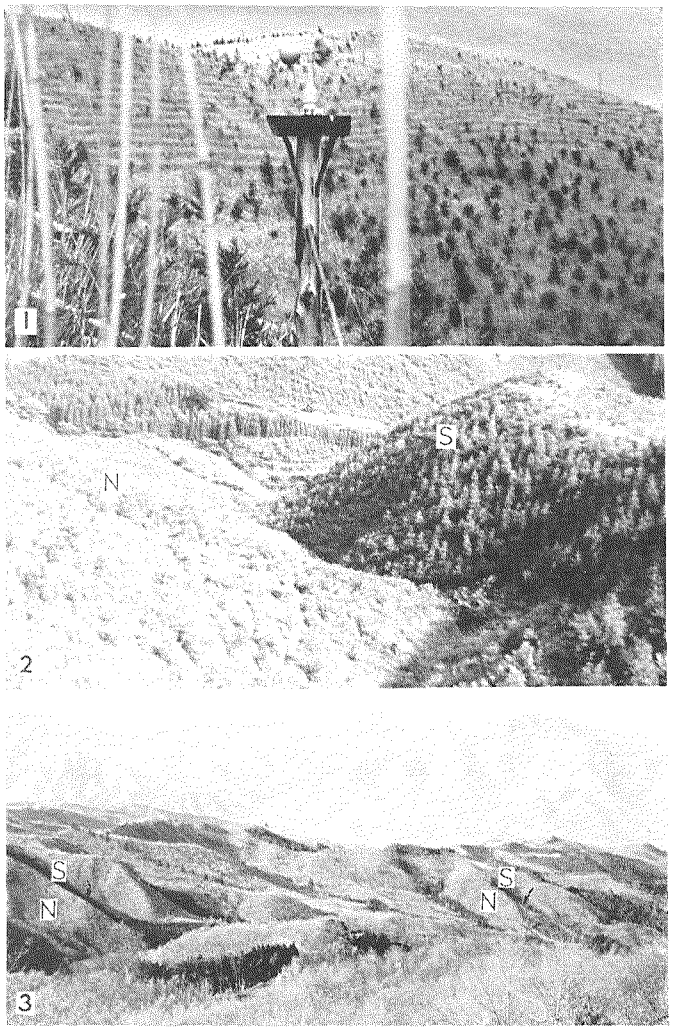

Fig. 4. Desiccation damage of cryptomerias in winter

1. Place: Northern mountain areas (Tsukute: 1 in Fig. 3) in Aichi Prefecture; Altitude: About 600 m above sea level; Latitude: 35°N. In the upper part of wind-swept northern slopes, cryptomerias can hardly be grown
2. Place: Satomi (2 in Fig. 3) in Ibaragi Prefecture; Altitude: About 650 m above sea level; Latitude: 36.5°N; N and S indicate northern and southern slopes respectively. Cryptomerias grown on northern slopes invariably suffer desiccation damage
3. Place: Ikaho (3 in Fig. 3) in Gunma Prefecture; Altitude: About 880 m above sea level; Latitude: 36.5°N; N, Northern slope; S, Southern slope. A characteristic contract in growing of cryptomerias can be observed between northern and southern slopes

Fig. 5. Damage at the tips of stems of large cryptomerias. In northern Kanto districts, this damage occurred in the winter of 1963–64 when severe cold weather prevailed during the midwinter. Even the stems of huge cryptomerias remained frozen for about one month

young cryptomerias and cypresses were seriously damaged by desiccation during this winter. Besides, the tips of stem of large cryptomerias suffered desiccation damage (Fig. 5). In the midwinter of 1963–64, in the northern Kanto district, daily maximum temperatures remained below zero for about 20 days. And the xylem in the trunks of cryptomerias, especially their center part and their northern side remained frozen for a long time. It may be considered that, under these conditions, desiccation damage occurred only at the tips of large trees which were exposed to strong winds. In the middle part of Hokkaido, which exceeds the northern economic limit for the growth of cryptomeria, the same damage at the tips of cryptomerias is generally observed in wind-swept areas.

In the northern parts of Japan proper and in Hokkaido, the soil usually freezes all winter even on flat land and on the southern slopes, provided that the snow cover does not exceed 30 to 50 cm. Therefore, desiccation damage in winter can be observed in all wind-swept areas, irrespective of the direction of the slope. The desiccation damages of conifer in the northern Tōhoku district and in Hokkaido are shown in Fig. 6–1, 2, 3.

Even in cold districts, in which the average environmental temperatures in January are below −4°C or thereabouts, the soil generally remains unfrozen if the snow cover exceeds 30 to 50 cm. However, the stem at 5 to 10 cm

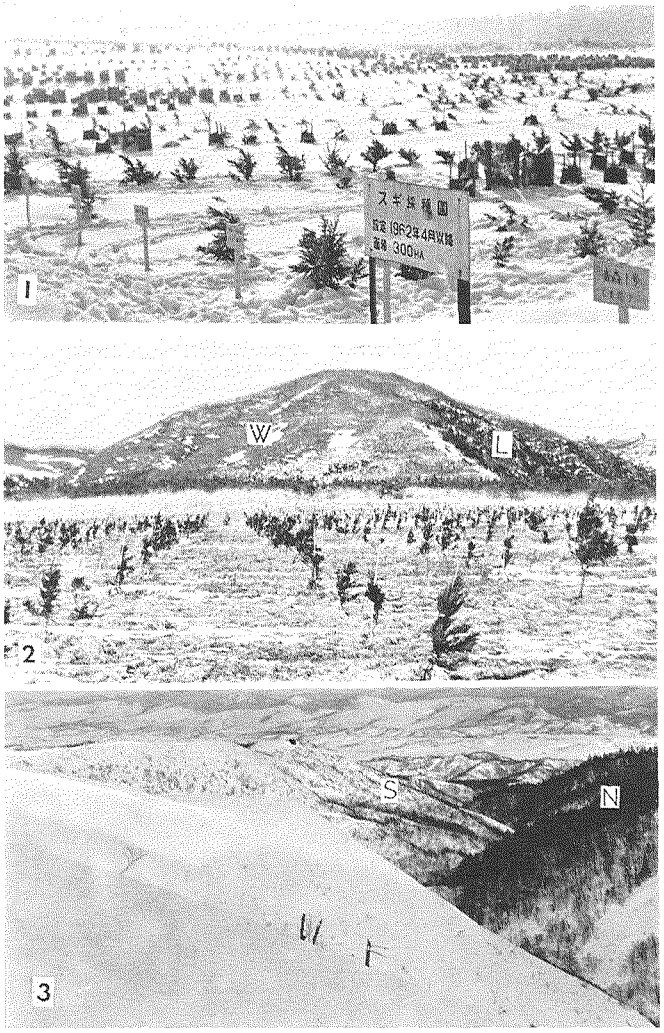

Fig. 6. Desiccation damage of conifers in winter

1. Place: Takizawa (4 in Fig. 3) in Iwate Prefecture; Altitude: 250 m above sea level; Latitude: About 40°N. In this district, cryptomerias suffer desiccation damage even on flat land in wind-swept areas. Soil freezes in flat land throughout the winter, when the snow cover does not exceed about 30 cm
2. Place: Matsumae (5 in Fig. 3); Altitude: 10 m above sea level; Latitude: 41°N; W, wind-swept area (south-western slope); L, lee side. In this district, very strong westerly winds sweep the area during winter, and cryptomerias suffer desiccation damage even on flat land in wind-swept areas
3. Place: Toikanbetsu (7 in Fig. 3); Altitude: About 30 m above sea level; Latitude: About 45°N. In this district, strong southerly winds sweep the area throughout the winter. And no conifers can be grown on wind-swept southern slopes (S), because of desiccation damage in winter unlike northern slopes (N)

below the snow surface is usually in a frozen state for a considerable length of time (Fig. 7, 8). Therefore, in wind-swept areas, the leaves, small twigs and upper parts of stems appearing above the snow surface are exposed to strong winds during winter, causing desiccation damage. Desiccation damage of American arborvitae appearing above the snow surface in wind-swept areas

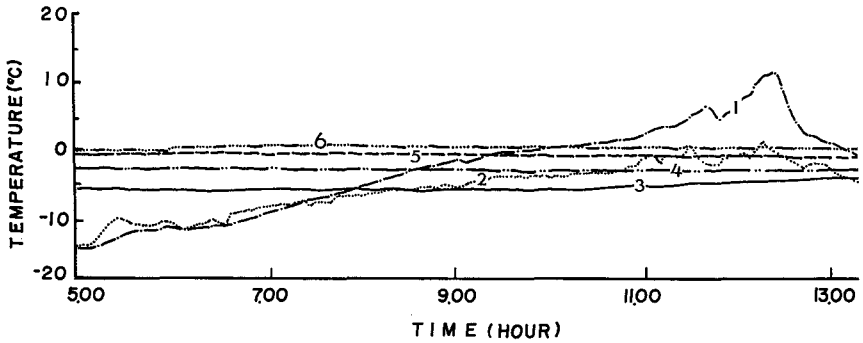

Fig. 7. Daily temperature fluctuations of a stem of cryptomeria at various heights above or below the snow surface

Date: February 21, 1967. Place: Matsumae (5 in Fig. 3). Diameter of the stem 60 cm above the ground surface: 3 cm. Snow cover: About 60 cm. Environmental temperature was measured in the shelter 60 cm above the snow surface. Curves: Temperature (south side) in outer xylem of the stem 10 cm above the snow surface (1), environmental temperature (2), temperature in outer xylem of the stem 10 cm below the snow surface (3), temperature in the snow at 30 cm (4) and 50 cm (5) below the snow surface, and temperature 5 cm below the ground surface (6)

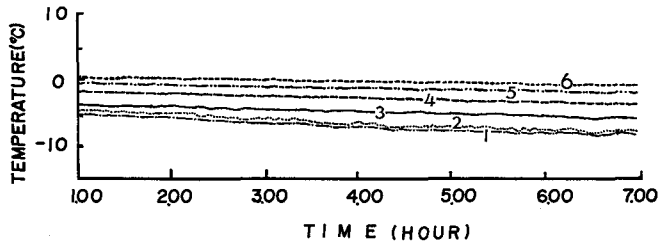

Fig. 8. Daily temperature fluctuations of a stem of cryptomeria at various heights above or below the snow surface

Date: February 10, 1967. Place: Matsumae (5 in Fig. 3). Diameter of the stem 60 cm above the ground surface: 3 cm. Snow cover: About 60 cm. Curves: Temperature in outer xylem (south side) of the stem 10 cm above the snow surface (1), environmental temperature (2), temperature in outer xylem (south side) of the stem 10 cm below the snow surface (3), temperature in the snow at 20 cm (4), 30 cm (5) and 50 cm (6) below the snow surface, respectively

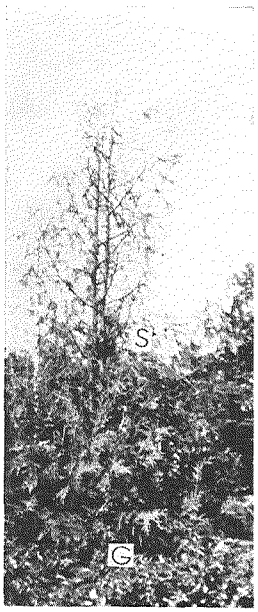

Fig. 9. Desiccation damage of American arborvitae appearing above the snow surface in wind-swept areas (January, 1966)

This type of damage in conifers is usually observed in Hokkaido. S, snow surface in winter (about 1 m above the ground surface); G, ground surface

is also shown in Fig. 9.

IV. Meteorological and topographical conditions at the experimental station

To investigate desiccation damage in Hokkaido, Ezo spruces (40 to 50 cm in length) were planted in the middle of May in 1961. This afforested land (6 in Fig. 3, 280 m above sea level) is located on a plateau facing Lake Shikotsu (250 m above sea level). This place is exposed to strong northwesterly winds from Lake Shikotsu during the winter. As shown in Fig. 10, A (60 m in length, 30 m in width and 10 m in height) and B are dense wind breaks on the slope facing Lake Shikotsu, while, C and E are wind-swept areas. The soils are composed of volcanic ashes and lapilli. In this plantation, the soil usually continues to freeze from about the middle of November to late April, and the depth of frozen soil amounts to about 30 cm in winter. The snow cover ranges from 20 to 30 cm. The minimum temperature and the average minimum temperature in January are about −20 and −6°C respectively. Meteorological conditions in winter in this plantation in the

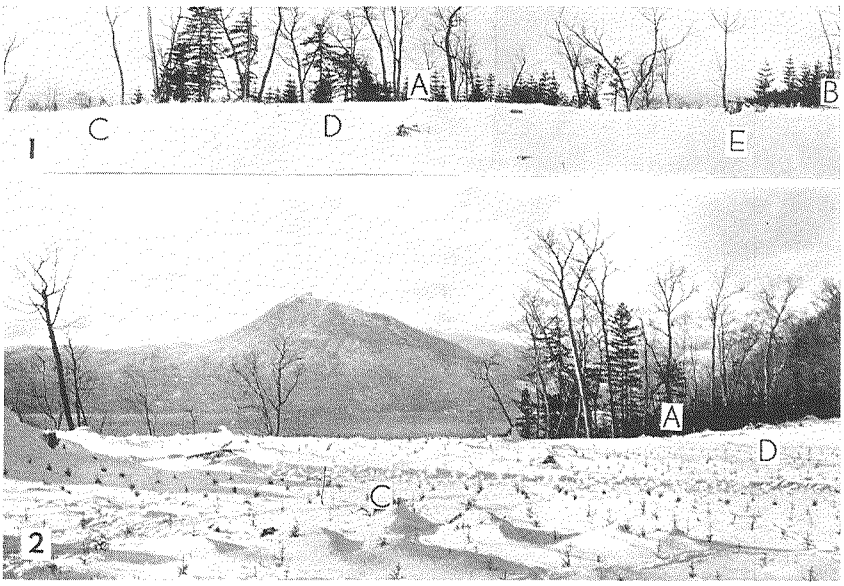

Fig. 10. Experimental plantation

1. General view of the experimental plantation
2. Details at the left part

Place: Plateau facing Lake Shikotsu (6 in Fig. 3, about 280 m above sea level). A, wind-break (60 m in length, 30 m in width and 4 to 10 m in height) stands on the slope facing Lake Shikotsu and it consists of Marie's firs and some deciduous trees; B, wind-break; C and E, wind-swept areas; D, lee side of wind-break

Table 1. Meteorological conditions in experimental plantation (1961–1962)

	Minimum air temperature (°C)	Mean maximum air temperature (°C)	Mean air temperature (°C)	Relative humidity (%)	Minimum soil temperature* 10 cm below ground surface (°C)
October	−5.2	14.3	8.5	56.0	—
November	−7.0	10.0	4.1	58.7	—
December	−13.3	1.2	−2.7	51.7	−4
January	−19.3	−0.7	−5.6	52.3	−7
February	−20.6	0.3	−5.7	52.0	−5
March	−16.5	2.1	−2.8	53.7	—

* Soil temperature was determined under conditions without snow cover. Snow cover ranged from about 20 to 30 cm in the winter

winter of 1961–62 are shown in Table 1. The temperatures of frozen soil at 10 to 20 cm below the ground surface varied from −2 to −7°C in January. The soil temperature was determined under conditions without snow cover.

V. Experimental results

Frost resistance of stem and root of Ezo spruce

Stems of Ezo spruce in winter were observed to withstand freezing at −30°C. The roots could also survive freezing at about −20°C during the winter. It is therefore unlikely that the stems and the roots of Ezo spruce wintering in the experimental plantation suffer frost damage during winter.

Time of occurrence of desiccation damage

The investigation of damage in the experimental plantation was made for a period from December to April using about 200 Ezo spruces. As shown in Fig. 11, in early January all spruces were normal. Afterwards, the damage gradually increases as the season advances from early January to late February. In the following winter, 1962–63, the soil froze for the first time in late October, one month earlier than usual, and the cold weather lasted from late autumn to winter. Therefore, almost all of the Ezo spruces were seriously damaged towards the end of January. The time of the onset of the desiccation damage differs considerably from year to year, depending on environmental conditions such as the time of freezing of soil, depth of frozen soil, depth of snow cover, humidity and strength of winds.

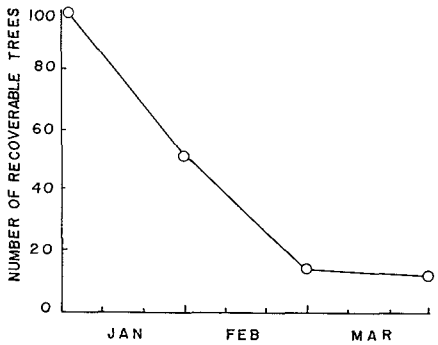

Fig. 11. Time of occurrence of desiccation damage
Investigation of damage was made in wind-swept areas (C in Figs. 10, 12)

Effect of winds on the degree of damage

To determine the effect of winds on the degree of damage, the investigation was made in the plantation in early March. The result is shown in

Fig. 12. Almost all of the spruces growing in the lee of the wind break (D), especially within a distance of about 60 m removed from the wind break, were normal, while those in the wind-swept area (C and E areas in Fig. 12) were seriously damaged during the winter. Also, the spruces growing in the low lands (20 to 40 cm lower) even in wind-swept areas are usually remain undamaged, because of a complete snow cover unlike those in flat and raised

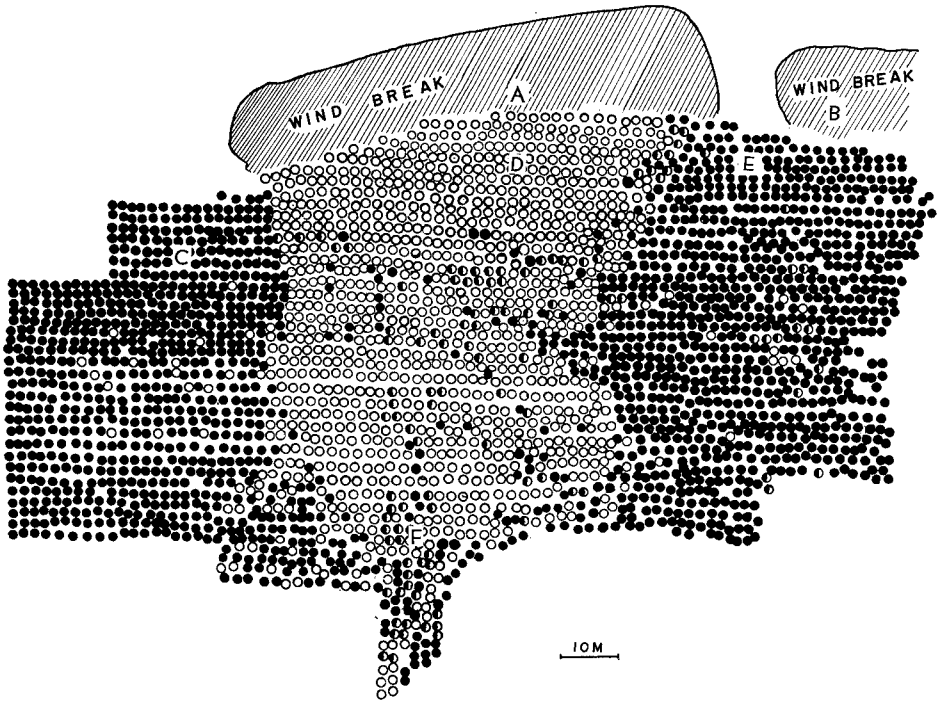

Fig. 12. Distribution of damaged trees in the experimental plantation
A and B, wind-break; C and E, wind-swept areas; D, lee side of wind-break; ○, normal; ◐, damaged; ●, dead
In this plantation, north-westerly strong winds sweep the area throughout the winter

Table 2. Effect of velocity of wind upon desiccation damage (March 5, 1963)

	Location of station*			
	D	C	E	F
Velocity of wind (m/second)	0	4.5	5	2.5

* The locations of stations are shown in Fig. 12

lands. This is a characteristic in the desiccation damage in winter. The velocity of wind was also determined at different places (C, D, E and F in Fig. 12) in the plantation. From the results presented in Table 2, it seems apparent that there is an intimate relation between the degree of desiccation damage and the velocity of winds.

Relation between degree of damage and water content in various tissues

To clarify the relation between the degree of damage and water content, the water content in different tissues of Ezo spruces which sustained damage in various degrees, were investigated in late February. As shown in Table 3, even in seriously damaged spruces, the water content of stems except for the upper parts and roots were nearly the same as in normal spruces. Water content of twigs and leaves of damaged spruces were much lower than that of the normal spruces. The critical water content of leaves in Ezo spruce was found to be about 25 to 30% per wet weight.

Table 3. Relation between the degree of damage and water content (February 28, 1963)

Degree of damage	Water content (% per wet weight)				
	Leaf	Twig	Stem*		Main root
			Cortex	Xylem	
Dead or serious	23.3	17.5	30.7	24.4	48.2
Slight and medial	28.8	23.5	34.0	25.3	50.7
Normal	33.3	27.5	33.5	25.7	51.9

* Middle part of stem

Damage was found in twigs, leaves and upper stems, but was not found in the middle and basal stems and roots

Based on the above results it is considered that the young trees wintering in frozen soil and wind-swept areas are damaged by desiccation due to an unbalance of water in leaves, small twigs and the upper stems including terminal buds which resulted from the freezing of soil or stems for a long time. In addition, the fact that water evaporation from tissues is remarkably accelerated by wind and the fact that Ezo spruces grown in less windy areas are usually undamaged, indicate that wind is a decisive factor causing desiccation damage in trees wintering in frozen soil. However, to clarify the mechanism of desiccation damage in winter, the following facts should be further investigated: 1) Determination of the temperatures at which water ascent in the stem and root is blocked. 2) Determination of freezing points of various tissues in stems and main roots. 3) Artificial induction of desic-

cation damage.

Temperature blocking water ascent in the stem

To determine the specific temperature at which the water ascent in the stem was blocked, a potted cryptomeria was placed in a chamber held at about 10°C, and a part of the stem 5 to 10 cm above the ground surface was locally kept at 0°C by the thermoelectric method (Fig. 1). Then, the part of the stem above the chilled part was enclosed in a double polyethylene bag, in which a cotton bag containing 2 kg of dried silica gel was placed (Fig. 2). After about 16 hours, the inside of the polyethylene bag became saturated with water vapour, and small water particles condensed on the polyethylene bag innerface (Fig. 13). After 5 days of this treatment, the chilled part of the stem was further cooled down to −3°C. After freezing at −3°C, the part of the stem was held at temperatures between −0.55 and −0.6°C in a frozen state. As a result, the part of the stem enclosed in the polyethylene

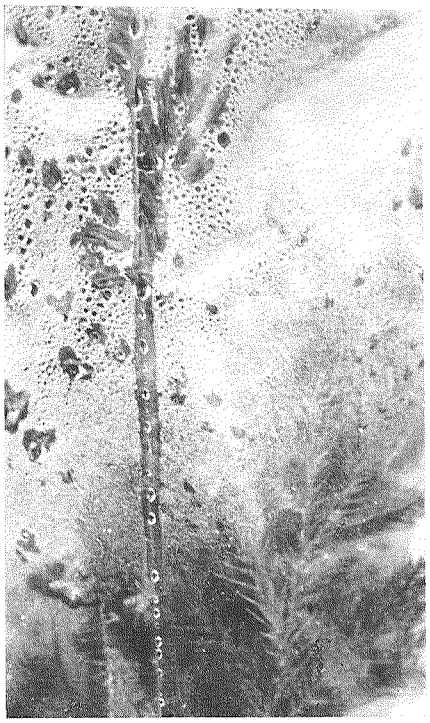

Fig. 13. Water particles condensing on the polyethylene bag innerface. The basal stem of a cryptomeria was kept at 0°C and was enclosed in a polyethylene bag containing 2 kg dried silica gel. The cryptomeria was potted 1 year prior to time of observation

bag was gradually dehydrated and finally killed after 5 days (Table 4).

Using a cryptomeria planted in a pot before the experiment, the same experiment was made. Even when the basal stem of the cryptomeria was kept at 0°C, no water particles condensing on the polyethylene bag innerface were observed. After 5 days of the treatment, the upper part of the stem

Table 4. Desiccation damage in the cryptomeria kept frozen at the basal stem, while the stem above the frozen part was maintained in a dry state (January, 1967)

Tissue tested	Water content (% per dry weight)		
	Before treatment	After treatment for 5 days	Viability
Upper part of stem	130	50	dead
Middle part of stem	108	49	dead
Twigs	112	20	dead
Leaves	178	45	dead
Immediately above the frozen part of stem	—	43	dead
Immediately below the frozen part of stem	110	94	normal

A potted cryptomeria was placed in a chamber held at 10°C, and a part of the stem 5 to 10 cm above the ground surface was locally kept at −0.55 to −0.60°C in a frozen state. Then, the part of the stem above the frozen part was enclosed in a double polyethylene bag containing 2 kg of dried silica gel. The cryptomeria was potted 1 year prior to the experiment

Table 5. Desiccation damage of a cryptomeria planted in a pot prior to carrying out the experiment (January, 1967)

Tissue tested	Water content after 5 days of treatment (% per dry weight)	Viability
Upper part of stem	22.7	dead
Middle part of stem	40.9	dead
Tip parts of twigs coming out from the middle part of the stem	12.4	dead
Lower part of stem	118.0	normal
Immediately below the cooled part of stem	120.0	normal

A potted cryptomeria was placed in a chamber held at 10°C, and a part of the stem 5 to 10 cm above the ground surface was locally kept at 0°C. Then, the part of the stem above the chilled part was enclosed in a double polyehylene bag, containing 2 kg of dried silica gel

and the tip parts of the twigs coming out from the middle part of the stem dried out, while the lower part of the stem remained normal (Table 5).

Freezing points of soil and xylem of the main root

A part of a main root (2 cm in length, 1 cm in diameter) at 1 to 3 cm below the ground surface was cut and enveloped with soil. Thermocouples were inserted in the center of xylem of the main root and on the soil to obtain these freezing curves. Tissue freezing point was calculated from the height of the plateau on a freezing curve. Freezing points of soil and xylem of the main root were found to be 0 and −0.25°C respectively (Fig. 14). Further, in the xylem which was stripped of bark from the main root, nearly the same freezing point (−0.26°C) was obtained (Fig. 15).

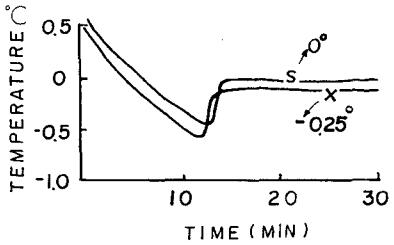

Fig. 14. Freezing curves of soil and xylem in a main root (January, 1967)
S: Freezing curve of soil; X: Freezing curve of xylem in a main root
A part of a main root (1 cm in diameter) at 1 to 3 cm below the ground surface was cut and enveloped with soil. Thermocouples were inserted in the center of the xylem and in the soil respectively

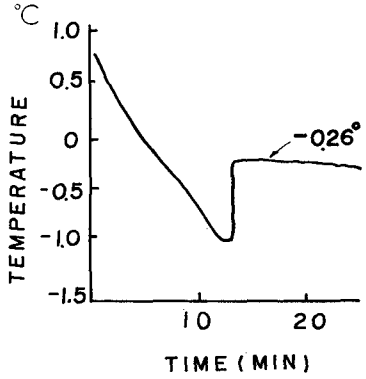

Fig. 15. Freezing curve of xylem in a main root (January, 1967)
A thermocouple was inserted into the xylem which was stripped of bark from the main root

Freezing points of bark and xylem in the basal stem

A piece of basal stem (1 cm in diameter) at 1 to 3 cm above the ground surface was cut and thermojuctions were inserted in the bark and in the center of the xylem. As shown in Fig. 16, the first rebound (1) occurred at about −1.0°C in the xylem and about one minute later, the other rebound (2) occurred in the bark. Further, another rebound in the bark was observed at about −3.3°C (3). It is apparent, therefore, that the first rebound in the bark (2) appeared as a result of the transmission of latent heat released by

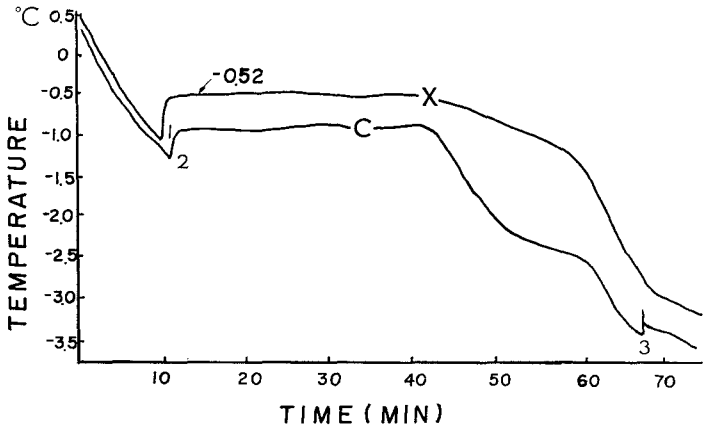

Fig. 16. Freezing curves of xylem and cortex in a basal stem (January, 1967)
X: Freezing curve of xylem; C: Freezing curve of cortex; 1 and 3 indicate super-cooling points of xylem and cortex respectively. Rebound (2) in bark appeared as a result of the transmission of latent heat released by freezing in xylem

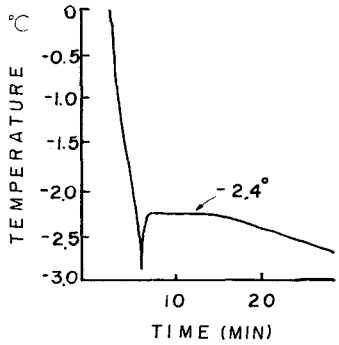

Fig. 17. Freezing curve of sap taken from the cortex on the basal stem (January, 1967)

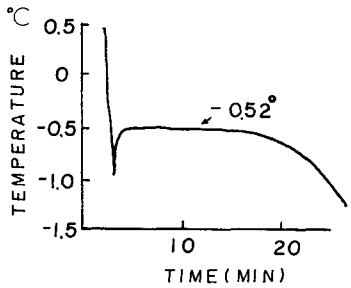

Fig. 18. Freezing curve of sap taken from the xylem in the basal stem (January, 1967)

freezing in the xylem. To look further into this problem, the freezing point of the sap taken from the bark on basal stem was investigated. As shown in Fig. 17, its freezing point was about −2.4°C. Besides, the freezing point of sap taken from the xylem in the basal stem was found to be about −0.52°C (Fig. 18).

VI. Discussion

Effect of low temperature on the water ascent in slender stems

The temperature at which water ascent is blocked in slender stems has been investigated by many workers. Hardley[9] reported that when a part of the stems of young trees (1 m in height) of maple and platanas was cooled to the temperatures between 0 and −2°C, the leaves wilted, but did not above 2°C. Zimmermann[10] reported that stems froze at −1 to −2°C and the water ascent was blocked in this temperature range. In his method, a part of stem (30 cm in length) was cooled by a coolant running through a rubber tube surrounding the surface of the stem. Therefore, the temperature of the stem above the cooled part descends depending upon the amount of water going up through the cooled part of the stem. If a part of the stem remains frozen, the temperature descent hardly occurs in the stem. In this method, the daily fluctuation in the amount of water ascent can be determined. However, the freezing temperature of stem and the temperature blocking water ascent can not be exactly determined. Johnston[11] reported that when the stem of *Pinus radiata* was kept at temperatures above −2°C (the freezing point), the rate of evaporation was hardly affected, but decreased considerably in the stem when kept frozen below −2°C.

In all of the experiments listed above, the effect of temperature upon the water ascent in stems was investigated by means of evaporation rate, wilting of leaves and temperature fluctuations in different parts of the stem above the cooled part. However, in these methods, it is difficult to determine the temperature at which water ascent in stems is blocked. In the present experiment, the stems and twigs above the cooled part on a stem were enclosed in a plyethylene bag to isolate them from the environment. Therefore, if water can pass through the cooled part of the stem, water particles condense on the polyethylene bag innerface, although dried silica gel is contained in the bag. Under this conditions, if the temperature in the cooled part of the stem is locally varied, the temperature at which the water ascent is blocked, is easily determined on the basis of disappearance of water particles condensed on the bag innerface or when an abrupt decrease in humidity in the bag is seen.

In the basal stem of cryptomeria, when the xylem is kept frozen at −0.55 to −0.60°C, which temperatures are just below the freezing point (−0.52°C), the water ascent is almost completely blocked. In this temperature range, the bark of the basal stem still remained unfrozen, because the freezing point of the bark is about −2.4°C. From these facts, the temperature which blocks water ascent in a stem can be regarded to be nearly the same one as the freezing point of the xylem.

In cold districts in which the environmental temperatures in January are below −4°C or thereabouts and the snow cover exceeds 30 to 50 cm, cryptomerias wintering above the snow surface, suffer desiccation damage in wind-swept areas, although the soil remains unfrozen. Under these conditions, the xylem of the stem at about 5 to 10 cm below the snow surface usually remains frozen for a long time, which makes water movement from the root to the higher stem difficult, and causes damage in such trees wintering above the snow surface.

Effect of soil freezing upon desiccation damage

The soil freezes at 0°C, while the xylem in main root freezes at about −0.25°C. When the temperature of the frozen soil is near 0°C, and the depth of frozen soil is comparatively slight, the bark and xylem in a main root remain unfrozen. Under these conditions, especially during the warm day time, water ascent may occur from roots in unfrozen soil to stem parts, even if the soil remains frozen at any depth below the ground surface. On the other hand, at night, as the temperature descends, the xylem of main root freezes again, which makes water movement difficult. For this reason, the depth of frozen soil may have a serious effect upon the degree of desiccation damage in warm districts. While, in severe cold districts, the depth of frozen soil has hardly no important effect on the desiccation damage, because the soil and main roots remain frozen even in the day time throughout the winter.

In some tender trees such as tea plants and oranges, if the freezing of soil continues for a few days, these leaves suffer a serious desiccation damage. Besides, in many subtropical plants, when the soil is cooled to the temperatures between 5 and 0°C, the ability of roots to adsorb water decreases considerably. Therefore, the leaves of these trees growing in wind-swept areas suffers desiccation damage even in the unfrozen soil areas.

Some methods for protecting forest trees against desiccation damage

One of the greatest difficulties in growing cryptomeria, cypress, pine, Marie's fir and Ezo spruce, which are important forest trees in Japan, is to

protect desiccation and frost damages during the winter. Hence, studies for selecting hardier cryptomerias and for protecting young cryptomerias from desication damage have been made by our team.[12] There are many local varieties of cryptomeria in Japan, and the degree of frost resistance differs considerably among them. Besides, since propagation by cutting is rather easy in cryptomeria, it is not difficult to select hardier cryptomerias and to propagate them. To select hardier cryptomerias from artificial plantations of 770 hectars in southern Hokkaido, various experiments have been made for several years.[12] As a result of the investigations in various artificial plantations of cryptomeria, it was found that, in natural conditions, cryptomerias of tree types I and II suffered less desiccation damage than type III. Twigs of different tree-type collected at random in mid winter were frozen at $-20°C$ for 20 hours to determine the degree of freezing resistance among them. Twigs from trees of types I and II were found to be much hardier than type III. Besides, twigs from trees of type I showed a considerably higher desiccation resistance than type III. 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. Finally, 46 trees with the highest freezing resistance and high cutting ability among 750 trees were selected by three freezing tests and one cutting test.

At present, in other forest trees, no trial for selecting hardier trees has been made in Japan.

In northern Kanto district, cryptomerias grown on the northern slopes are covered with soil during the winter to protect them from desiccation damage. In the eastern part of Hokkaido, in which severe cold prevails during the winter and where the snow cover is usually slight, young trees of Marie's fir and Ezo spruce are pinned down on the ground surface to facilitate a complete coverage of snow as early in the season as possible. To protect conifers from desiccation damage, they are planted to the lee side of wind breaks, in less wind areas and on the southern slopes on which soil remains unfrozen during winter in Japan proper.

Acknowledgments

The author thanks Mr. M. Saito, Mr. I. Takatoi, Mr. T. Watanabe and Mr. T. Eguchi for assistance in some of the experiments and the investigations.

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