Winter Hardiness of Grasses and Its Enhancement

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Temperate grasses and legumes introduced into Japan often encounter adverse conditions such as too high or low temperature, and wet condition, which jeopardize their perenniality or longer survival. In northern part of Japan, particularly in Hokkaido, cold winter tends to expose temperate grasses to severe environments for their survival.

When herbage can not endure the exposed conditions, winterkilling occurs in grasslands causing a great damage in its production and longevity. Actually, failure in wintering of temperate grasses has occasionally been observed in various districts belonging to the cold temperate zone,[4,7] even though northern types of the grasses are mostly grown there because of their superiority under the cold temperate condition.

From this point of view, attempt has been made to introduce hardier species or varieties having an ability to withstand harsh conditions to grasslands in this area. At the same time, the main purpose of breeding has been to enhance winter hardiness. However, it is not so easy to develop in a short period new cultivars with higher winter hardiness and higher productivity as well. Accordingly, improved methods of grassland management have also been devised to help wintering.

This paper presents the current status of research on the winter hardiness of grasses in Japan.

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Species or varietal difference

There are many species belonging to so-called temperate grasses. These species differed in hardiness and were evaluated from potentiality of wintering.[1,2]

The above results were obtained in the district where soil freezing scarcely advances and air temperature in winter does not normally decline to $-20° \sim -25°C$.

Severe winterkilling takes place more frequently in the eastern part of Hokkaido with much colder and worse conditions. For instance, mean minimum temperature is $-9°C$, in December, $-14°C$ in January, $-15°C$ in February and occasionally it declines to below $-25°C$, rarely to below $-30°C$. Snow cover begins at the end of December, and reaches around 60 cm depth. Soil freezing depth is nearly 40 cm in February.

Therefore, more intensive experiments have been conducted in the latter district where grassland farming is prevalent because the bad weather there inhibits other types of farming. Initially winter-hardy species such as timothy (*Phleum pratense*) was introduced into this area. The strategy had really succeeded until two decades ago. As more intensive utilization of grassland aiming at more economic land use became common, need for other species came to be recognized. The weakest point of timothy is slow regrowth, so that the plants can't endure frequent defoliation such as grazing. It is becoming more difficult for timothy to cope with the above change of grassland use.

As a result, several species which are more

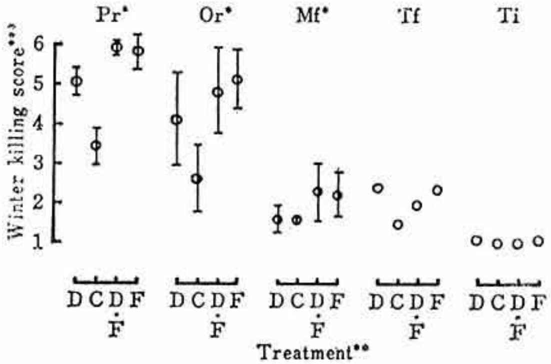

Fig. 1. Effects of snow removal and fungicide on winter killing in five grasses as evaluated by scores

* Mean value of 8–9 varieties is shown with its standard error (bar).

** D: Disease not controlled Snow cover not removed
C: Disease controlled Snow cover not removed
D.F: Disease not controlled Snow cover removed
F: Disease controlled Snow cover removed

*** Rated from 1 (slightest) to 6 (completely damaged)
Pr: perennial ryegrass
Or: orchardgrass
Mf: meadow fescue
Tf: tall fescue
Ti: timothy

vigorous in regrowth such as orchardgrass (*Dactylis glomerata*), meadow fescue (*Festuca elatior*), and perennial ryegrass (*Lolium perenne*) were introduced. Results of several trials revealed the hardiness of these species[16] (Figs. 1 & 2). Of the species used, the hardiest was timothy followed by tall fescue (*Festuca arundinacea*), meadow fescue, orchardgrass and perennial ryegrass in that order. As to the variety of these species Canadian ecotypes were more resistant to cold than other types.

Judging from the plant response to climatic condition of eastern Hokkaido, orchardgrass was thought to be promising among the species tested.[16] However, since this grass is not always hardy to winter in this area, studies on winter hardiness has been focused on orchardgrass in Japan.

Adverse conditions for wintering

1) Low temperature

Low temperature in winter causes freezing of plant tissues, and destroys the function of the plant itself when the temperature is lower than a tolerable limit for the plant. Such a critical temperature, however, ranges rather widely, depending on not only cultivar but also plant conditions, even in the same variety, such as part of plant,[13] way of hardening,[9,20] growing stage, way of cooling,[12,14] etc. Problem is a difference between artificial hardening and natural one. In the latter case, particularly, many environmental factors are involved in the process of the hardening such as light intensity,[9] way of temperature change,[12] nutritional condition of plant, soil moisture[19] etc. Therefore, experimental simulation of natural conditions seems to be very difficult.

Nevertheless, attempts have been made to determine the critical temperature. After artificial hardening trials, the temperature around $-15°C$ at crown was shown as fatal to the survival of orchard grass.[13] Recently, however, a longer period of treatment (more than 2 weeks) at much higher temperature such as $-4°C$ was shown to give critical damage to comparatively weaker cultivars.[20]

Among parts of plant, root was shown to be most susceptible to low temperature. Leaves were most resistant to it[13] (Tables 1 & 2).

Because of difficulties in simulating natural condition of wintering by experiments, the actual process happening in the field during winter has not been shown experimentally up to now. For instance, when a grass dies back, how it dies back under a natural condition remains unknown. Thus, it is not easy to understand even such a problem as critical temperature.

2) Disease attack

Even in wintering, diseases attack the grasses under the snow cover and occasionally

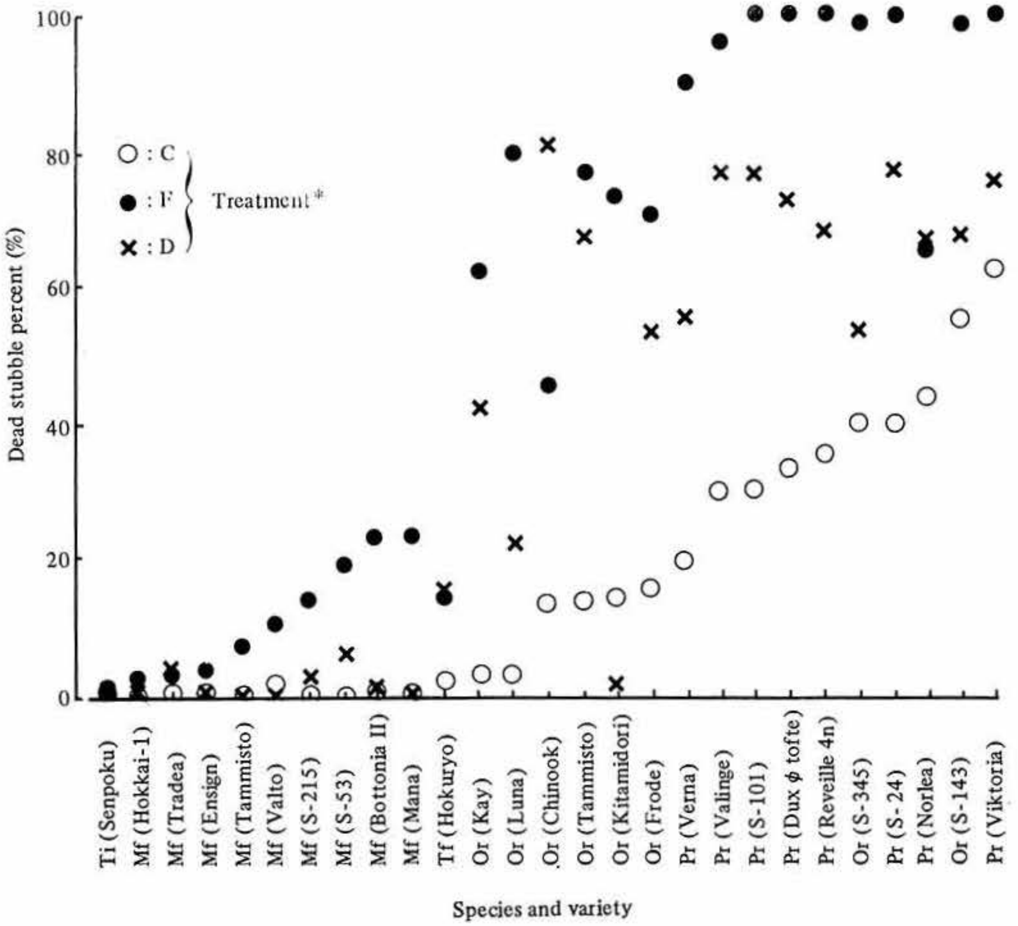

Fig. 2. Relation between freezing injury and damage by snow blight disease as expressed by percentages of dead stubbles
* Symbols used are the same as in Fig. 1.

Table 1. Freezing resistance of grasses with crown above ground

Species	Critical temperatures causing freezing damage of each organ (°C)					
	Leaf	Leaf base	Shoot	Leaf primordia	Root primordia	Root
Orchardgrass	−15[a)] (−20)[b)]	−10 (−15)	−10 (−15)	−7 (−15)	−15[c)]	−7 (−10)
Meadow fescue	−15 (−20)	−13 (−17)	−13 (−17)	−10 (−15)	−17	−10 (−15)
Perennial ryegrass	−13 (−20)	−13 (−17)	−10 (−17)	−10 (−15)	−17	−10 (−13)

a) Temperature when a slight injury occurred.
b) Temperature when complete death occurred is shown in parenthesis.
c) Lowest temperature when new roots from root primordia developed.

Table 2. Freezing resistance of grasses with subterranean organs

Species	Critical temperatures causing freezing damage of each organ					
	Leaf	Stem base	Shoot	Rhizome or Corm	Root primordia	Root
Timothy	−17[a] (−25)[b]	−15 (−25)	−15 (−25)	−10 (−15)	−25[c]	−10 (−15)
Kentucky bluegrass	−15 (−25)	−13 (−17)	−15 (−20)	−10 (−15)	−17	−7 (−10)
Tall fescue	−15 (−20)	−13 (−17)	−10 (−17)	−7 (−13)	−17	−7 (−10)
Smooth bromegrass	−13 (−17)	−7 (−15)	−10 (−17)	−7 (−13)	−15	−7 (−13)
Wheatgrass	−10 (−15)	−10 (−15)	−10 (−15)	−7 (−13)	−17	−7 (−13)
Reed canarygrass	−10 (−13)	−10 (−15)	−10 (−15)	−7 (−13)	−13	−7 (−13)

a), b) The same as in Table 1.
c) Lowest temperature when new roots developed from node of rhizome, base of stem, and shoot.

cause severe damage on grasslands. The main disease is caused by infection of *Sclerotinia borealis* and *Typhula* spp. The former has been considered to be more prevalent in eastern Hokkaido.[19] The species or varieties susceptible to low temperature are liable to be attacked by the disease. In other words, cold tolerance is accompanied with disease resistance, and freezing damage may become a trigger of outbreak of the disease.[11,18] Actually, in winter of 1974–75, severe damage occurred in grasslands of Tokachi district, eastern Hokkaido, due to the infection of *Sclerotinia borealis*.[4] However, usually, such big damage is not observed although it depends on conditions during winter. Moreover, if chemicals for sterilization are applied, outbreak of the disease can be suppressed rather easily.[11]

3) Encasing in ice

In early winter or later winter, the temperature is rather mild in the daytime but it lowers in the night. Comparatively warm temperature brings about rainfall or melting of snow cover.

Under such a condition, grasses are likely to be encased in ice. The encasing causes anaerobic condition which exerts a worse effect on the wintering of grasses.[5,6] In the spring of 1973, a severe outbreak of winter-killing of pasture species was observed in Kenebetsu area in Nakashibetsu, eastern Hokkaido.[7] It was not caused by *Sclerotinia* snow blight which used to occur in the past. In this case, the damage was severer on concave portions of fields. It was concluded that the primary factors determining the ratio of damaged area were grass species and micro-topography related to water conditions suggesting the encasing of grasses in ice (Fig. 3). Although direct evidence has not been presented for the suffocation of grasses in ice, several reports imply the possibility of its occurrence. Difference of resistance to encasing in ice among species was also shown by a model experiment.[6] It is well known that rain in winter including artificial one causes severe winterkilling of herbages.[7]

Recently, other mechanisms have been suggested for the reason why the encasing in ice gives an adverse effect on wintering of grasses. Effect of hardening is likely to be lost if grasses are encased in ice.[14] Damage due to low temperature was accelerated by an encasing condition in wheat trial.

4) Flooded condition

In early spring or late winter, melted snow occasionally remains as submerging water on

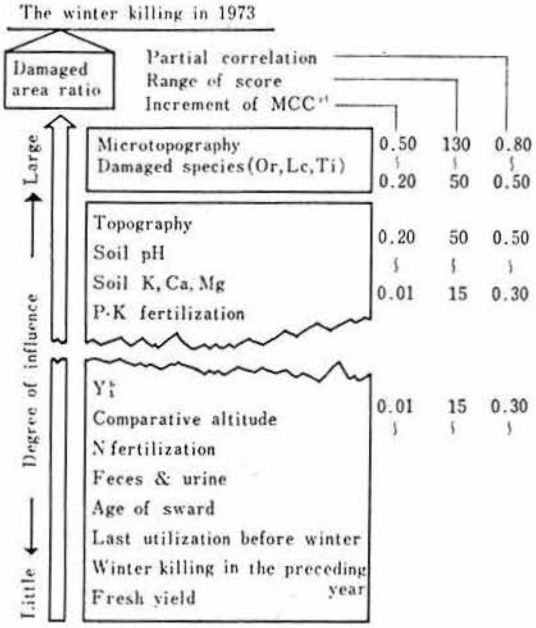

Fig. 3. Schema showing the relative rank of individual factors influencing the ratio of damaged sward area
a) MCC: Multiple correlation coefficient.
b) Y_1: Exchange acidity.

field surface. If the water stays for several weeks, there must be damage on grasses due to lack of air.[10] However, such a situation takes place very rarely.

Other factors, such as physiological weakening of grass and dryness in soil, are also considered to be related to the wintering. However, low temperature or coldness is the key factor to which the other factors are related in various ways.

Struggle against adverse condition

1) Preparation for struggle

This process is generally called hardening in the broad sense. Most temperate grasses have an ability to be hardened. The extent of hardening varies with species or varieties and conditions surrounding grasses. Natural condition is so variable that the extent of hardening is not consistent even in the same variety. When a grass is not hardened enough, it can't overcome the severe winter condition even if it has higher hardiness originally.

What happens in the process of hardening? Although it seems to be not completely under stood, following changes are suggested so far.

(1) Biochemical change such as increase in polymeric carbohydrate[8] (fructosan) content.

(2) Physiological change such as decrease in water content,[20] and occurrence of dormancy.[21]

(3) Morphological change such as increased number of new tillers,[17] and tillers or leaves changed to the flat shape like rosette.

(4) Improvement of nutritional condition.[17]

These processes advance with the changes of climatic conditions such as air temperature, length of daytime, and light intensity.

2) Struggle of grass in winter

Natural condition in winter is so complicated that the real state of struggle has not been understood well. Several adverse conditions act on the grass in various ways such as simultaneously or successively. Moreover, the period of exposure or the severity of adverse condition differs in different years. The grass has to withstand whatever conditions occur during winter, otherwise winter-killing will take place. On the other hand each cultivar has its own characters and has to struggle with winter by each resistance power prepared in hardening process.

Less hardy varieties tend to be damaged more or less almost every year. On the contrary, hardier ones rarely suffered from worse winter conditions. Unfortunately, plant type of hardier cultivars tends to approach to timothy type which is less productive in autumn than orchardgrass. If only cultivars of this type are introduced, meaning of introduction of orchardgrass will be lost.

Therefore, less hardy cultivars have to be used before we develop new cultivars which have both high hardiness and high productivity.

Tactics for better wintering

Better management of grasslands can help less hardy varieties to struggle with winter. However, as there is no practice to be done during winter, better preparation can lead better wintering. The management listed below was shown to be useful for cultivars intermediate in winter hardiness.

(1) Autumnal management including cutting timing and fertilization.[15]

(2) Promoted production of new small tillers or shooting by N, P, K application at the end of summer[17] (Figs 4. & 5).

(3) Improvement of drainage to avoid ice-encasing.[7]

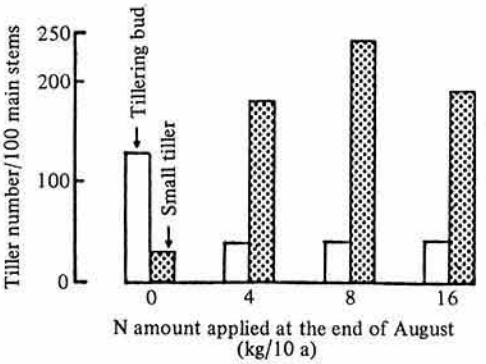

Fig. 4. Effect of N supply at the end of August on the tillering habit before wintering

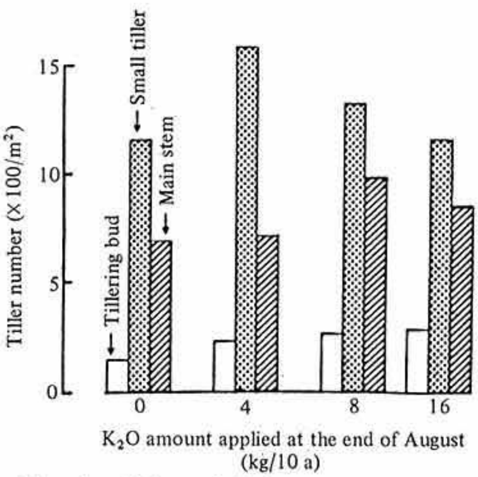

Fig. 5. Effect of K_2O supply at the end of August on the tillering habit before wintering

(4) Proper N application not to lower disease resistance[18] or spraying of chemicals for sterilization.

(5) Soil improvement to suppress weed invasion and disease infection.[17]

As each practice can increase the resisting ability to a specific adverse condition, the combination of several practices would be better for improving wintering.

Actually, higher productivity was sustained by the combination of several practices[17] (Fig. 6).

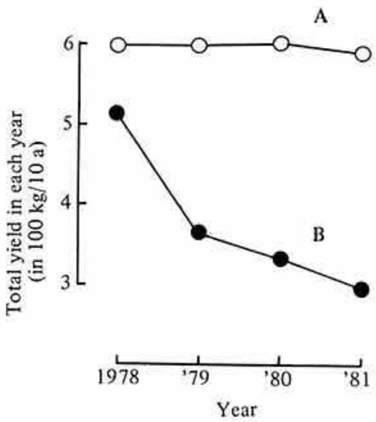

Fig. 6. Effect of management on yearly yields in an orchardgrass-dominant sward
A: K_2O applied in amount twice that of N.
Basic material applied.
No cut in early October.
B: N applied in amount same as K_2O.
Basic material not applied.
Cut in early October.
In both A and B, N, P and K were applied at the end of August.

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