オーチャードグラスのヨーロッパ品種の越冬性と低温下における伸長性

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Winter Hardiness and Growth at Low Temperature in European Varieties of Orchardgrass (*Dactylis glomerata* L.)

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Synopsis

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Genotypic variations of resistance to snow mold caused by *Typhula ishikariensis*, freezing tolerance, and growth at low temperatures were examined in 21 European and four Japanese varieties of orchardgrass. Geographic origin of genotypes had a strong bearing on resistance to snow mold and freezing tolerance, which were closely correlated ($r=0.89^{***}$). The tolerance to winter stresses of genotypes from various regions could be ranked in descending order as follows : Russian and Norwegian groups≧Swedish and Japanese groups>East European group≧Central European group>French group. Tolerance to winter stresses and recovery of growth in spring were slightly correlated as some genotypes from the warm regions grew well at low temperatures despite their low winter hardiness. In contrast, the correlations between tolerance to winter stresses, resistance to stem rust and growth in late autumn were strongly negative. The results indicate that genetic resources from eastern Europe deserve special attention from the view point of improving orchardgrass in Hokkaido because of the similarity of latitude, compared to northern Europe and the continental climate with more severe winter than in western Europe as well.

Key words : European variety, Fall vigor, Freezing tolerance, Orchardgrass, Snow mold resistance, Spring recovery.

Introduction

The cultivation of orchardgrass is mainly limited to the central and western regions of Hokkaido, which are the northern limit of its distribution in Japan. Extension of its cultivation into eastern Hokkaido is proving difficult, mainly because very low temperatures in this region often damage the crop to predispose it to snow mold disease caused by *Sclerotinia borealis* before establishment of continuous snow cover[14,16]. The demand and preference for orchardgrass over timothy in grazing remains high there however. It is, therefore, necessary to improve its winter hardiness to meet such demand there and also maintain stable forage production in central and western regions along the Sea of Japan.

We had examined earlier the Russian populations of orchardgrass from high latitudes because these were considered to adapt to very harsh winters[13]. They displayed an extremely high tolerance to winter stresses but their growth was poor especially in late autumn. This prompted us to search for genetic resources from relatively low latitude regions with an extended growing season. Because most temperate forage grasses including orchardgrass have evolved in the western part of Eurasian continent[9], it is appropriate to look for varieties from this region that meet the dual requirements of high tolerance to winter stresses and good growth at low temperatures. Previous reports suggest that the European varieties possess a wide diversity of traits including winter hardiness and high growth vigor at low temperatures depending on ecological conditions of their origin[1,5,9].

The objectives of the present study were to assess variation in resistance to snow mold, freezing tolerance, and field performance in selected European varieties of orchardgrass, and examine the interrelationships among these traits.

Materials and Methods

1. Varieties

We evaluated 21 orchardgrass varieties from various European countries including France (6), Germany (2), Switzerland (1), Netherlands (1), Denmark (4), Rumania (1), Ukraine (1), Sweden (2), Norway (1) and Russia (2). Four Japanese varieties from Hokkaido were included as the controls (Table 1).

A part of this work was presented at the 48th meeting (April 1993) of the Japanese Society of Grassland Science.

Table 1. Orchardgrass varieties evaluated in this study.

Site No.	Variety	Breeding site	Earliness to heading
	Northern Europe		
1	Dedinovskaja 4	Moscow, 55.8°N, 37.7°E, Russia	Very late
2	Sverdlovskaja 79	Cherjabinsk, 55.2°N, 61.4°E, Russia	Medium early
3	Apelsvoll	Kapp, 60.8°N, 10.7°E, Norway	Early
4	Dactus	Landskrona, 55.7°N, 12.7°E, Sweden	Medium early
5	Loke	Landskrona, 55.7°N, 12.7°E, Sweden	Medium early
	Eastern Europe		
6	Kievskaja Ranniaja	Kiev, 50.4°N, 30.5°E, Ukraine	Early
7	Olimp	Fundulea, 44.5°N, 26.6°E, Rumania	Early
	Central Europe		
8	Amba	Store Heddinge, 55.3°N, 12.4°E, Denmark	Early
9	Filippa	Store Heddinge, 55.3°N, 12.4°E, Denmark	Medium early
10	Jesper	Store Heddinge, 55.3°N, 12.4°E, Denmark	Early
11	Rano Trifolium	Store Heddinge, 55.3°N, 12.4°E, Denmark	Early
12	Leigestra	Lippstadt, 51.7°N, 8.1°E, Germany	Medium early
13	Lidaglo	Lippstadt, 51.7°N, 8.1°E, Germany	Late
14	Pizza	Vlijmen, 51.7°N, 5.2°E, Netherlands	Medium early
15	Prato	Nyon, 46.4°N, 6.3°E, Switzerland	Late
	Western Europe		
16	Amply	Rodez, 44.4°N, 2.6°E, France	Late
17	Arly	Rodez, 44.4°N, 2.6°E, France	Medium early
18	Athos	Brissac-Quince, 47.4°N, 0.4°W, France	Late
19	Lucyle	Lusignan, 46.4°N, 0.1°E, France	Late
20	Lully	Lusignan, 46.4°N, 0.1°E, France	Medium early
21	Lutetia	Lusignan, 46.4°N, 0.1°E, France	Late
	Japan		
22	Wasemidori	Sapporo, 43.1°N, 141.3°E, Hokkaido	Early
23	Okamidori	Sapporo, 43.1°N, 141.3°E, Hokkaido	Medium early
24	Hayking II	Sapporo, 43.1°N, 141.3°E, Hokkaido	Very late
25	Hokuto	Obihiro, 42.9°N, 143.2°E, Hokkaido	Late

2. Resistance to snow mold caused by *Typhula ishikariensis*

Twenty seeds per variety were sown (1 seed per 9 cm^2) on 22 September 1992 in a plastic box (40×30×7 cm) filled with 7 kg commercial soil (Engei baido, Hokkai Sankyou Co.) containing 0.4 g N, 1.5 g P_2O_5 and 0.4 g K_2O per kg soil. Seedlings were initially grown in a greenhouse and transferred outdoors on 19 October for hardening. The naturally hardened plants were inoculated with pathogen on 8 January 1993. *T. ishikariensis* (biotype A) was cultured at 15℃ for one month in a medium of wheat bran-vermiculite-distilled water (10 : 10 : 9, v/v)[3,13]. The inoculum was spread onto the soil surface at 0.06 g cm^{-2}. Plants were then covered with about 50 cm snow layer. Plants were transferred to a greenhouse 45, 60 or 75 days after inoculation. The number of surviving plants was counted three weeks after transfer.

3. Freezing tolerance

Seeds were sown into paper pots on 21 September 1992 and seedlings transplanted on 19 October into a field at a spacing of 30×10 cm. Freezing tolerance, expressed as LT_{50}, was tested on 7 December[11,13]. In each variety, 50 crowns of 3 cm long were randomly allocated to five freezing treatments at an interval of 2℃. Samples were placed in a programmable freezer (Tabai Co. LU-112). After ice nucleation at −2.5℃ for 8 h, temperature was reduced by 1℃ per h. Samples were removed at desired temperatures and placed in a freezer at 2℃ overnight. After regrowth for two weeks in a greenhouse, the number of surviving plants with new shoots and roots was counted.

4. Field performance

Seeds were sown into paper pots on 30 May 1991. Twenty seedlings of each variety were transplanted into a field at a spacing of 80×80 cm on 12 July. The plants were cut once in the sowing year. The recovery of plant growth in spring was visually scored two weeks after snow melt (28 April 1992) on a scale of 1-9 (1, poor growth due to severe injury and 9, good growth with no visible injury). The plants were cut twice on 3 July and 21 October. Resistance to stem rust caused by *Puccinia graminis* was scored on a scale of 1-9 (1, the most susceptible and 9, the most resistant) on 1 October. Regrowth in late autumn (fall vigor) was visually scored on a scale of 1-9 (1, poor growth and 9, good growth) on 11 November.

Results

1. Snow mold resistance

Resistance to snow mold was expressed as the mean % of survived plants in three inoculation treatments (Fig. 1). There were distinct differences in snow mold resistance among regional groups in descending order as follows; northern Europe, Japan and eastern Europe > central Europe > western Europe (Table 2). Of all varieties, Dedinovskaja 4 and Sverdlovskaja 79 (Russia), Apelsvoll (Norway) and Hokuto (Japan) were the most resistant with more than 80% of survived plant. The other three Japanese varieties, two Swedish varieties and Olimp from Rumania ranked next to them with 70 to 80% plant survival. Kievskaja Ranniaja from Ukraine, Lidaglo from Germany, Amba from Denmark and Pizza from Netherlands were moderately resistant with more than 60% plant survival. Other varieties from central Europe including Prato from Switzerland were susceptible, with plant survival varying between 30 and 53%. French varieties were the most susceptible with less than 34% plant survival.

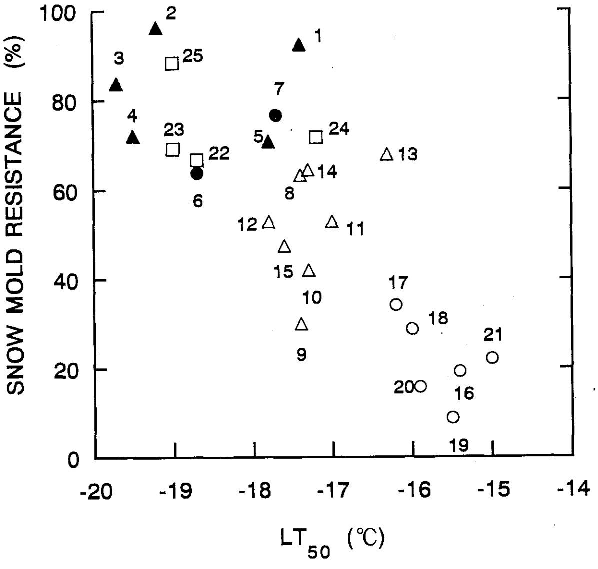

Fig. 1. Relationship between freezing tolerance (LT_{50}) and resistance to snow mold by *T. ishikariensis* (expressed as % plant survival). Closed triangles and circles, and open triangles, circles and rectangles indicate accessions from north, east, central and western Europe, and varieties from Japan, respectively. Numbers denote the sites listed in Table 1.

2. Freezing tolerance

Winter hardiness varied with the geographic origin of genotypes. In general, hardiness decreased from northern Europe (−17.4 to −19.7℃) to Japan (−17.2 to −19.0℃) ≧ eastern Europe (−17.7 to −18.7℃) ≧ central Europe (−16.3 to −17.8℃) ≧ western Europe (−15.0 to −16.2℃) (Fig. 1 and Table 2).

A Russian (Sverdlovskaja 79) and two Scandinavian (Apelsvoll and Dactus) varieties showed high tolerance to low temperature. Kievskaja Ranniaja and three Japanese varieties ranked next with LT_{50} values around −19℃. The other Russian, Swedish and Japanese varieties (Dedinovskaja 4, Loke, and Hayking II) were moderately tolerant with LT_{50} values varying from −17 to −18℃. All varieties from Denmark, Germany, Rumania and Switzerland also fell into this category with the exception of a German variety, Lidaglo. French varieties were the least tolerant as their LT_{50} values ranged from −15 to −16.2℃.

A significant positive correlation (r=0.89***) was found between resistance to snow mold and freezing tolerance (Table 3). This result is in agreement with that of a previous experiment using orchardgrass varieties different from those used in this experiment[3]. Cold hardy varieties with LT_{50} values lower than −18℃ showed resistance to snow mold with more than 60% plant survival. In contrast,

Table 2. Characteristics related to winter hardiness of orchardgrass.

	Freezing tolerance (LT_{50})	Snow mold resistance (%)	Spring recovery[1]	Fall vigor[1]	Stem rust resistance[1]
Northern Europe	−18.7 a[2]	85 a	5.6 ab	2.3 c	2.6 c
Eastern Europe	−18.2 ab	75 a	6.7 a	3.6 b	4.1 b
Central Europe	−17.3 b	57 b	5.6 ab	3.9 b	3.9 b
Western Europe	−15.7 c	26 c	5.1 b	5.5 a	5.8 a
Japan	−18.5 a	78 a	6.3 a	2.5 c	3.6 b

[1] Visual estimation is on a 1—9 scale where 1, worst and 9, best.

[2] Values within a column followed by the same letter are not significantly different (p=0.05) as determined by multiple-range test.

Table 3. Correlation coefficients among various characteristics related to winter hardiness of orchardgrass.

	Snow mold resistance	Spring recovery	Fall vigor	Stem rust resistance
Freezing tolerance	+0.889***	+0.458*	−0.855***	−0.870***
Snow mold resistance		+0.611**	−0.941***	−0.950***
Spring recovery			−0.698***	−0.652**
Fall vigor				+0.963***

*, **, *** : Significant at 5%, 1% and 0.1% levels, respectively.

French varieties were the most susceptible to both stresses. The moderately cold tolerant varieties mainly from central Europe, however, showed a comparatively wide variation in snow mold resistance. Of the varieties from central Europe, Danish varieties were, in general, more susceptible to snow mold than others.

3. Plant growth in early spring

An association was found between recovery of growth in spring and freezing tolerance or snow mold resistance (Fig. 2). On the average, the Japanese varieties bred at the experimental site in Sapporo exhibited good recovery in spring together with east European varieties. In contrast, all French varieties except Lully and nearly half of north European varieties showed poor growth. Of all varieties, Dedinovskaja 4 was the most vigorous in growth followed by Olimp and Kievskaja Ranniaja, which were moderately cold tolerant with LT_{50} values ranging between −17℃ and −18℃. Among French varieties, Lully showed good growth similar to that of the Japanese varieties.

4. Plant growth in autumn

Growth vigor of the aftermath of cutting on 21 October again varied with the varietal background (Fig. 3). Daily maximum and minimum temperatures during this period were 12.1 and 2.5℃, respectively. Growth vigor at this stage was, therefore, considered to reflect both tolerance to low temperature and the period of onset of winter dormancy, during which carbon assimilates are preferentially allocated to storage rather than productive organs[7].

Despite their low winter hardiness, French varieties showed vigorous growth (score : >5) in autumn characterized by low temperature and short days. In contrast, the Russian and Norwegian varieties grew little (score : <2) while the Swedish, and Central and East European ones were moderate (Fig. 3). Freezing tolerance in most of these varieties was also moderate. However, the late-heading varieties such as Dedinovskaja 4 and Hayking II showed poor growth in autumn despite their moderate freezing tolerance.

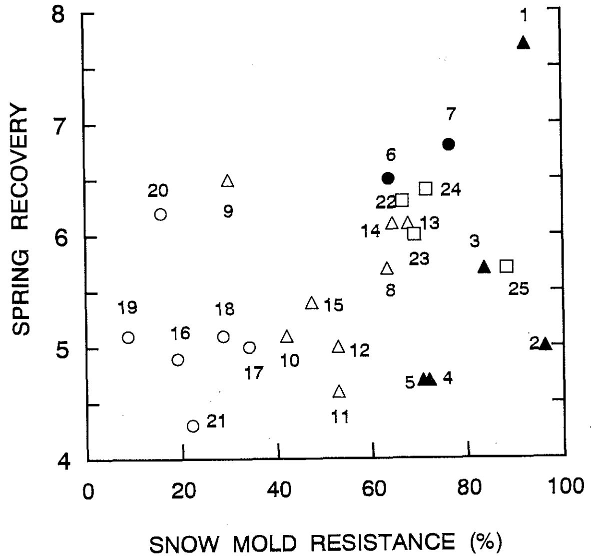

Fig. 2. Relationship between resistance to snow mold by *T. ishikariensis* (expressed as % plant survival) and recovery in spring (vigor of plant growth scored on a 1-9 scale ; 1, poor and 9, good growth). Numbers and symbols are as in Fig. 1.

5. Tolerance to stem rust infection

Resistance to stem rust was maximum in French varieties followed by Prato from Switzerland and Fillipa from Denmark. The Japanese varieties were moderately susceptible as the remaining varieties from central and eastern Europe, and Sweden (score : 3-4). The Russian and Norwegian varieties were the most susceptible.

Resistance to stem rust was positively correlated with autumn growth, and negatively with snow mold resistance and freezing tolerance (Table 3, Fig. 4 and 5).

Discussion

Forage grasses are widely distributed throughout Europe, but the feature and extent of their distribution show a consistent geographic pattern depending on mainly weather conditions. For instance, a predominant species varies from ryegrass to orchardgrass and to timothy as latitude increases.

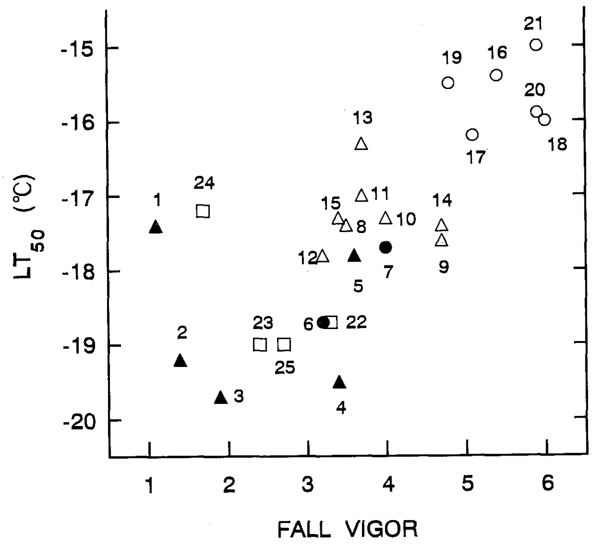

Fig. 3. Relationship between freezing tolerance (LT$_{50}$) and vigor of regrowth in late autumn (scored on a 1-9 scale; 1, no visible growth and 9, most vigorous growth). Numbers and symbols are as in Fig. 1.

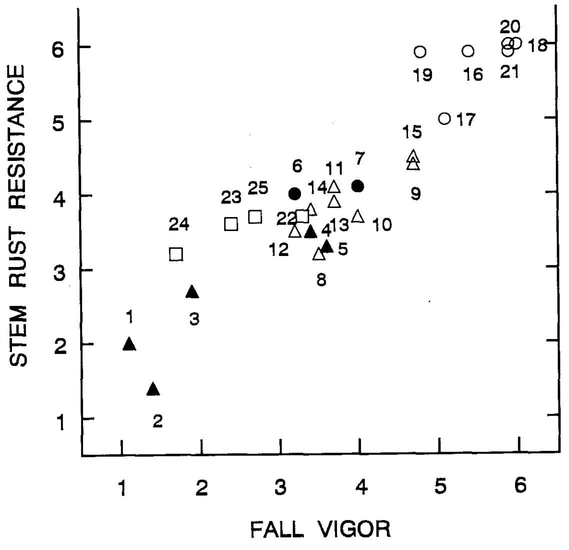

Fig. 4. Relationship between resistance to stem rust (scored on a 1-9 scale; 1, susceptible and 9, resistant) and vigor of regrowth in late autumn (scored on a 1-9 scale; 1, no visible growth and 9, most vigorous growth). Numbers and symbols are as in Fig. 1.

This pattern is also found in the differences of winter hardiness among varieties of orchardgrass. The varieties bred in northern Europe and eastern Hokkaido, where timothy is more dominant, have high tolerance to winter stresses as evidenced by Sverdlovskaja 79, Apelsvoll and Hokuto. In contrast, the varieties from France, where ryegrass dominates, have low winter hardiness.

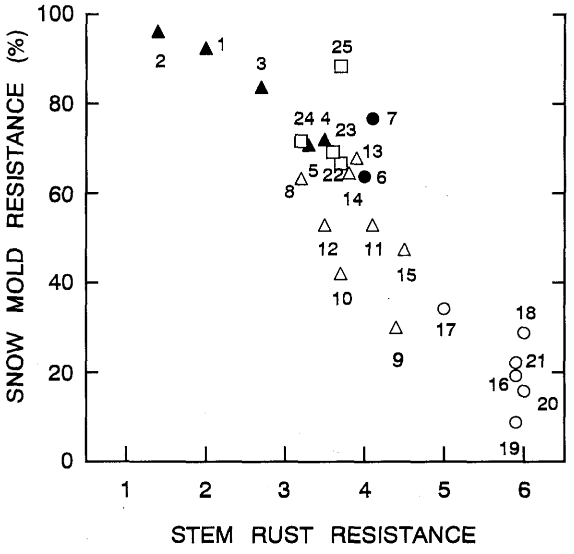

Fig. 5. Relationship between resistance to stem rust (scored on a 1-9 scale; 1, susceptible and 9, resistant) and snow mold by *T. ishikariensis* (expressed as % plant survival). Numbers and symbols are as in Fig. 1.

It has been reported that winter hardiness is associated with several factors in each region. In Hokkaido, tolerance to both low temperature and snow mold is very important[14-16]. We observed that maximum freezing tolerance was attained in Hokkaido varieties from late December to January in Sapporo[11]. Because freezing tolerance in this experiment was assessed on 7 December, plants seemed not to have attained maximum cold tolerance by then. However, the relative ranking of varieties remained consistent, because varietal differences in freezing tolerance can be discriminated by hardening treatment for two weeks in controlled environments[2,10].

Freezing tolerance and resistance to snow mold were positively correlated, but two Central European varieties (Filippa and Lidalgo) were exceptions to this overall trend. This seems due to the large variation in resistance to snow mold (ranging from 30 to 70% plant survival) and small variation in freezing tolerance (a difference of only 1℃ in LT$_{50}$ values).

Limited herbage production in off-season (late autumn and early spring) is a major drawback of hardy varieties. The response of leaf expansion to low temperature[5,6] is an important determinant in out-of-season production. It was reported that the varieties from northern Europe grew less vigorously than those from the warmer regions at 5℃[7] and hardening in winter-hardy varieties started at relatively higher temperatures and much earlier in season, thereby limiting herbage production in late autumn[8]. On the other hand, growth recovery in spring is greatly influenced by the ability to maintain normal leaf expansion at low temperatures in addition to winter injury. Hardier varieties can overwinter without much damage but tend to commence growth much later⁶⁾. Relatively weak correlations between growth recovery in spring and tolerance to winter stress, or autumn growth in the present study seem due to these antinomies. However, a close association between growth in early spring and in late autumn was reported in western Europe with mild winters[5,6].

Resistance to stem rust was positively correlated with autumn growth and negatively with freezing tolerance and resistance to snow mold (Table 3). Meyers and Chilton[12] reported a negative correlation between resistance to stem rust and winter hardiness in timothy that was severely infected with stem rust in the preceding year.

The fact that stem rust occurs in warm region more than in cool region will perhaps lead to more vigorous growth in autumn and a higher resistance to stem rust in the varieties from warm region than those from cool region. Correlation of stem rust resistance with recovery in spring ($r=-0.65$) was lower than that with growth in autumn ($r=0.96$). This may be partly explained by the fact that favoring growth at low temperatures of tender varieties and great tolerance to winter stresses of hardy varieties affects growth recovery complicatedly in spring.

Finally, the usefulness of various genetic resources for the improvement of orchardgrass in relation to its seasonal herbage production in Hokkaido is considered. Snow-cover for as long as five months in northern Hokkaido and low temperature below −20℃ in eastern Hokkaido suggest that Hokkaido is one of the most northern regions where orchardgrass distributes. Since Hokkaido is also located in relatively medium latitude, plants grow under long day condition for several months. Daily mean temperature falls below 5℃ much later in Sapporo than in other regions (Sverdlovsk, early October ; Moscow and Oslo, mid October ; Stockholm, late October). Winter in eastern Europe such as Rumania is relatively severe, but daylength there is similar to that in Hokkaido. From the viewpoint of further improvement of orchardgrass in Hokkaido, Olimp from Rumania (44 to 48°N) deserves special attention, as it exhibited vigorous growth in fall and high resistance to snow mold. Further efforts are, therefore, needed to search for useful germplasms from countries in medium latitude regions in order to improve the off-season growth of orchardgrass without reducing its winter hardiness.

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References

1) ABE, J. (1980) Winter hardiness in Turkish populations of cocksfoot, *Dactylis glomerata L. Euphytica* **29**, 531-538.
2) ABE, J. (1980) Screening techniques for cold tolerance in cocksfoot. *J. Japan Grassl. Sci.* **26**, 255-258*.
3) ABE, J. and N. MATSUMOTO (1981) Resistance to snow mold disease caused by *Typhula* spp. in cocksfoot. *J. Japan Grassl. Sci.* **27**, 152-158.
4) BORRILL, M. (1961) Grass resources for out-of-season production. Rep. Welsh Plant Breed. Stn. for 1960. 107-113.
5) COOPER, J.P. (1964) Climatic variation in forage grasses. I. Leaf development in climatic races of *Lolium* and *Dactylis*. *J. Appl. Ecol.* **1**, 45-61.
6) DAVIES, A. and D.M. CALDER (1969) Patterns of spring growth of different grass varieties. *J. Brit. Grassl. Soc.* **24**, 215-225.
7) EAGLES, C.F. and Ø. OSTGÅRD (1971) Variation in growth and development in natural populations of *Dactylis glomerata* from Norway and Portugal. I. Growth analysis. *J. Appl. Ecol.* **8**, 367-381.
8) FULLER, M.P. and C.F. EAGLES (1980) The effect of temperature on cold hardening of *Lolium perenne* seedlings. *J. Agric. Sci.* **95**, 77-81.
9) HARLAN, J.R. (1975) Crops and Man. American Society of Agronomy. Madison. pp. 63-81.
10) LOLENZETTI, F., B.F. TYLER, J.P. COOPER and E.L. BREESE (1971) Cold tolerance and winter hardiness in *Lolium perenne*. 1. Development of screening techniques for cold tolerance and survey of geographical variation. *J. Agric. Sci.* **76**, 199-209.
11) MORIYAMA, M., J. ABE, M. YOSHIDA, Y. TSURUMI and S. NAKAYAMA (1995) Seasonal changes in freezing tolerance, moisture content and dry weight of three temperate grasses. *Grassland Sci.* **41**, 21-25.
12) MEYERS, W.M. and S.J.P. CHILTON (1941) Correlated studies of winter hardiness and inbred progenies of orchardgrass and timothy. *J. Amer. Soc. Agron.* **33**, 215-220.
13) NAKAYAMA, S. and J. ABE (1996) Winter hardiness in orchardgrass (*Dactylis glomerata* L.) populations introduced from the former USSR. *Grassland Sci.* **42**, 235-241.
14) OZAKI, M. (1979) Ecological study of *Sclerotinia* snow blight disease of orchardgrass. *Bull. Hokkaido Pref. Agric. Exp. Stn.* **42**, 55-65.*
15) SHIMADA, T. (1989) Breeding studies on freezing tolerance and resistance to *Sclerotinia* snow mold of orchardgrass. *In* Proc. 1st Intl. Symp. Agric. Tech. Cold Regions. Obihiro. pp.123-130.
16) SHIMADA, T., S. SHIBATA and I. MASUYAMA (1993) Meteorological factors responsible for winter injury of orchardgrass. *J. Japan Grassl. Sci.* **39**, 77-85.
*: In Japanese with English summary.

要　旨

中山貞夫・大同久明*・阿部二朗（1997）：オーチャードグラスのヨーロッパ品種の越冬性と低温下における伸長性．*Grassland Science* **43**, 224–230．北海道農業試験場（062 札幌市豊平区羊ヶ丘 1），
* 草地試験場（329-27 栃木県那須郡西那須野町千本松 768）

ヨーロッパ各国より導入したオーチャードグラス21品種に北海道育成4品種を加え，幼苗の耐凍性と雪腐病抵抗性（黒色小粒菌核病 *Typhula ishikariensis*）の検定および圃場における早春の草勢，病害，晩秋の伸長性を調査し，育種材料としての評価を行った。耐凍性および雪腐病抵抗性は品種の地理的起源と密接に関連していた。これらの抵抗性の品種間の順位はロシア・ノルウェー群≧スウェーデン・北海道群＞東ヨーロッパ群≧中央ヨーロッパ群＞フランス群であった。耐凍性と雪腐病抵抗性の間には $r=0.89^{**}$ の強い正の相関が認められた。越冬ストレス抵抗性（耐凍性と雪腐病抵抗性）と早春の草勢の間には正の有意な相関が認められたが，この相関の弱さは暖かい地域からの品種の中に越冬ストレス抵抗性が弱いにも関わらず，早春の草勢が優れているものがあったことによる。一方，越冬ストレス抵抗性と黒さび病抵抗および晩秋の伸長性の間には強い負の相関が認められた。以上の結果から越冬性と秋の伸長性の優れた品種育成のためには，北海道と同緯度で冬の気象条件が厳しい東ヨーロッパの遺伝資源に注目する必要があると考えられた。

キーワード：オーチャードグラス，秋季伸長性，早春草勢，耐凍性，
雪腐病抵抗性，ヨーロッパ品種．