Bromegrass in Alaska. I. Winter Survival and Forage Productivity of *Bromus* Species, Types, and Cultivars as Related to Latitudinal Adaptation

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SUMMARY

This report summarizes seven separate field experiments, conducted over more than two decades at the University of Alaska's Matanuska Research Farm, that compared strains within three bromegrass *(Bromus)* species for winter hardiness and forage production. Species were (a) smooth bromegrass (*B. inermis* Leyss.), (b) native Alaskan pumpelly bromegrass (*B. pumpellianus* Scribn.), and (c) meadow bromegrass (*B. biebersteinii* Roem. and Schult.), a species native to southwestern Asia.

- Regar, the only cultivar of meadow bromegrass evaluated, was not winter-hardy and performed poorly in this area, far north of latitudes to which this species is adapted.

- All cultivars of southern-type smooth bromegrass evaluated in these experiments were inadequately winter-hardy for dependable use in this area; those cultivars included Achenbach, Elsberry, Fischer, Lancaster, Lincoln, Lyon, and Sac.

- Saratoga and Redpatch, relatively northern-adapted cultivars of southern-type smooth bromegrass, were intermediately winter-hardy between northern-type cultivars and southern-selected, southern-type cultivars.

- The generally excellent winter hardiness of the Alaska hybrid cultivar Polar (predominantly *B. inermis* x *B. pumpellianus*) in all experiments where it was included, confirms that it is the most winter-hardy, dependable, and productive of all cultivars evaluated.

- Following mild to moderately stressful winters, introduced cultivars of northern-type smooth bromegrass produced forage yields equivalent to those of the Alaska cultivar Polar and native Alaskan pumpelly bromegrass. More severe winters injured introduced northern-type cultivars and reduced their forage yields. The introduced northern-type strains evaluated were Canadian "commercial" and the cultivars Carlton, Frigga, Magna, Manchar, Mandan 404, and Martin.

- Native Alaskan pumpelly bromegrass was extremely winter-hardy and persisted well for the full term of all tests where it was included, producing high yields of forage. Its first-cutting yields averaged 104% of those of Polar, but second-cutting yields were only 63% of those of Polar. Total forage dry-matter yields of pumpelly brome were about 90% of those of Polar when averaged over 20 two-cut harvest years in four experiments.

- Good forage yields of the relatively unselected native Alaskan pumpelly bromegrass used in these experiments suggest potential for direct utilization of this subarctic-adapted, very winter-hardy grass for forage. It also could be used in additional controlled hybridization with the introduced smooth bromegrass to produce superior, adapted, interspecific hybrids for forage production or soil stabilization purposes in northern environments with extreme winter stresses.

- The marginal–to–poor winter survival of bromegrass cultivars grown far north of their latitude of adaptation is believed due to inadequate cold-hardiness development when their growth in Alaska subjects them to an unaccustomed environmental stimulus pattern during late-summer/autumn at this latitude. Such introduced cultivars experience an inadequate term of appropriately short photoperiods/long nyctoperiods (conducive to cold-hardiness development) prior to onset of winter stresses.

- The relative proportions of total-season forage yield harvested in first vs. second cutting can be influenced by (a) date of first cutting, (b) extent of winter injury that may curtail first-cut yields, (c) adequacy of soil moisture, and (d) inherent growth characteristics of strains.

- The northernmost-adapted bromegrasses produced a higher proportion of total annual forage yield in the first cutting than the more southern-adapted cultivars. For example, the proportion of total-season yield in first cuttings of four diversely adapted strains ranked as follows: native pumpelly brome > Polar > Carlton > Manchar, paralleling north–to–south latitudinal adaptation.

- Established stands of winter-hardy, adapted smooth or pumpelly bromegrass can persist and produce good yields of forage over many years. This valuable characteristic reduces frequency of tillage and replanting requirements, thereby seldom exposing soils to the erosional influences of wind and water that can cause soil losses during tillage and before planted crops become well established.

- These results (a) provide a ranking of inherent winter hardiness among northern-type cultivars, (b) confirm the desirability of utilizing only northern-adapted strains of bromegrass for forage production in southcentral Alaska, and (c) confirm the general unsuitability of southern-type smooth bromegrass and meadow bromegrass for use in this area.

- These findings, derived in experiments involving forage production, can also be applicable in selecting adapted strains of bromegrass for soil stabilization and other non-forage uses in Alaska.

Introduction

Smooth bromegrass (*Bromus inermis* Leyss.), a tall-growing species of Eurasian origin, is the most widely utilized of the cultivated bromegrasses, well suited for pasture, hay, and silage (Carlson and Newell 1985; Smith et al. 1986). It is an important forage in the northern half of the USA and in Canada (Knowles and White 1949). Moreover, its rhizomatous, sod-forming (Figure 1), long-lived perennial characteristics contribute to its effectiveness in reducing soil erosion (Carlson and Newell 1985; Hanson 1972).

Northern and Southern Types

Two types of smooth bromegrass, northern and southern, are recognized in North America, based on several characteristics, including ecological preference and morphological, physiological, and behavioral differences (Carlson and Newell 1985; Fortmann 1953; Knowles and White 1949; Smith et al. 1986; Wilsie 1962). The types called northern and southern in North America are believed to correspond, respectively, to "meadow" and "steppe" groupings recognized in the USSR (Wilsie 1962). Numerous cultivars have been developed within each of these types (Carlson and Newell 1985; Hanson 1972).

Evaluations Elsewhere

Knowles and White (1949) reported comparisons of numerous strains of northern and southern-type bromegrass at nine stations ranging from 49° to 55° N in western Canada. No differences in winter hardiness were reported, but the southern cultivar Achenbach persisted much better than commercial bromegrass or the northern-type cultivar Parkland in a locality of low rainfall and high summer temperatures. Neither northern nor southern-type strains were consistently superior in forage production, and general performance of types could not be related to latitudinal or climatic differences at test localities.

Thomas et al. (1958) evaluated five cultivars of the northern type and six of the southern type for forage and seed production at six locations from 37° to 49° N in the northcentral United States. No differences in winter survival were reported. Southern-type cultivars yielded more forage than those of the northern type, and differences increased from northern to southern test locations.

Fortmann (1953) in New York found three southern-type cultivars produced more forage than two cultivars of the northern type. Newell and Keim (1943) in Kansas compared 24 smooth bromegrass strains originating from a range of latitudes (40° to 52° N) in the Great Plains. Highest forage yields were obtained from southern strains that originated from latitudes near that of the test site.

Latitudinal Adaptation and Winter Hardiness

Wilsie (1962) discussed latitudinal races or ecotypes in several plant species and the selectively acquired, genetically controlled, physiologic harmony of ecotypes in relation to accustomed seasonal climatological patterns. Culture of plants far north of their latitudinal origin can upset or adversely modify physiologic processes important to preparation for winter (Hodgson 1964; Klebesadel 1985a; Klebesadel and Helm 1986; Smith et al. 1986). Divorcing plants in this manner from accustomed seasonal patterns of environmental influences can lead to inferior winter survival (Bula et al. 1956; Hodgson and Bula 1956; Klebesadel 1970, 1971a, 1971b, 1985a, 1985b; Klebesadel et al. 1964; Klebesadel and Helm 1986; Wilton et al. 1966).

Bromegrass and Legume Mixtures

Throughout its cultural range in North America, smooth bromegrass is commonly grown in mixtures, usually with alfalfa (Carlson and Newell 1985; Smith et al. 1986). Although much progress has been made toward developing legume strains with improved winter hardiness for use in Alaska (Klebesadel 1971b), no dependably winter-hardy perennial forage legumes are currently in general use on Alaskan farms. Therefore, winter-hardy grasses are grown in monoculture with nitrogen (N) and other fertility requirements supplied by commercial fertilizers.

Bromegrass in Alaska

Lack of adequate winter hardiness is the major deficiency limiting use in Alaska of most perennial forage species and cultivars introduced from other areas. Smooth bromegrass was identified early as one of the best adapted grasses for use in Alaska (Alberts 1933; Irwin 1945). Earliest recorded seedings of smooth bromegrass in Alaska were in 1902, and by 1919 it had been evaluated in numerous trials at five experiment stations in the Territory (Irwin 1945). Original sources and geographic adaptation of seed lots used were not recorded, however.

Moreover, early references to smooth bromegrass culture in Alaska did not recognize the distinction between northern and southern types (Aamodt and Savage 1949; Alberts 1933; Irwin 1945). Only after about 1950 did field trials in Alaska provide performance information that distinguished between northern and southern types, and reveal the generally better adaptation of strains of the northern type for use here (Hodgson et al. 1955).

Smooth bromegrass has become the most widely

Table 1. *Two-test means of oven-dry forage yields of northern and southern-type smooth bromegrass cultivars during the first two harvest years after establishment (no seeding-year harvest). (Experiments 1 and 2; planted in May of 1950 and 1952, respectively).*[1]

	Harvest year (2 cuttings per year)				
	First		Second[2]		
Type and cultivar	1 July	4 Sep	7 July	22 Sep	Total
	Tons/acre				
Northern type:					
Martin[3]	1.64 a[4]	1.30 ab	1.42 a	1.90 a	6.26 a
Manchar[3]	1.50 a	1.41 a	1.36 a	1.85 a	6.12 a
Mandan 404	1.78 a	1.23 ab	1.27 a	1.63 ab	5.91 a
Canadian commercial	1.74 a	1.19 ab	0.98 a	1.37 b	5.28 a
Southern type:					
Fischer	0.55 b	0.93 bc	—[5]	—	1.48 b
Elsberry	0.57 b	0.90 bc	—	—	1.47 b
Lyon	0.52 b	0.92 bc	—	—	1.44 b
Lincoln	0.56 b	0.87 bc	—	—	1.43 b
Lancaster	0.61 b	0.74 c	—	—	1.35 b

1 Previously unreported results derived by H.J. Hodgson, formerly agronomist, Alaska Agric. Exp. Sta., used here with permission.

2 Second-year yields from one test only.

3 Considered by some to be intermediate between northern and southern types.

4 Within each column, means not followed by a common letter are significantly different (5% level) using Duncan's Multiple Range Test.

5 No further yields from totally or predominantly winter-killed, very weedy stands.

used perennial forage grass on rotational croplands in Alaska. Cultivars of the northern type, despite being generally well adapted, have been found to display a considerable range of hardiness under Alaskan conditions. During winters of severe stress, all are marginal to inadequate in hardiness (Wilton et al. 1966). Previous reports (Klebesadel 1970, 1971a) have shown the southern-type cultivars Achenbach and Southland to be deficiently winter-hardy in Alaska. With the development of new cultivars in North America and northern Europe, uncertainty exists as to which cultivars are the best choices for dependable use in relatively long-term forage stands in Alaska.

Pumpelly Bromegrass

Pumpelly bromegrass (*B. pumpellianus* Scribn.), also a rhizomatous perennial (Elliott 1949; Klebesadel 1984) and closely related to *B. inermis* (Elliott 1949; Mitchell 1967), is native in North America. Its principal distribution is cordilleran from Alaska to Colorado (Elliott 1949; Hitchcock 1950; Hulten 1968), and identical or very similar forms occur adjacent to Alaska in eastern Siberia (Hulten 1968). *B. pumpellianus* occurs widely in Alaska (Hulten 1968; Mitchell 1967) and is highly variable in taxonomic characteristics. Hulten (1968) recognizes three subspecific taxonomic categories (varieties *pumpellianus, arcticus,* and *villosissimus)*, but Mitchell (1967) sets forth only two (subspecies *pumpellianus* and *dicksonii).* The native Alaskan bromegrass evaluated in this report is considered to be variety or subspecies *pumpellianus.*

Introgression has occurred where introduced *Bromus inermis* has come in contact with *B. pumpellianus* in its natural range (Elliott 1949). A practical manifestation of controlled hybridization between these taxa is represented in 'Polar' bromegrass, a synthetic cultivar

Table 2. Oven-dry forage yields and comparative winter survival of smooth bromegrass types and cultivars from diverse latitudinal origins (no seeding-year harvest). (Experiment 3; planted 3 July 1962.)

Type and cultivar	First harvest year–1963 (3 cuttings)				Winter-kill	Second harvest year	Grand total
	12 June	8 Aug	17 Sep	Total		24 June	
	------------ Tons/acre ------------				%	--- Tons/acre --	
Northern type:							
Polar[1]	0.97 ab[2]	1.19 a	0.36 b	2.52 a	0	1.05 a	3.57 a
Carlton	1.09 a	1.18 a	0.44 b	2.71 a	14	0.62 b	3.33 a
Manchar[3]	0.85 b	1.03 a	0.61 a	2.49 a	26	0.42 c	2.91 b
Southern type:							
Saratoga	0.17 c	1.01 a	0.58 a	1.76 b	70	0.06 d	1.82 c
Sac	Tr[4]	Tr	0.34 b	0.34 c	63	Tr	0.34 d

[1] Predominantly of hybrid origin (*B. inermis* x *B. pumpellianus*).

[2] Within each column, means not followed by a common letter are significantly different (5% level) using Duncan's Multiple Range Test.

[3] Considered by some to be intermediate between northern and southern types.

[4] Trace amount of herbage (from severely winter-injured stand) insufficient for harvestable yield.

developed in Alaska predominantly from hybrid clones (Hodgson et al. 1971; Wilton et al. 1966). Native Alaskan pumpelly bromegrass, well adapted to north-latitude climatic conditions, is extremely winter-hardy here (Klebesadel 1970, 1971a, 1984). Incorporation of northern-adapted *B. pumpellianus* germplasm in the cultivar Polar has conferred a higher level of winter hardiness for use in subarctic areas than is available in *B. inermis* strains (Wilton et al. 1966).

B. pumpellianus collections from numerous sources throughout Alaska have been evaluated during the past two decades in spaced-plant nurseries at the Matanuska Research Farm. Superior-performing lines from several sources have been bulked, the seed increased, and the species evaluated in more comprehensive studies (Klebesadel 1970, 1971a, 1984; Mitchell 1982), including the investigations reported here.

Meadow Bromegrass

Meadow bromegrass *(B. biebersteinii* Roem. and Schult.) is a cool-season grass introduced from southwestern Asia (Hanson 1972). The cultivar Regar, selected in Idaho from an accession collected near 41° N in northeastern Turkey, was released in 1966. Regar heretofore has been little evaluated in Alaska, but is reported to possess "excellent winter hardiness" in the Pacific Northwest states (Foster et al. 1966).

This report summarizes winter hardiness and forage productivity comparisons among different bromegrass species and cultivars from diverse latitudinal sources. All results are from field experiments conducted at the University of Alaska's Matanuska Research Farm (61.6° N) in southcentral Alaska.

Experimental Procedures

Seven separate field tests were planted in sites selected for good surface drainage in Knik silt loam (coarse-silty over sandy or sandy-skeletal, mixed, nonacid Typic Cryochrept). Commercial fertilizer disked into plowed seedbeds before planting supplied N, phosphorus (P_2O_5), and potassium (K_2O), respectively, at 18, 40, and 22 lb/acre in Experiments 1 and 2; at 24, 96, and 48 lb/acre in Experiment 3; and at 32, 128, and 64 lb/acre in Experiments 4, 5, 6, and 7. All experiments utilized broadcast-seeded plots; no companion crops were planted. Planting rates were adjusted on the basis of germination tests to plant all bromegrasses at 15 lb pure live seed per acre in Experiments 1 and 2, and at 20 lb/acre in the others. Individual plots measured 5 x 20 feet. All experiments utilized randomized complete block experimental designs with 3 or 4 replications.

Table 3. *Two-test means of seeding-year and subsequent oven-dry forage yields of bromegrass species and cultivars from diverse latitudinal origins. Dates are means of two experiments. (Experiments 4 and 5; planted 15 June 1967 and 18 June 1968, respectively.)*

Species, types, and cultivars or strains	Seeding year	Full harvest years										Total
		First		Second		Third		Fourth		Fifth		
	29 Sep	1 July	1 Oct	1 July	30 Sep	5 July	19 Sep	9 July	28 Sep	8 July	20 Sep	
	Tons/acre											
Pumpelly brome (B. *pumpellianus*):												
Indigenous Alaskan	0.30 b[1]	1.60 a	0.82 b	1.29 a	0.74 bc	1.23 a	1.00 b	2.48 a	0.80 b	2.97 a	0.47 c	13.70 bc
Smooth brome *(B. inermis)*:												
Polar[2]	1.21 a	1.41 a	1.06 ab	1.09 ab	0.99 ab	1.01 ab	1.74 a	1.72 b	1.19 a	3.01 a	0.93 b	15.36 a
Carlton	1.28 a	1.09 b	1.12 a	1.05 ab	1.12 a	1.11 ab	1.69 a	1.18 c	1.33 a	2.76 ab	1.24 a	14.97 ab
Manchar	1.38 a	0.93 b	1.08 ab	0.93 b	1.02 ab	0.87 b	1.45 a	0.82 c	1.17 a	2.43 b	1.38 a	13.46 c
Meadow brome *(B. biebersteinii)*:												
Regar	1.10 a	0.25 c	0.34 c	0.24 c	0.71 c WK[3]	—	—	—	—	—	—	2.64 d

[1] Within each column, means not followed by a common letter are significantly different (5% level) using Duncan's Multiple Range Test.

[2] Predominantly of hybrid origin (*B. inermis* x *B. pumpellianus*).

[3] Stand winter-killed completely; no further yields.

Table 4. *Seeding-year and subsequent oven-dry forage yields of bromegrass species, types, and cultivars at the Matanuska Research Farm. (Experiment 6; planted 6 June 1969.)*

Species, types, and cultivars or strains	1969	1970		1971		1972		1973		1974		Total
	7 Oct	9 July	16 Sep	7 July	27 Sep	5 July	2 Oct	10 July	10 Sep	21 June	17 Sep	
	Tons/acre											
Pumpelly brome (*B. pumpellianus*):												
Indigenous Alaskan	Tr[1]	2.28 a[2]	0.98 b	1.02 a	1.53 a	3.19 a	0.21 b	3.26 a	0.58 c	2.59 a	0.49 a	16.13 a
Smooth brome (*B. inermis*):												
Northern type:												
Polar[3]	0.22 b	2.98 a	1.57 ab	0.83 a	2.20 a	3.12 a	0.80 ab	3.53 a	1.01 b	2.25 a	0.54 a	19.05 a
Manchar[4]	0.83 a	2.59 a	1.47 ab	0.19 c	1.84 a	2.16 b	1.25 a	3.46 a	1.38 a	2.00 a	0.86 a	18.03 a
Carlton	0.28 b	2.78 a	1.71 a	0.31 bc	1.71 a	2.08 b	1.07 a	3.19 a	1.20 ab	2.05 a	0.61 a	16.99 a
Frigga	0.70 a	2.30 a	1.37 ab	0.57 b	1.91 a	2.02 b	1.19 a	3.05 a	1.17 ab	1.84 a	0.51 a	16.63 a
Southern type:												
Redpatch	0.92 a	2.16 a	1.42 ab	0.01 c	0.46 b	WK[5]	—	—	—	—	—	4.97 b

1 Trace amount of herbage insufficient for harvestable yield.

2 Within each column, means not followed by a common letter are significantly different (5% level) using Duncan's Multiple Range Test.

3 Predominantly of hybrid origin (*B. inermis* x *B. pumpellianus*).

4 Considered by some to be intermediate between northern and southern types.

5 Stand winter-killed completely; no further yields.

Table 5. *Seeding-year and subsequent oven-dry forage yields of bromegrass species, types, and cultivars at the Matanuska Research Farm. (Experiment 7; planted 25 June 1970.)*

Species, types, and cultivars or strains	1970 22 Sep	1971 8 July	1971 7 Oct	1972 5 July	1972 18 Oct	1973 11 July	1973 12 Sep	1974 27 June	1974 10 Sep	1975 26 June	1975 19 Sep	Total
	----------	----------	----------	----------	----------	Tons/acre	----------	----------	----------	----------	----------	----------
Pumpelly brome (*B. pumpellianus*):												
Indigenous Alaskan	Tr[1]	0.48 a[2]	1.00 a	3.08 a	0.32 abc	2.76 a	0.39 ab	2.87 a	0.34 a	1.51 abc	0.67 c	13.42 ab
Smooth brome (*B. inermis*):												
Northern type:												
Polar[3]	0.11 b	0.12 b	1.13 a	2.22 b	0.62 ab	2.94 a	0.62 a	2.96 a	0.17 ab	2.10 a	1.95 ab	14.94 a
Magna[4]	0.62 a	0.01 b	0.57 ab	1.26 c	0.72 a	2.67 ab	0.45 ab	1.92 b	0.07 ab	1.70 ab	2.15 a	12.14 ab
Frigga	0.32 ab	0.02 b	0.62 ab	1.51 bc	0.52 abc	1.78 bc	0.49 ab	1.72 b	0.11 ab	1.11 bc	1.87 ab	10.07 b
Manchar[4]	0.37 ab	0.01 b	0.01 b	0.22 d	0.13 c	0.52 d	0.31 b	0.01 c	0.02 b	0.81 c	1.29 abc	3.70 cd
Southern type:												
Redpatch	0.76 a	0.01 b	0.23 b	0.04 d	0.27 bc	1.42 cd	0.62 a	0.85 c	0.23 ab	0.88 c	1.22 bc	6.53 c
Achenbach	0.60 a WK[5]	—	—	—	—	—	—	—	—	—	—	0.60 d
Meadow brome (*B. biebersteinii*):												
Regar	0.43 ab WK	—	—	—	—	—	—	—	—	—	—	0.43 d

[1] Trace amount of herbage insufficient for harvestable yield.

[2] Within each column, means not followed by a common letter are significantly different (5% level) using Duncan's Multiple Range Test.

[3] Predominantly of hybrid origin (*B. inermis* x *B. pumpellianus*).

[4] Considered by some to be intermediate between northern and southern types.

[5] Stand winter-killed completely; no further yields.

With all forage harvests, yields were derived as reported previously (Klebesadel 1985a). Samples from each plot were dried to constant weight at 140° F; all yields are reported on the oven-dry basis. Each spring following establishment, commercial fertilizer top-dressed in late March or early April, before initiation of spring growth of grasses, supplied N, P_2O_5, and K_2O, respectively, at 80, 40, and 0 lb/acre in Experiments 1 and 2, and at 125, 96, and 48 lb/acre in Experiments 3 through 7. Ammonium nitrate supplying N at 85 lb/acre was top-dressed one to three days after the first cutting in Experiments 3 through 7 in each year that two or three harvests were taken; no mid-season top dressing was applied in Experiments 1 and 2.

Experiments 1 and 2: The same four northern-type and five southern-type cultivars were compared in both experiments; they are listed with mean harvest dates and two-test forage-yield means in Table 1. Both experiments were planted in early May but two years apart; no harvests were taken during the seeding year in either. Two harvests per year were taken during each of the two consecutive years after establishment in Experiment 1, but during only the first year after establishment in Experiment 2. (These two experiments were conducted by former Alaska agronomist Dr. H.J. Hodgson and results are included here with permission.)

Experiment 3: Five cultivars listed in Table 2 were included in Experiment 3; no seeding-year harvest was taken. Three harvests were taken during the first year after establishment on dates indicated in Table 2, but only one harvest was taken in the following year.

Experiments 4, 5, 6, and 7: Five bromegrass strains in three species were compared in Experiments 4 and 5 (Table 3), six strains in two species in Experiment 6 (Table 4), and eight strains in three species in Experiment 7 (Table 5). Seeding-year harvests were taken near the end of the growing season in all experiments, and two harvests were taken per year on dates indicated in the tables (mean dates in Table 3) during the subsequent five years in each experiment.

Results and Discussion

Stand Establishment

Good seeding-year stands were obtained in all experiments except Experiment 7, discussed later. Native pumpelly brome produced the least vigorous seedlings and significantly lower seeding-year forage yields than other bromes in two tests (Table 3); in two other experiments it did not produce harvestable seeding-year yields (Tables 4 and 5).

Winter Hardiness and Forage Yield

Considerable differences were noted in relative winter hardiness among the types and species of bromegrass compared. In general, differences in winter survival were related to latitudinal origin; northern-adapted strains survived winters better than those from more southern sources.

Eight cultivars of southern-type smooth brome were evaluated in the seven experiments. In Experiment 1, five of those cultivars survived the first winter following establishment to produce forage yields equal to northern-type strains in both cuttings during the second year (Table 1). However, all of the southern-type cultivars winter-killed during the second winter. The same cultivars established well but winter-killed totally or so extensively during the first winter in Experiment 2 that no harvestable yields were obtained during the second year. As a result, the two-test mean forage yields of southern-type cultivars Fischer, Elsberry, Lyon, Lincoln, and Lancaster were significantly lower than the three northern-type cultivars Martin, Manchar, and Mandan 404, and the Canadian commercial strain (Table 1). The four northern-type entries were harvested for two years in Experiment 1 before the test was discontinued. The five relatively non-hardy, southern-type cultivars were essentially similar in forage yields (Table 1). Similarly, forage yields differed little among the four more winter hardy northern-type strains.

Cultivars classed as southern or intermediate in type (Hanson 1972) differed in winter survival and, hence, forage yields in Experiments 3 and 7. Saratoga from New York was clearly more winter-hardy than Sac from Wisconsin (Experiment 3, Figure 2, Table 2), and Redpatch, selected in Ontario, surpassed Achenbach in winter survival (Experiment 7, Table 5). The poor winter hardiness of Achenbach in Experiment 7 paralleled similar earlier results (Klebesadel 1970) with that cultivar in southcentral Alaska.

In forage trials near 60° N in Norway, Opsahl (1962) similarly found northern-type Canadian common, Mandan 404, Manchar, and Frigga more productive than true southern-type cultivars (Achenbach, Fischer, Lancaster, Lincoln, and Lyon); the latter group produced 83% of Canadian common over three years. However, the more northern-adapted, southern-type cultivar Saratoga produced well there where winter temperatures typically are less severe than at Palmer (mean January temperature at Oslo = 23° F (-5.0°C), and at Palmer = 12.6° F (-10.8° F.)

Redpatch, selected at 45.5° N, is considered intermediate between northern and southern types (Hanson 1972) but is classed as northern adapted (Smith et al. 1986) Redpatch succumbed during the third winter in Experiment 6 (Table 4). It sustained considerable injury during the first two relatively severe winters in Experiment 7 (Table 5); however, it recovered to survive the next three milder winters and produced modest yields during the last three years. These results show that

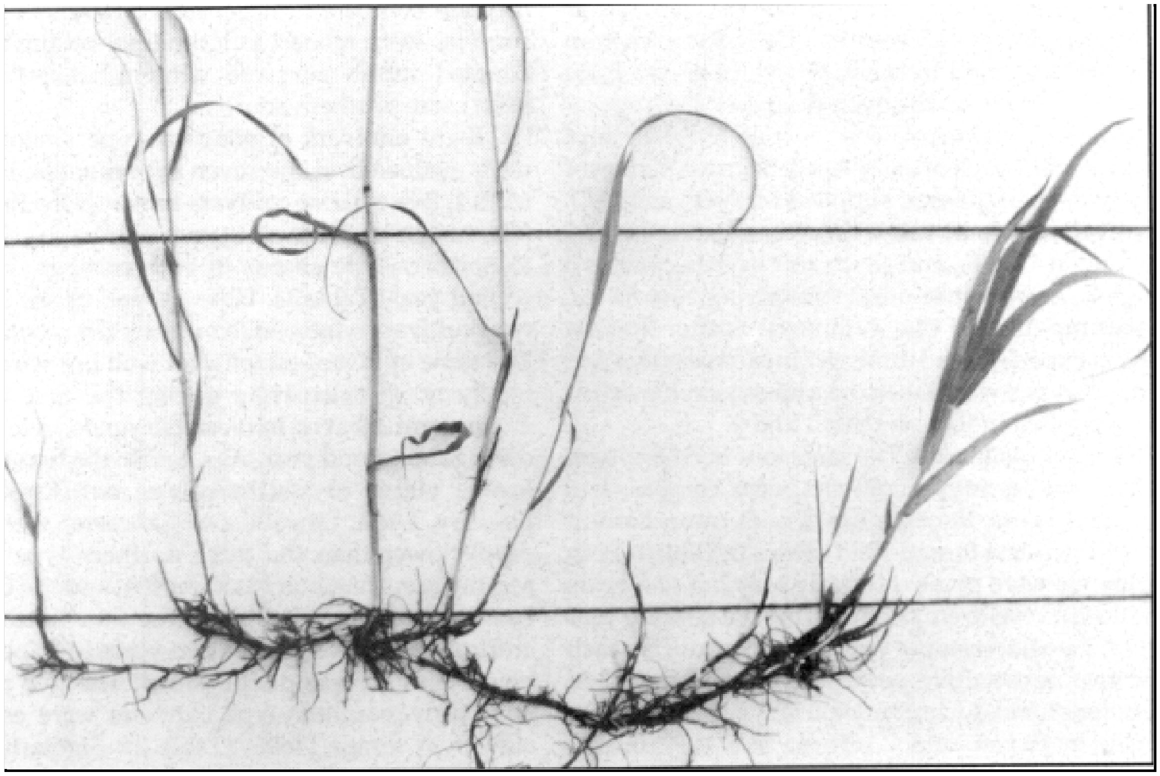

Figure 1. An individual plant of Polar bromegrass that has been dug from plant nursery, soil washed from underground parts, and photographed near the end of the first season of growth. Lower black line represents soil surface; evident below that line is the development of underground stems (rhizomes) that interlace with those of adjoining plants to form a sod. They also give rise to new tillers that emerge through the soil surface (14 apparent in photo) and develop into elongated stems (culms).

Redpatch is more winter-hardy in Alaska than the true southern cultivar Achenbach, but less hardy than the hybrid Polar (Figure 3) or northern-type cultivars Carlton and Frigga. In contrast to results in Experiment 6 (Table 4), Redpatch surpassed Manchar in Experiment 7 (Table 5) in total yield for the six-year test. Manchar has performed generally like other northern-type cultivars in Alaska and is considered to be of the northern-type by those who described its origin in Manchuria and selection in North America (Stark and Klages 1949). However, Manchar is considered by some (Carlson and Newell 1985; Hanson 1972) to be intermediate between the northern and southern types.

Polar consistently produced highest total forage yields over the full term of each of Experiments 4 through 7; however, in no instance were total yields of Polar significantly higher than other high-yielding strains (Tables 3, 4, and 5). Only in certain instances where Polar sustained less winter injury than introduced cultivars did the Alaska cultivar surpass them in first-cutting yields (1971 in Table 4; 1974 in Table 5). That differential winter hardiness, relatively minor in these tests, was much more apparent in earlier results (Hodgson et al. 1971; Wilton et al. 1966) when Polar survived severe winter stress with only 15% winter kill at this location while stands of Carlton, Manchar, and Canadian commercial were virtually eliminated with winter kill estimated at 87%, 93%, and 97%, respectively.

The Canadian cultivar Magna, considered intermediate in type (Carlson and Newell 1985; Hanson 1972), and the northern cultivars Carlton from Canada and Frigga from Sweden generally produced forage yields equaling or only slightly inferior to Polar (Tables 3, 4, and 5). Manchar, too, produced total yields equivalent to the highest-yielding bromes in all tests except for two-year total yields in Experiment 3 (Table 2), and Experiment 7 (Table 5); in the latter case Manchar established poorly. Occasionally, first-cutting yields of Manchar were significantly lower than Polar when winter injury of the less winter-hardy Manchar curtailed its spring growth. Mitchell (1982) reported equivalent yields from Manchar and Polar in another comparison in the Matanuska Valley.

Regar, a cultivar of meadow bromegrass selected at Aberdeen, Idaho (43° N), from germplasm introduced from near 41° N in Turkey has been described as possessing "excellent winter hardiness" (Foster et al.

1966; Hanson 1972). In contrast to its performance at more southern latitudes, Regar was one of the least winter-hardy cultivars evaluated in these experiments (Tables 3 and 5). It winter-killed during the first winter in Experiment 4 (Figure 4) and Experiment 7. In Experiment 5, it produced modest forage yields before succumbing during the third winter. These results show that Regar is poorly suited for use in subarctic Alaska, an area far north of its latitude of adaptation.

After the establishment year, native pumpelly bromegrass produced first-cutting forage yields equivalent to or surpassing the other strains. This was especially true in the first cuttings of Experiments 6 and 7 (Tables 4 and 5) following the winter of 1970-1971 when all of the less winter-hardy, introduced cultivars sustained some injury.

Total forage yields of pumpelly bromegrass over the full terms of Experiments 4 through 7 tended to be slightly lower than those of Polar, but differences were not statistically significant. Total yields of pumpelly brome in each experiment were equivalent to those of the most winter-hardy introduced cultivars (Tables 3, 4, and 5).

Filling of Stands

For reasons not clearly understood, less-than-ideal establishment conditions resulted in marginal initial stands of three bromegrass strains in Experiment 7 (Table 5). In autumn of the seeding year, estimated percentages of full stands averaged over the three replicates were: pumpelly bromegrass 47%, Polar 43%, and Manchar 67%; all others were rated at 80% or better. In that experiment, the relatively severe winter of 1970-1971 injured all bromes, with Manchar sustaining more injury (estimated 87% winter kill) than Polar (43%) or pumpelly brome (28%). A better initial stand of Redpatch (87%), followed by winter injury approximately equal to that of Manchar, left both with badly decimated stands in spring of 1971. Both recovered slowly over the next five years, producing low forage yields, but Redpatch surpassed Manchar.

In contrast to Redpatch and Manchar, the somewhat better stands of Polar, Frigga, and Magna, though winter-injured and rated at only 20% to 25% of full stands in spring of 1971, recovered rapidly during 1971 to produce forage at modest levels in 1972 and near full potential in 1973. Pumpelly bromegrass, rated slightly better than the other strains at 43% of full stand in spring 1971, recovered more rapidly to produce highest first-cutting yields of all bromes only one year later. This ability of bromegrass to recover from poor establishment or winter-injured stands through vigorous rhizomatous spread and tiller development is a valuable attribute. Such recovery can save tilling and replanting if a 20% to 50% uniformly distributed stand exists to initiate filling of the stand.

Seasonal Distribution of Yield

Pumpelly brome yields were significantly higher than those of Polar and the other highest-yielding introduced cultivars in 6 of 20 first cuttings (Tables 3, 4, and 5). The native bromegrass was equivalent to the other highest-yielding cultivars in 14 first cuttings, and in no instance was its first-cutting yield lower. Generally inferior second-cutting yields of pumpelly brome, however, tended to offset its heavy first-cutting yields; in 8 of 20 individual second cuttings, yields of pumpelly brome were significantly lower than those of Polar.

Four major factors can influence the proportion of the total annual forage yield in the first and second cuttings. One of these is the date of the first harvest. As the date of the first-cutting is delayed, increasingly more of the total year's production occurs in the first harvest and progressively less time is available for the regrowth that is harvested in the second cutting.

Winter injury is another factor; stands significantly winter-injured produce lower-than-potential first-cutting forage yields. Consequently, spring-applied fertilizer, unused prior to the first harvest by a winter-injured stand, can provide greater-than-normal stimulation of growth as the stand recovers during the regrowth period, resulting in relatively inflated second-cutting yields.

A third factor that can raise or lower yields in either cutting is abundance or deficiency of soil moisture available to plants during the respective growth periods.

The fourth factor influencing forage yield distribution in first and second harvests, in the grass strains compared, is obviously genetic. When not winter injured, all bromegrasses typically produced a very vigorous spring growth of culms harvested in the first cutting. Alaskan pumpelly bromegrass, however, differed considerably from smooth bromegrass cultivars in the nature of the regrowth following the first cutting; it produced a more leafy aftermath growth with far fewer aerial culms (Klebesadel 1984). This effect was magnified as date of first cutting was delayed. A growth pattern similar to that of pumpelly bromegrass has been noted here also in northernmost-adapted cultivars of timothy (*Phleum pratense* L.), such as Engmo from northern Norway (Klebesadel and Helm 1986).

As a result of the cumulative influences of the aforementioned factors, differences among bromegrasses in yield distribution in first and second cuttings were quite apparent. Considering those strains common to Experiments 4, 5, and 6 (Tables 3 and 4), where initial winter injury did not greatly set back new stands as occurred in Experiment 7, the percentages of total-season yield in the first cutting (averaged over 15 harvest years) were: pumpelly brome 72%, Polar 59%, Carlton 53%, and Manchar 50%.

Those percentages show an obvious relationship

Figure 2. Comparative winter survival of (left to right) bromegrass cultivars Sac, Manchar, Polar, and Saratoga photographed on 26 May; plots seeded the previous year on 3 July. Numbered stakes in plots are three feet tall.

between seasonal distribution of forage yields in the two cuttings and latitudinal origin of the bromegrasses. In contrast, Newell and Keim (1943) found southern strains more productive in early spring than northern strains when grown in Nebraska near the southern limits of bromegrass adaptation. However, earlier initiation of spring growth by southern strains was interpreted as an acquired growth pattern that avoided drought conditions of spring and summer.

Stand Persistence and Productivity

Experiments 4 through 7 represent the longest-duration forage-production trials reported for perennial crops in Alaska. Total yields of the most winter-hardy cultivars vary upward and downward from year to year. These yearly variations can be influenced considerably by winter injury (especially as occurred in winter 1970-71, Tables 4 and 5), and by moisture supply; precipitation was below normal in several of the years resulting in suppressed yields. Nonetheless, forage yields in the final years of Experiments 4 through 7 (Tables 3, 4, and 5) show that the most winter-hardy cultivars remain as productive as in earlier years.

These results are consistent with local farm experience whereby bromegrass stands, if adequately fertilized, remain productive for considerably longer terms than the six-year experiments summarized here. The long life of adapted bromegrass stands circumvents the costs, labor, and soil-erosion hazards inherent in the more frequent tillage and replanting required with annual, biennial, or shorter-lived perennial crops. The relatively dense, rhizomatous sod formed by bromegrass is an effective soil binder that prevents soil erosion for as long as the sod is allowed to remain undisturbed.

Conclusions

These results, wherein northern-type smooth bromegrass cultivars consistently surpassed those of the southern type in forage yields, are in sharp contrast to other North American reports of equal yields from both types of bromegrass, or opposite results (Fortmann 1953; Knowles and White 1949; Newell and Keim 1943; Thomas et al. 1958). The lower yields of southern-type bromes in Alaska were due to winter kill or injury that did not occur at the more southern test sites.

The term winter hardiness infers avoidance of, or tolerance to, all of the individual and cumulative vicissitudes of winter that may injure or kill a plant, including freezing, heaving, smothering, and desiccation (Steponkus 1978). A given plant ecotype generally possesses the acquired genetic potential to develop cold hardiness adequate for its specific environment. However, the seasonal attainment of adequate cold hardiness can be realized only in response to the conditioning effects of accustomed environmental stimuli, principally lowering temperatures and shortening diurnal photoperiods (lengthening nyctoperiods) that precede winter (Bula et al. 1956; Hodgson 1964; Klebesadel 1971a, 1985b; Smith 1964; Steponkus 1978).

Experiments contributing to this report confirm the deficient winter hardiness of southern-type smooth bromegrass and Regar meadow bromegrass for use in Alaska, an area far north of their latitudes of adaptation. However, it was recognized earlier (Hodgson 1964; Klebesadel 1971a, 1985b; Klebesadel and Helm 1986) that stresses during typical winters (Klebesadel 1974) in this subarctic area generally are not sufficiently severe to account for the often dramatically poorer winter survival of cultivars from temperate latitudes where winter stresses also can be severe. Consequently, other influences apparently operate to curtail winter survival of strains introduced from more southern latitudes.

Growing seasons in this area terminate shortly after the autumnal equinox. Temperate-adapted forage strains normally are exposed in their area of origin to a much longer term of short diurnal photoperiods (long nyctoperiods) that promote adequate cold hardiness development prior to a relatively later onset of winter conditions. Artificially shortened diurnal photoperiods (lengthened nyctoperiods) for several weeks prior to the end of the subarctic growing season can provide a pattern here (61.6° N) similar to that occurring prior to freeze-up at their latitude of adaptation. This treatment enhanced development of cold tolerance in Ranger alfalfa (Hodgson 1964) and improved actual winter survival in Southland bromegrass (Klebesadel 1971a, 1985b), cultivars originating from Nebraska and Oklahoma, respectively. Those results demonstrated that temperate-adapted cultivars are not adequately stimulated to develop cold hardiness to their full potential under the unaccustomed subarctic photoperiod/nyctoperiod pattern prior to onset of winter conditions.

Newell and Keim (1943) observed that performance differences, as influenced by adaptation, are more likely to occur toward the periphery of the region of adaptation of a particular grass. That concept, derived from work at Lincoln, Nebraska (40.8° N) near the southern limits of bromegrass culture, is shown by the present results to be equally true near the northern limits of

Figure 3. *Comparative winter survival of (left) the southern-type cultivar Redpatch smooth bromegrass from Canada, and (right) the northern-adapted hybrid cultivar Polar, developed in Alaska, following the relatively severe winter of 1970-71; photo 22 June 1971. (These plots are part of Experiment 5, but Redpatch is not included in Table 3, which summarizes Experiments 4 and 5, because Redpatch was not included in Experiment 4.)*

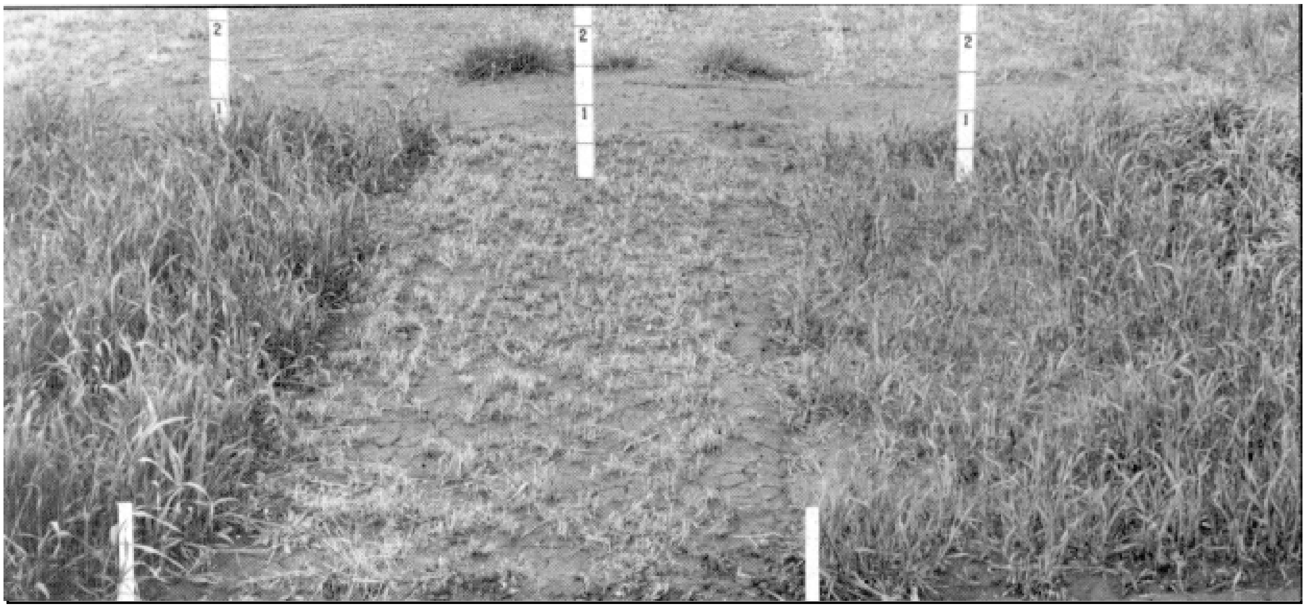

Figure 4. Comparative winter survival of (left to right) bromegrass cultivars Polar, Regar, and Carlton photographed on 31 May; plots seeded the previous year on 15 June. Numbers on stakes indicate height in feet.

bromegrass use. The several tests summarized in this report, and earlier-reported results (Klebesadel 1970, 1971a, 1985b; Wilton et al. 1966) at this location, provide a general ranking of relative winter hardiness among bromegrass strains that has not been apparent in tests at lower latitudes (Carlson and Newell 1985; Fortmann 1953; Knowles and White 1949; Newell and Keim 1943; Smith et al. 1986; Thomas et al. 1958):

Relative Winter Hardiness in Alaska

Excellent	Good	Fair	Poor
Pumpelly	Carlton	Redpatch	Regar
Polar	Magna	Saratoga	Achenbach
	Frigga	Sac	Elsberry
	Manchar		Fischer
	Mandan 404		Lancaster
	Martin		Lincoln
	Canadian commercial		Lyon
			Southland

The indigenous Alaskan pumpelly bromegrass evaluated in these experiments represents a subarctic-adapted ecotype in a species with an extensive north-south native range. Hence, these results apply only to this northern ecotype and not to more southern ecotypes or to the species as a whole. The good forage yields, extreme winter hardiness, and high seed yields of northern-adapted pumpelly bromegrass in these experiments and in other tests in Alaska (Klebesadel 1970, 1984; Mitchell 1982) suggest that it may offer selections immediately useful for forage production or soil stabilization throughout the North in areas of severe winter stresses.

Polar is a 16-clone synthetic cultivar comprised of 11 *B. inermis* x *B. pumpellianus* lines and five of *B. inermis* (Wilton et al. 1966). Parental germplasm used to produce the original hybrids represents a small sampling of the genetic diversity available within northern-adapted *B. pumpellianus.* The desirable agronomic characteristics of Polar infer that additional hybridization and subsequent selection should result in additional superior hybrid material for use in northern regions.

These results, demonstrating marked differences in winter hardiness in Alaska among bromegrass strains, were derived from experiments designed primarily to evaluate their usefulness in forage production. However, smooth and pumpelly bromegrass possess many valuable growth characteristics that contribute to their usefulness in non-forage applications as well. Therefore, these results should be helpful in selecting ideally adapted bromegrass species and strains for soil stabilization and various other non-forage plantings in Alaska that require species with winter hardiness, long-lived stands, and soil-binding capabilities.

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