Bromegrass in Alaska. IV. Effects of Various Schedules and Frequencies of Harvest on Forage Yields and Quality and on Subsequent Winter Survival of Several Strains

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SUMMARY

Effects of different annual harvest schedules and frequencies on several cultivars and strains of bromegrass (*Bromus* species) were measured in five field experiments at the University of Alaska's Matanuska Research Farm (61.6°N) near Palmer in southcentral Alaska. Most cultivars evaluated and compared were smooth bromegrass (*B. inermis* Leyss.). Native Alaskan pumpelly bromegrass (*B. pumpellianus* Scribn.) and the predominantly hybrid (*B. inermis* x *B. pumpellianus*) cultivar Polar, developed in Alaska, were included also.

• Bromegrasses compared showed a considerable range of inherent winterhardiness. Saratoga sustained less winter injury and yielded more than Sac; however, both of those southern-type cultivars were inferior in winter survival to all of the more northern-adapted strains compared.

• Although all cultivars were not compared in every experiment, results generally ranked winterhardiness of strains as follows: Native pumpelly > Polar > Carlton = Canadian commercial ≥ Manchar > Saratoga > Sac > Achenbach.

• The different harvest schedules and frequencies resulted in dissimilar total annual forage dry-matter yields as well as differences in herbage quality in individual harvests as measured by crude protein concentration in the herbage.

• Three, four, or five harvests per year generally resulted in lower total annual dry-matter yields than two harvests per year.

• Crude protein concentration was highest, and percent dry matter lowest, in herbage cut frequently (3, 4, or 5 times per year) and therefore at the more immature stages of plant development.

• Interruption of the very rapid growth of bromegrass during June, with harvest prior to late June, resulted in marketdly lower first-cut yield, a slow rate of grass regrowth, and decreased total annual forage yield.

• First-cutting dry-matter yields in mid-June were approximately half of first-cutting yields obtained only two weeks later.

• With two harvests per year, no increase in total annual forage yield accrued from deferring the second harvest to the late-September/early-October period; moreover, quality of second-cutting forage was higher with harvest in late August or very early September than in late September or early October.

• Little consistent difference was noted in total forage yield during the year of differential harvests among the introduced northern-type smooth bromegrass strains (cultivars Carlton and Manchar, and Canadian "commercial"), or the Alaska cultivar Polar.

• The various harvest schedules and frequencies influenced subsequent winter survival when winters were moderately to severely stressful. Three harvests per year frequently predisposed Carlton, Canadian commercial, Manchar, and occasionally Polar, to markedly greater winter injury (and lower first-cutting forage yields the following year) than two harvests.

• When three harvests per year resulted in significant subsequent winter injury of brome strains, taking the third harvest in mid-September resulted in more injury than a third harvest in early October.

• When winter injury occurred following two harvests per year, it was more severe when the second harvest was taken in late September or early October than with the second harvest approximately one month earlier in late August or very early September.

• Native pumpelly bromegrass often yielded less than the northern-type smooth bromes; however, when winter injury of those strains was moderate to severe, pumpelly brome surpassed all other strains in sustaining least winter injury and consequently produced higher first-cutting forage yield the following year.

• Total annual yields of crude protein ranged from 780 to 1209 lb/A with little relationship between protein yield and harvest treatments.

• Adequacy of early-season rainfall, especially during April and May (which normally are modest-rainfall months in this area), was very important toward realizing the full forage-production potential of the usually very heavy spring growth of bromegrass.

• The duration of the final regrowth period prior to winter appeared to be important to continued bromegrass stand vigor. Interruption of that last regrowth period with a final harvest in mid-September or later was more damaging with three than with two cuts per year.

• With intensive utilization (frequent harvests) of bromegrass during the first half of the growing season, uninterrupted regrowth after about mid-August apparently permitted stands to restore good energy status prior to winter.

• Three major factors influence winter survival of bromegrass in this area: (a) the severity of winter stresses during each winter, (b) the inherent winterhardiness of the bromegrass cultivar or strain used, and (c) harvest schedule and frequency. Factor (a) is unpredictable and uncontrollable; however, (b) and (c) are controllable, and prudent choices can ensure against stand loss from winter injury or total winterkill. Polar is the most winterhardy cultivar currently available, and harvest schedule and frequency should be in harmony with the grasses' seasonal growth pattern and physiological processes. Two harvests per year, the first near late June/very early July and the second in late August/very early September should provide high yields of good quality forage and insure against weakening the grass stand.

Introduction

Smooth bromegrass (*Bromus inermis* Leyss.) is the dominant perennial forage species grown on rotational croplands in Alaska. It was introduced into North America from Europe and Asia and has become widely used in the northern U.S. and in Canada (Carlson and Newell 1985; Smith *et al*. 1986). A vigorous, leafy, tall-growing, sod-forming, long-lived perennial, bromegrass responds well to fertilizers (Branton *et al*. 1966; Laughlin 1953, 1962, 1963) and thrives during the relatively cool growing seasons of this northern area.

Species and Cultivars

Many improved cultivars (varieties) of smooth bromegrass have been developed in the United States and Canada (Carlson and Newell 1985; Hanson 1972). Polar, an extremely winterhardy cultivar developed in Alaska (Hodgson *et al*. 1971; Wilton *et al*. 1966), is a 16-clone synthetic. Eleven of those clones are hybrids between smooth bromegrass and northern-adapted, North American pumpelly bromegrass (*B. pumpellianus* Scribn.).

The native range of pumpelly bromegrass in North America extends from northern Canada and Alaska south to Colorado (Elliott 1949). Agronomic characteristics of Alaskan pumpelly bromegrass have been reported earlier (Klebesadel 1984). It is believed that the superior freeze tolerance (Klebesadel 1993a) and therefore winterhardiness in Alaska of Polar over other bromegrass cultivars (Klebesadel 1993a; Wilton *et al*. 1966) is attributable in large measure to the incorporation of northern-adapted *B. pumpellianus* germplasm in that cultivar. Due to the extreme winterhardiness and agronomic potential of native Alaskan pumpelly bromegrass (Klebesadel 1984), that species was included in two of the experiments reported here.

Bromegrass Types, Latitudinal Adaptation, and Winter Survival

Numerous experimental trials conducted previously in Alaska have revealed a consistent superiority of cultivars and regional strains of northern-type smooth bromegrass over those of the southern type. Cultivars of the southern type rarely have escaped some degree of winter injury if not total winterkill in these trials (Klebesadel 1970, 1971; Klebesadel and Helm 1992).

Winterkill has been a continuing problem with many biennial and perennial forage crops grown in Alaska. In general, winterkill in this area is less severe with cultivars or strains introduced from similar northern latitudes, such as from Scandinavian countries, than cultivars or strains in the same species from more southern latitudes (Klebesadel 1970, 1971, 1985a, 1985b, 1993a, 1993c; Klebesadel *et al*. 1964; Klebesadel and Dofing 1990; Klebesadel and Helm 1986, 1992). Smooth bromegrass, however, is grown to a very limited extent in the Scandinavian countries (Opsahl 1962) and so strains utilized in Alaska usually have been obtained from elsewhere in North America.

Utilization and Winter Injury of Stands

On Alaska farms bromegrass commonly is (a) harvested twice per year and stored as hay or silage, (b) harvested more frequently and fed as "green-chop" forage, or (c) pastured by grazing stock. During recent decades, occasional winters that were unusually rigorous have resulted variously in modest winter injury to widespread winterkill of bromegrass in southcentral Alaska.

Cumulative evidence raised the suspicion that some of this damage was attributable to the specific schedule or frequency of harvests during the previous growing season, and that certain schedules of harvest might weaken a bromegrass stand more than others. If some harvest frequencies or schedules did in fact weaken a stand, the grass logically would be more subject to winter injury, especially if then subjected to unusually rigorous winter stresses.

Local winters vary considerably in stresses imposed on overwintering crops (Klebesadel 1974, 1977); stresses that have seemed unusually injurious to plants include thaw-refreeze oscillations, extreme low temperatures (especially shortly after thaw intervals), and winter winds that remove insulating snow cover.

Research Elsewhere Comparing Bromegrass Harvest Schedules and Frequencies

Numerous reports concerning the responses of smooth bromegrass to harvest frequencies have been published; in general they agree that this species is more productive with infrequent harvests (2 to 3 cuttings per year) than more frequent defoliation (Bird 1943; Fairey 1991; Jung *et al*. 1974; Marten and Hovin 1980; Paulsen and Smith 1968).

In addition to sensitivity to frequency of harvest, the scheduling of harvests, especially the timing of the first cutting as it relates to growth stage of bromegrass, has also been noted to influence both total annual forage production and stand persistence. Kunelius (1979) in eastern Canada obtained higher total annual forage yields with first harvest when fully headed than at head-emergence stage.

Paulsen and Smith (1969) in Wisconsin reported that after two years of three harvests per year, with the first harvest taken at eight different stages of plant development, residual vigor of bromegrass (as measured by a uniform-evaluation harvest in the third year) was lowest where harvest had been at jointing stage and highest where first harvest had been at fully headed stage. Knievel *et al*. (1971), also in Wisconsin, reported highest yields and best stand persistence with first harvest at early anthesis, compared with first harvest at tillering or head-emergence stages.

Raese and Decker (1966) in Maryland found that harvest of bromegrass at the latest of four growth stages (late anthesis), compared with three earlier stages, resulted in best persistence and least weed invasion of stands. In a similar vein, Hamilton *et al*. (1969) reported that the latest of four initial harvests of bromegrass produced the highest first-cutting yield and therefore that treatment resulted in the highest total annual yield.

Wright *et al*. (1967), summarizing bromegrass response to harvest schedules in six northeastern states, reported that bromegrass stands were sensitive to early harvesting of the spring crop, and harvesting the first crop at progressively later growth stages increased yields markedly.

Others reporting that more frequent harvests than two or three per year adversely affects continued vigor and persistence of bromegrass stands include Jung *et al*. (1974) and Marten and Hovin (1980). Thus, the aforementioned reports from elsewhere in North America generally agree that smooth bromegrass productivity and persistence are favored by permitting the spring growth to reach fully headed to anthesis stage before first harvest, and that infrequent harvests (2 to 3 per year) are superior to more frequent cuttings.

Food Reserves as Related to Growth and Management

Carbohydrate food reserves stored within plants provide the energy required to develop freeze tolerance in overwintering tissues, to support metabolism during winter dormancy, and to provide for new growth in spring and after each cutting (Smith 1964; Smith and Nelson 1985).

Several reports from this station have shown a correlation between high pre-winter levels of stored food reserves and superior winter survival of perennial grasses (Klebesadel 1985a, 1991, 1993a, 1993c; Klebesadel and Helm 1986). Although no differential management influences were involved, those reports illustrate the importance of high levels of food reserves to subsequent winter survival. Northernmost-adapted strains stored higher levels of food reserves and exhibited superior winter survival over more southern-adapted strains (within the same species) that stored lower levels of food reserves.

Other work at this location with smooth bromegrass plants harvested at different times during the seeding year revealed that harvest dates that resulted in highest pre-winter levels of stored food reserves also resulted in best winter survival and highest subsequent forage yields (Klebesadel 1993b).

Reports concerning harvest or pasture defoliation of perennial grasses and attendant effects on storage and utilization of plant food reserves have been reviewed by Graber (1931), May (1960), Smith and Nelson (1985), and Weinmann (1948). Other investigators have documented interrelationships between harvest management and food reserves in smooth bromegrass and how those factors relate to persistence of stands or to winter survival.

It is known from investigations elsewhere that levels of stored reserves within bromegrass plants fluctuate considerably during a growing season, both as influenced by stage of grass development and by harvest schedules (Paulsen and Smith 1968, 1969; Reynolds and Smith 1962; Smith *et al*. 1986). Without the intruding effects of forage harvests, the normal food-reserve fluctuations in plants are cyclic, changing during the growing season in concert with seasonal growth and developmental changes of the plant.

In early spring, as well as after a forage harvest removes all of the food-manufacturing leaves (Fig. 1), new plant growth activity necessarily utilizes stored energy (nonstructural carbohydrates) available within the plant system, drawing upon and lowering those energy levels. Conversely, photosynthetic activity, principally within the leaves, manufactures sugars that are translocated to storage sites, replenishing energy levels within the plants.

When bromegrass starts growth in spring, food reserves stored during the previous growing season are

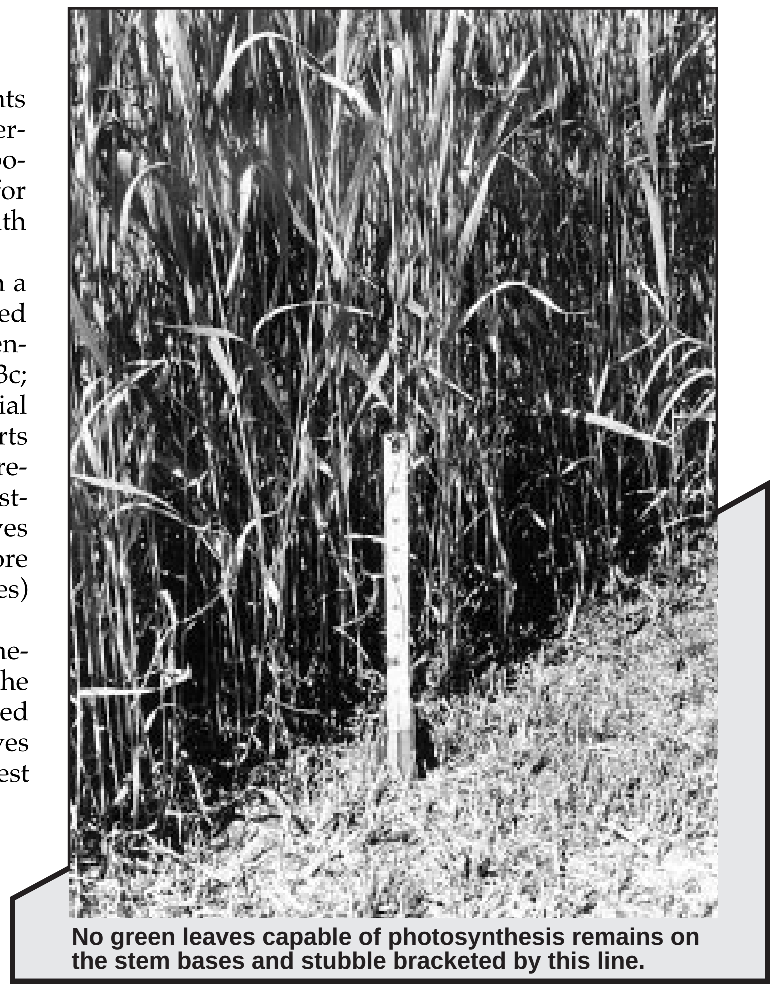


Figure 1. Appearance of cut and uncut bromegrass photographed on 21 June. Tall growth in background has photosynthetically active leaves on top 2/3 of culms (stems) while shaded leaves near culm bases have dried and become nonfunctional. With forage harvest of tall growth (foreground), all food-manufacturing leaves are removed and only bare, leafless stubble remains with no photosynthetic capabilities. New growth will arise from tillers in the stubble. However, until new growth produces leaves for photosynthesis, that growth must draw upon energy reserves stored in the parent plant, levels of which are highest after emergence and flowering of seed heads (Reynolds and Smith 1962; Smith et al. *1986).*

drawn upon and reduced while providing the energy to produce new leaves and to start the elongation of short tillers into tall culms (Smith and Nelson 1985). Photosynthetic activity (food manufacture) by the new leaves then gradually reverses the trend of lowering food reserves and begins to increase levels of nonstructural carbohydrates within the plant; that increase continues until it reaches a maximum after anthesis (flowering) of seed heads (Reynolds and Smith 1962; Smith *et al*. 1986).

Tall-growing grasses, such as bromegrass, are not weakened excessively if forage harvests are taken at times during the growing season (stages of plant development) when food reserves within the plant are at high levels. Conversely, if harvests are taken (especially more than once during the growing season) when plant food reserves are at low levels, plants may enter the winter in a weakened condition and would then be more subject to winter injury, especially during an unusually stressful winter.

Therefore, to be least harmful to the energy status within plants, the scheduling and frequency of forage harvests should be in harmony with plant needs, removing stem and leaf growth at specific times (plant developmental stages) when energy levels are at high instead of low levels (Paulsen and Smith 1968; Reynolds and Smith 1962; Smith and Nelson 1985).

Reynolds and Smith (1962) showed decreasing levels of total available carbohydrates (TAC) in crown tissues of bromegrass during early spring growth and during regrowth after harvests; however, when harvested twice per year (27 June = green seed stage + 29 Aug = green seed stage), TAC levels had been restored to high levels by the time each harvest was taken. With three harvests per year (3 June = early heading, + 18 July = stem elongation, + 29 Aug = vegetative), TAC levels in plants were lower at each harvest than occurred with the 2-cut schedule. The intervals (average = 44 days) between harvests on the 3-cut schedule were not as adequate for full food-reserve replenishment as occurred with two cuts per year where harvests were 63 days apart. With both harvest frequencies, 74 days elapsed for grass regrowth from the last harvests on 29 August until the final pre-winter sampling on 11 November; that period of 74 days was adequate for full replenishment of TAC to high levels prior to onset of winter.

Thus, to maintain stand vigor and a high productive capacity in perennial forages such as bromegrass, plant energy levels should be permitted to reach relatively high levels (a) prior to each harvest and (b) prior to the winterhardening period (Smith 1964; Smith and Nelson 1985). Then, regardless of winter severity, forages are less subject to winter injury, and possess more energy for growth the following spring, if they enter the winter dormant period with a high level of stored food reserves.

These Experiments

To gain insights into the effects of differential harvest management on bromegrass in Alaska, several field experiments were initiated to compare the responses of various cultivars and strains of bromegrass to different schedules and frequencies of harvest. Results presented here are from five separate experiments conducted at the University of Alaska's Matanuska Research Farm (61.6°N) near Palmer in southcentral Alaska.

Experimental Procedures

All experiments were field plantings in Knik silt loam (Typic Cryochrept) with good surface drainage. Pre-plant commercial fertilizer disked into the soil supplied nitrogen (N), phosphorus (as P_2O_5), and potassium (as K_2O) at 28, 105, and 54 lb/A, respectively.

All bromegrass strains were broadcast-seeded at 20 pounds of germinable seed per acre in individual plots measuring 5 by 20 feet. Seed was covered lightly by stirring into the surface ¾-inch of soil and seedbeds were then firmed by drawing a corrugated-roller packer over the entire experimental area. Split-plot experimental designs were used with four replications. Harvest schedules were used as whole plots and strains as sub-plots. All references to statistical significance in this report are based on 95% probability levels.

Plots were left unharvested during the seeding year in all experiments except Exp. II when all plots were harvested on 5 August of the year of establishment. Each spring, old growth present on plots from the previous growing season was clipped and removed shortly after snow melt and before bromegrass spring growth had started. Experiments were topdressed uniformly with a complete commercial fertilizer shortly after snow melt. A second topdressing of ammonium nitrate, supplying approximately 40% of total N for the year, was made near mid-season in the year of differential harvests to provide better seasonal distribution of forage yield than occurs with all N applied in spring (Laughlin 1963). Rates and application dates for each experiment appear in the table captions.

Bromegrass strains were harvested on three or four different schedules during the second-last year of each experiment. Bromegrass strains and harvest schedules and frequencies compared in Exps. I through V appear in Tables 1 through 5, respectively. To remove border effects, a strip 1.25 feet wide was clipped and removed immediately prior to each harvest from both ends of plots to be harvested. Harvests were accomplished by clipping and weighing a swath 2.5 feet wide and 17.5 feet long from the centerline of each plot, leaving about a 2-inch stubble. The remaining grass growth on each plot, bordering the harvested swath, was also clipped and removed immediately.

A small, bagged sample was taken from the herbage harvested from each plot, weighed immediately, then dried to constant weight at 140°F; percents dry matter in samples were used to calculate oven-dry yields reported. These samples were then ground finely and analyzed for crude protein (N x 6.25) by the Kjeldahl method.

In the final year of each experiment, visual estimates of winter injury (if apparent) were recorded for each plot. Then all plots in each experiment were harvested on the same date (identified in tables) in late June to provide a comparative measure of the effects of the different schedules and frequencies of harvest during the previous growing season.

Following is a schedule of events in the five experiments reported here; experiments are arranged by type of treatments (harvest schedules), rather than chronologically, to simplify discussion of results:

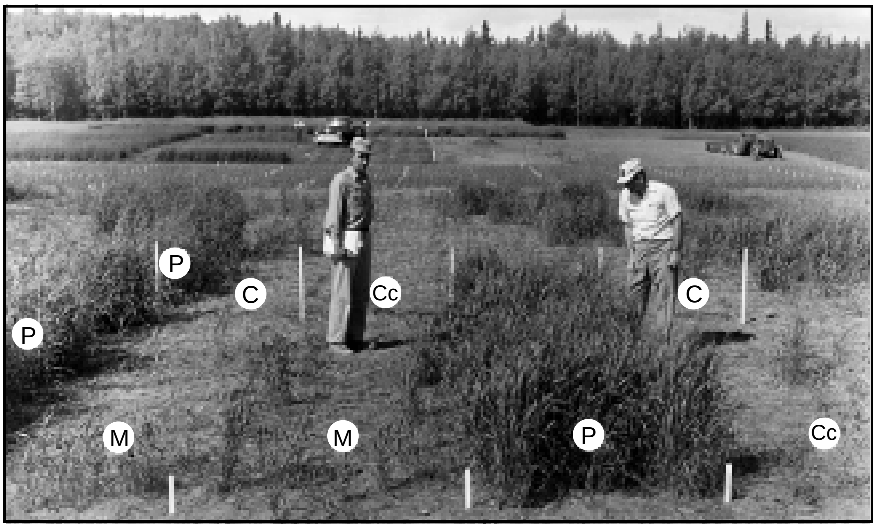
Exp. I: 1962 Seeded 3 July
1963 Four harvest schedules (2 at 3 cuts, 2 at 2 cuts; Table 1)
1964 Uniform harvest 24 June

Exp. II: 1964 Seeded 22 May; seeding-year harvest 5 August
1965 Four harvest schedules (2 at 3 cuts, 2 at 2 cuts; Table 2)
1966 Uniform harvest 29 June

Exp. III: 1962 Seeded 19 June
1963 Two harvests of all plots (5 July and 20 Sep.) while Achenbach recovered from winter injury
1964 Three harvest schedules (5 cuts, 4 cuts, 2 cuts; Table 3)
1965 Uniform harvest 24 June

Exp. IV: 1963 Seeded 29 May
1964 Four harvest schedules, but no regrowth for 3-cut final harvests
1965 Two harvests of all plots (25 June and 1 Sep.) to dissipate 1964 treatment effects
1966 Four harvest schedules (5 cuts, 4 cuts, 3 cuts, 2 cuts; Table 4)
1967 Uniform harvest 22 June

Exp. V: 1962 Seeded 3 July
1963 Four harvest schedules
1964 Uniform harvest 24 June. Uniform harvest 2 Sep. (Exp. I)
1965 Four harvest schedules (5 cuts, 4 cuts, 3 cuts, 2 cuts; Table 5)
1966 Uniform harvest 29 June



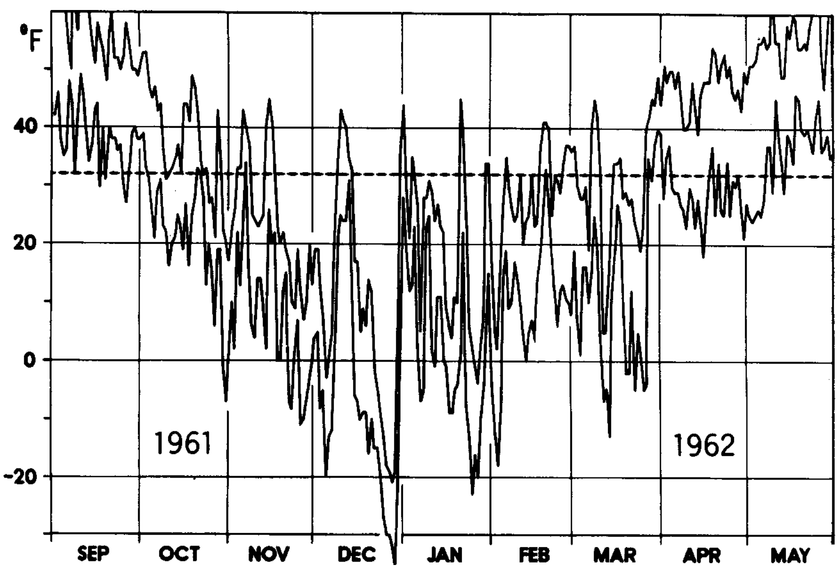


Figure 2. (Upper): Comparative winter survival of four bromegrass strains in the initial but un-numbered experiment in this series. Only stands of the Alaska cultivar Polar (plots indicated by letter (P) = estimated 15% winterkilled) survived that first winter after planting with stands adequate for further use; therefore, the experiment was necessarily terminated before differential harvests could be initiated. Visual estimates of percent winterkill of the other less winterhardy strains were: Carlton (C) 87%, Manchar (M) 93%, Canadian commercial (Cc) 97% (value for each strain is mean of estimates for 16 plots). (Lower): Daily maximum and minimum temperatures recorded near the experimental site for the winter during which injury occurred.

Results and Discussion

Each of the experiments in this study ideally involved three consecutive growing seasons: first, the year of establishment, second, the year of differential harvests, and third, the final year with a first-cutting harvest of all plots on the same date in late June. That final-year harvest served as a uniform evaluation and comparison of the effects of treatments in the second year as they influenced (a) subsequent winter survival during the second winter of the experiment and (b) stand vigor as indicated by forage productivity in the first cut of the third and final year of the experiment. Experiments III, IV, and V involve certain exceptions to this pattern as described in the following discussion of each.

The first experiment established for this series was a victim of such severe winterkill during the first winter after establishment that it was necessarily terminated before differential harvests could be initiated (Fig. 2). Three of the four bromegrass strains were so decimated by winterkill that they were judged incapable of adequate recovery for continuation of the experiment.

When plants are alive at onset of winter and dead the following spring, the absence of monitoring capabilities of plant viability (and time of demise) during relatively long subarctic winters precludes knowledge of what specific winter stress(es) caused plants to die. Many factors can operate singly or interact with others to cause winter injury or death (Smith 1964).

Some of those include poor winter-hardening conditions during autumn; too-early onset of very low temperatures; the frequency, duration, and extent of wide temperature fluctuations; warm intervals that can cause dehardening of plants; the extent and duration of lethally low temperatures during the total course of winter; snow insulation or lack of it; ice coverage with possible smothering or buildup of toxic gas concentrations beneath the ice; wind effects; tissue dehydration; and a lethal drop in temperatures when plants are dehardening in spring. Consequently, injury or death during winter may be due to one unusually harmful event, or it may be the cumulative effect of two to several stress factors occurring at one time or serially throughout the winter.

A temperature record of the 1961-62 winter that caused severe winterkill of the introduced bromegrass cultivars appears in Figure 2. Conjecture as to possibilities of injurious effects in that record include (a) a very early plunge of temperatures to substantially below 0°F in late October, (b) a considerable number of temperature oscillations ranging from above freezing to below 0°F, and especially, (c) a several-day warm interval just prior to mid-December, followed fairly abruptly by (d) a rapid decline to seven consecutive days of minima at or below -20°F, four of those days at or below -30°F, and the lowest reaching -35°F.

The superior winter survival of the cultivar Polar during that stressful winter was probably due to its high level of tolerance to freezing temperatures and possibly to a measure of pre-winter physiologic dormancy exhibited by that cultivar (Klebesadel 1993a).

The significance of the early plunge to low temperatures shown in Figure 2 is that it parallels another winter (1975-76) during which much winterkill occurred locally following an abnormal, precipitous drop in temperatures to low levels during late October-early November (Klebesadel 1977). Inasmuch as the annual development of freeze tolerance in perennial plants is a gradual process, plants understandably may be injured or killed by temperatures in October that they would tolerate without injury later in the winter when freeze-tolerance development had progressed further.

The aforementioned incomplete and terminated initial experiment is not included in the numbered series described in this report. Winter-injury comparisons in that experiment were referred to previously (Wilton *et al*. 1966); however, they are included here also, along with Figure 2, as they were derived from the first experiment in the total series planned for this study. Those results therefore serve (a) to illustrate some characteristics and effects of a severe winter, (b) to demonstrate that occasional winters impose such severe stresses that use of the most winterhardy strains can provide insurance against winterkill, and (c) to complement and reinforce winterhardiness rankings of bromegrass strains and cultivars compared in the other five experiments in this report.

In the five experiments successfully completed in this series, crude protein concentration and percent dry matter in forage differed little at each harvest among bromegrass strains compared. Therefore, mean percents dry matter and crude protein of all strains are presented for each harvest in Tables 1 through 5. In the rare instances when differences in percent crude protein occurred, (a) pumpelly brome was slightly higher than other strains or (b) sparse herbage in a plot greatly thinned by winter injury was higher than others due to few plants benefiting from abundant applied fertilizer.

All strains established full stands in all experiments except native pumpelly bromegrass in Exp. 3 (Table 3); those were estimated at 60% of full stands at the end of the first growing season.

Experiment I: The five cultivars (Table 1) differed considerably in winterhardiness as indicated by consistently dissimilar winter survival among cultivars for the two winters. Sac, a southern-type cultivar from Wisconsin, was least hardy and was winter-injured so severely during the first winter that no harvestable yields were obtained during the year after establishment until the September and October harvests (Fig. 3).

Saratoga, a southern-type cultivar from New York, also sustained considerable injury during the first winter but to a lesser extent than Sac and produced harvestable yields at each cutting. However, Saratoga produced significantly lower yields in all first-cutting harvests than the more winterhardy Polar, Carlton, and Manchar. Saratoga recovered from winter injury more rapidly than Sac and, after mid-season of the year of differential harvests, Saratoga equalled the three more winterhardy cultivars in yields in all of the August, September, and October harvests.

Polar, Carlton, and Manchar were approximately equal in season-total yields within each harvest schedule. Over both 3-cut schedules, total annual yields of those three cultivars averaged 2.50 T/A while over both 2-cut schedules they averaged 3.61 T/A. All three cultivars produced significantly higher yields with either schedule of two cuttings per year than with either schedule of three cuttings. With only one exception (Polar vs. Saratoga, late third cut), the three more winterhardy

Table 1. Oven-dry forage yields of five bromegrass cultivars as influenced by four different harvest schedules, and effects of those harvest schedules on cultivars as measured by estimates of winterkill in May of the following spring, and subsequent uniform evaluation harvest of all plots on 24 June. Differential harvests were conducted on 1-year-old stands at the Matanuska Research Farm. (Exp. I; pounds per acre N-P_2O_5-K_2O, respectively, applied during year of differential harvests = 84-64-32 on 3 May, plus 60-0-0 on 21 June; 105-80-40 applied 13 April of year of final harvest).

Harvest schedules and cultivars	Year of differential harvests					Estimated winterkill	Uniform harvest subsequent spring
	Tons/acre					Percent	Tons/acre
3 cuts—early 3rd cut:							
	12 June	8 Aug	17 Sep		Season total		24 June
Polar	0.97 ab[1]	1.19 a	0.36 b		2.52 c	0 a	1.05 ab
Carlton	1.09 a	1.18 a	0.44 b		2.71 c	14 abc	0.62 de
Manchar	0.85 b	1.03 a	0.61 a		2.49 c	26 bcd	0.42 ef
Saratoga	0.17 c	1.01 a	0.58 a		1.76 e	70 g	0.06 h
Sac	Tr[2]	Tr	0.34 b		0.34 g	63 fg	Tr
Mean	0.62	0.88	0.47		1.96	35	0.43
(% D.M.)[3]	(27.1)	(24.7)	(21.0)				(27.7)
(% C.P.)[4]	(15.5)	(17.9)	(20.9)				
3 cuts—late 3rd cut:							
	12 June	8 Aug		4 Oct			
Polar	0.75 a	1.06 a		0.41 b	2.22 cde	0 a	1.08 ab
Carlton	0.97 a	1.10 a		0.44 b	2.51 c	0 a	0.87 bc
Manchar	0.90 a	0.95 a		0.69 a	2.54 c	6 a	0.75 cd
Saratoga	0.18 b	0.96 a		0.74 a	1.88 de	51 ef	0.19 gh
Sac	Tr	Tr		0.36 b	0.36 g	48 e	Tr
Mean	0.56	0.81		0.53	1.90	21	0.58
(% D.M.)	(27.1)	(24.7)		(25.8)			(27.7)
(% C.P.)	(15.5)	(17.9)		(18.1)			
2 cuts—early 2nd cut:							
	2 July	5 Sep					
Polar	2.33 a	1.57 a			3.90 a	0 a	1.04 ab
Carlton	2.17 a	1.53 a			3.70 ab	0 a	0.78 cd
Manchar	1.96 a	1.42 a			3.38 ab	0 a	1.03 ab
Saratoga	0.83 b	1.41 a			2.24 cde	13 ab	0.33 fg
Sac	Tr	0.63 b			0.63 fg	28 cd	Tr
Mean	1.46	1.31			2.77	8	0.64
(% D.M.)	(30.0)	(24.0)					(27.7)
(% C.P.)	(13.0)	(15.3)					
2 cuts—late 2nd cut:							
	2 July			4 Oct			
Polar	2.06 a			1.64 a	3.70 ab	0 a	1.01 ab
Carlton	2.07 a			1.57 a	3.64 ab	0 a	1.13 a
Manchar	1.83 a			1.51 a	3.34 b	5 a	1.21 a
Saratoga	0.74 b			1.63 a	2.37 cd	30 d	0.30 fg
Sac	Tr			1.00 b	1.00 f	63 fg	Tr
Mean	1.34			1.47	2.81	20	0.73
(% D.M.)	(30.0)			(33.8)			(27.7)
(% C.P.)	(13.0)			(10.5)			

[1]Means not followed by a common letter are significantly different (5% level) using Duncan's Multiple Range Test. For differential harvests during first year, comparisons are among each 5-cultivar data set in a column; for season totals, winterkill, and uniform evaluation harvest, comparisons are among all 20 means in each column.
[2]Trace amount of herbage inadequate for harvestable yield.
[3]Mean percent dry matter for all cultivars on each harvest date.
[4]Mean percent crude protein for all strains on each harvest date.

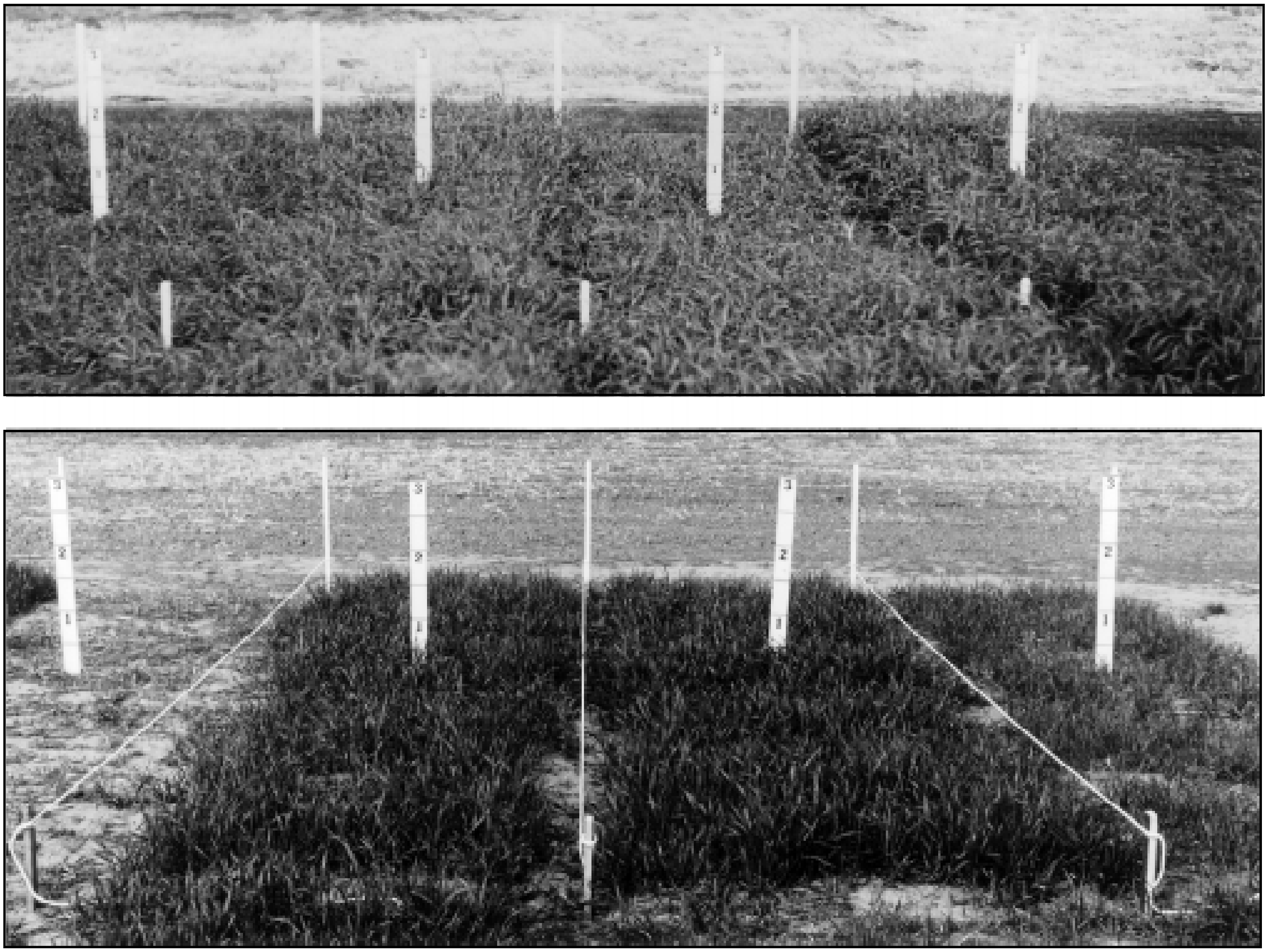


Figure 3. (Upper): Seeding-year growth, showing good establishment, of four bromegrass cultivars (left to right: Sac, Manchar, Polar, Saratoga) in Experiment I, seeded on 3 July and photographed on 6 October. (Lower): The same plots photographed 26 May of the following year showing differences in winter injury in spring of the year of differential harvests. White stake in center of each plot is three feet tall.

cultivars surpassed Saratoga and Sac in total yields during the year of differential harvest schedules.

During the second winter, Sac and Saratoga again were more injured than Polar, Carlton, or Manchar; when Sac and Saratoga differed significantly, Sac again sustained the greater injury. Yields of Saratoga in June of the final year were invariably lower than those of the three hardier cultivars. The badly thinned and weed-invaded stands of Sac did not produce harvestable yields at the final evaluation harvest, regardless of cutting schedule the previous year.

The different harvest schedules predisposed cultivars to different severities of winter injury. With three harvests per year, a third cutting in mid-September generally was more harmful than in early October. However, with two cuttings, survival tended to be better with the second cutting in early September than with a later second cutting in early October.

With the most damaging 3-cut schedule (12 June + 8 Aug. + 17 Sep.), visual estimates of winter injury and subsequent forage yields generally ranked the three hardiest cultivars in the order Polar > Carlton > Manchar in winterhardiness. Polar showed no evidence of winter injury with any harvest schedule and the yield of Polar in June of the final year was as high with the 3-cut schedule that injured other cultivars most as it was from the 2-cut schedule that injured the others least (2 July + 5 Sep.).

Experiment II: Three of the cultivars used in Exp. I, plus a strain of native Alaskan pumpelly bromegrass and a strain of Canadian "commercial" smooth bromegrass, were compared in Exp. II (Table 2) with four harvest schedules largely similar to those employed in Exp. I.

This was the only experiment in the series to be harvested during the seeding year. Owing to the earliest seeding date (22 May) and good growing conditions that resulted in more seeding-year growth than the other experiments, a decision was made to harvest all plots on 5 August. Oven-dry yields in tons per acre ranked as follows: Carlton 0.68, Manchar 0.56, Polar 0.50, Canadian commercial 0.49, and pumpelly 0.07. Yield of Carlton was significantly higher than, and pumpelly yield significantly lower than, the other three. Yields of Manchar, Polar, and Canadian commercial did not differ significantly.

Table 2. Oven-dry forage yields of five northern-adapted bromegrass strains as influenced by four different harvest schedules, and effects of those harvest schedules on the grasses as measured by estimates of winterkill in May of the following spring, and subsequent uniform evaluation harvest of all plots on 29 June. Differential harvests were conducted on 1-year-old stands at the Matanuska Research Farm. (Exp. II; pounds per acre N-P_2O_5-K_2O, respectively, applied during year of differential harvests = 126-96-48 on 24 March, plus 80-0-0 on 1 July; 126-96-48 applied 29 March of year of final harvest).

Harvest schedules and strains	Year of differential harvests				Estimated winterkill	Uniform harvest subsequent spring
	Tons/acre				Percent	Tons/acre
3 cuts—early 3rd cut:						
	15 June	30 July	10 Sep	Season total		29 June
Pumpelly	0.57 a[1]	0.93 a	0.51 a	2.01 hi	10 ab	2.48 abc
Polar	0.55 a	1.09 a	0.54 a	2.18 gh	48 bc	2.09 a-e
Carlton	0.41 a	1.26 a	0.57 a	2.24 gh	91 e	0.59 f
Canadian[2]	0.41 a	1.19 a	0.61 a	2.21 gh	95 e	0.44 f
Manchar	0.38 a	1.16 a	0.59 a	2.13 h	94 e	0.29 f
Mean	0.46	1.13	0.56	2.15	68	1.18
(% D.M.)[3]	(27.8)	(21.2)	(19.5)			(23.2)
(% C.P.)[4]	(19.0)	(22.7)	(25.6)			
3 cuts—late 3rd cut:						
	15 June	30 July	29 Sep			
Pumpelly	0.38 a	0.78 b	0.42 a	1.58 i	3 a	2.52 abc
Polar	0.57 a	1.04 a	0.83 a	2.44 d-h	69 d	1.48 e
Carlton	0.35 a	1.25 a	0.78 a	2.38 e-h	96 e	0.34 f
Canadian	0.32 a	1.09 a	0.91 a	2.32 fgh	94 e	0.43 f
Manchar	0.36 a	1.12 a	0.94 a	2.42 d-h	94 e	0.35 f
Mean	0.40	1.06	0.78	2.23	71	1.02
(% D.M.)	(27.8)	(21.2)	(22.2)			(23.2)
(% C.P.)	(19.0)	(22.7)	(22.1)			
2 cuts—early 2nd cut:						
	30 June	31 Aug				
Pumpelly	1.36 ab	1.32 b		2.68 c-g	10 ab	2.17 a-e
Polar	1.58 a	1.88 a		3.46 a	13 ab	2.77 a
Carlton	1.00 b	2.00 a		3.00 abc	30 bc	2.37 a-d
Canadian	1.13 ab	2.09 a		3.22 ab	23 ab	2.56 ab
Manchar	1.12 a	2.04 a		3.16 abc	20 ab	2.54 abc
Mean	1.24	1.87		3.10	19	2.48
(% D.M.)	(28.2)	(27.8)				(23.2)
(% C.P.)	(14.8)	(16.7)				
2 cuts—late 2nd cut:						
	30 June		29 Sep			
Pumpelly	0.85 a		1.32 b	2.17 h	10 ab	2.27 a-e
Polar	1.21 a		1.95 a	3.16 abc	20 ab	2.85 a
Carlton	0.89 a		2.00 a	2.89 bcd	53 d	1.72 cde
Canadian	0.78 a		1.97 a	2.75 b-f	63 d	1.58 de
Manchar	0.90 a		1.93 a	2.83 b-e	63 d	1.76 b-e
Mean	0.93		1.83	2.76	42	2.04
(% D.M.)	(28.2)		(30.0)			(23.2)
(% C.P.)	(14.8)		(13.8)			

[1]Means not followed by a common letter are significantly different (5% level) using Duncan's Multiple Range Test. For differential harvests during first year, comparisons are among each 5-strain data set; for season totals, winterkill, and uniform evaluation harvest, comparisons are among all 20 means in each column.
[2]Canadian commercial strain (not a cultivar).
[3]Mean percent dry matter for all strains on each harvest date.
[4]Mean percent crude protein for all strains on each harvest date.

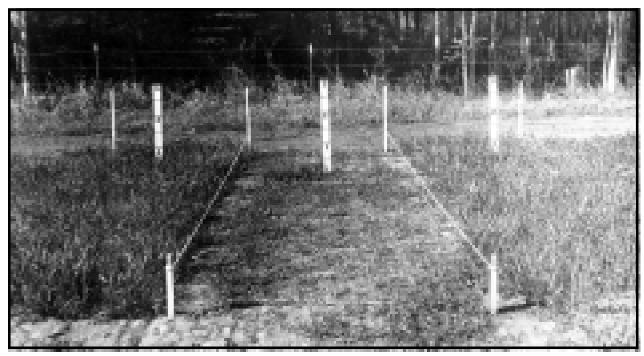
Figure 4. Winter injury of northern-adapted bromegrass strains in Exp. II in spring 1966 as influenced by harvest schedules during 1965. The five plots in foreground, harvested three times during the previous year (15 June + 30 July + 10 Sep) are (left to right) severely injured Polar, Manchar, Carlton, Canadian commercial, and less-injured native pumpelly brome. The five plots immediately behind, showing less injury with only two harvests the previous year (30 June + 29 Sep) are (left to right) Manchar, Carlton, pumpelly, Canadian commercial, and Polar. Planted 22 May 1964, photo 17 May 1966.

During the following year, all strains were generally equal in forage yield in each of the individual harvests within the various schedules, as well as in total annual yield (Table 2). An exception was lower yields of pumpelly bromegrass in certain of the second cuttings and in total-year yields under two of the harvest schedules.

Again, as in Exp. I, the different harvest schedules resulted in dissimilar extents of subsequent winter injury during the second winter (Table 2, Fig. 4). Both 3-cut schedules were about equal in predisposing stands to injury, and both were more damaging to stands than either 2-cut schedule. With two-cuttings, a second harvest in late September was significantly more damaging to the three less winterhardy strains (Carlton, Canadian commercial, Manchar) than a second cutting in late August.

Even though all five strains generally are considered to be very winterhardy in more southern growing areas, all three of the most damaging harvest schedules revealed clear and consistent differences in hardiness among strains; Carlton, Canadian commercial, and Manchar sustained more winter injury than Polar or native pumpelly bromegrass. Injury to the former three was approximately similar within each harvest schedule (Table 2, Fig. 4). Although Polar tended to exhibit more winter injury than pumpelly brome within all harvest schedules, the difference in percent winterkill was statistically significant only following the most injurious 3-cut schedule (15 June + 30 July + 29 Sep.).

Forage yields in late June of the final year showed that both 3-cut schedules (harvest frequencies that predisposed strains to greatest winter injury) also resulted in lower subsequent forage yields. Where two cuts per



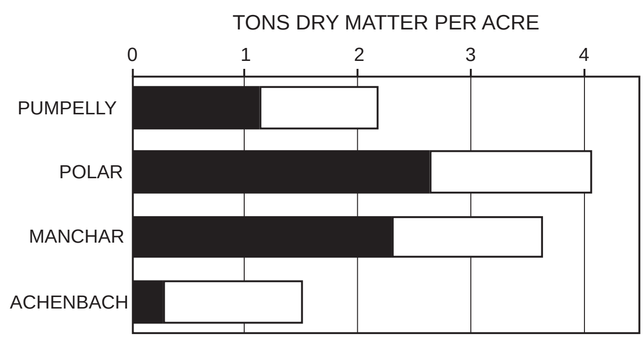


Figure 5. (Upper): Three plots in Experiment III (left to right: Polar, Achenbach, Manchar), photographed 26 May of the year following establishment, showing severe winter injury of the southern-type cultivar Achenbach. To permit Achenbach stands to recover, all plots were harvested twice on the same dates (5 July + 20 Sep.) during the year of the photo and differential harvests were deferred until the following year. (Lower): Graph of oven-dry forage yields during the year of the photo; solid portions of bars are first-cut yields and open portions are second-cut yields.

year caused little winter injury, strains did not differ in subsequent June forage yields. However, both 3-cut schedules resulted in winter injury to the extent that subsequent yields in the final evaluation harvest were higher with pumpelly and Polar than with the three less hardy strains. Pumpelly surpassed Polar significantly in yield where the third cut the previous year had been harvested in late September.

The ranking of winterhardiness of brome strains in Exps. I and II agreed generally with earlier results at this location (Klebesadel 1970, 1993a; Wilton *et al*. 1966).

Experiment III: This experiment, unlike the others, was located adjacent to and leeward from a wooded tract so that insulating winter snow remained in place; therefore, grasses were subjected to more modest winter stresses than in the other four experiments.

Despite that protective environment, however, stands of the southern-type cultivar Achenbach sustained extensive winter injury during the first winter (Fig. 5). Therefore, initiation of differential harvests was delayed for a year in the hope that the injured stands of Achenbach would recover adequately during the second year of growth to permit continuation of the experiment. Moreover, initially established stands of pumpelly brome were less dense than ideal so delay of one year permitted vegetative spread to increase stand density of that grass.

Thus, during the second year of growth, all plots were harvested only twice and on the same dates (Fig. 5). Although first-cut yields of Achenbach were very low, second cuttings of that cultivar were equivalent to the

Table 3. Oven-dry forage yields of four bromegrass strains as influenced by three different harvest frequencies, and effects of differential harvests on subsequent productivity of strains as measured by a uniform harvest of all plots on 24 June of the following spring. Differential harvests were conducted on 2-year-old stands at the Matanuska Research Farm. (Exp. III; pounds per acre N-P_2O_5-K_2O, respectively, applied during year of differential harvests = 105-80-40 on 13 April, plus 80-0-0 on 6 July; 105-80-40 applied 23 March of year of final harvest).

Harvest schedules and strains	Year of differential harvests						Uniform harvest subsequent spring
	Tons/acre						
5 cuts per year:							
	2 June	12 June	1 July	20 July	7 Aug	Season total	24 June
Pumpelly	0.18 b[1]	0.15 bc	0.20 a	0.08 b	0.18 b	0.79 de	1.39 ab
Polar	0.39 a	0.30 a	0.20 a	0.29 a	0.33 a	1.51 bcd	1.91 a
Manchar	0.40 a	0.24 ab	0.16 a	0.34 a	0.24 ab	1.38 bcd	1.95 a
Achenbach	Tr[2]	0.06 c	0.07 b	0.08 b	0.24 ab	0.45 e	1.55 ab
Mean	0.24	0.19	0.16	0.20	0.25	1.03	1.70
(% D.M.)[3]	(20.4)	(21.6)	(20.9)	(20.0)	(19.5)		(25.6)
(% C.P.)[4]	(31.9)	(28.6)	(25.1)	(33.4)	(29.3)		
4 cuts per year:							
	5 June	1 July	27 July	25 Aug			
Pumpelly	0.26 b	0.39 b	0.29 b	0.15 c		1.09 cde	1.40 ab
Polar	0.55 a	0.65 a	0.40 ab	0.49 a		2.09 b	1.73 a
Manchar	0.57 a	0.43 b	0.50 a	0.38 ab		1.88 b	1.84 a
Achenbach	0.05 c	0.18 c	0.26 b	0.29 bc		0.78 de	1.49 ab
Mean	0.36	0.41	0.36	0.33		1.46	1.62
(% D.M.)	(21.2)	(21.8)	(19.7)	(21.1)			(25.6)
(% C.P.)	(28.6)	(19.1)	(31.2)	(24.9)			
2 cuts per year:							
	1 July	8 Sep					
Pumpelly	1.27 a	0.66 c				1.93 b	1.01 b
Polar	2.69 a	1.49 a				4.18 a	1.39 ab
Manchar	2.61 a	1.49 a				4.10 a	1.60 ab
Achenbach	0.45 b	1.15 b				1.60 bc	1.08 b
Mean	1.76	1.20				2.95	1.27
(% D.M.)	(24.6)	(30.3)					(25.6)
(% C.P.)	(14.1)	(15.5)					

[1]Means not followed by a common letter are significantly different (5% level) using Duncan's Multiple Range Test. For differential harvests, comparisons are among each 4-strain data set in a column; for season totals and uniform evaluation harvest, comparisons are among all 12 means in each column.
[2]Trace amount of herbage inadequate for harvestable yield.
[3]Mean percent dry matter for all strains on each harvest date.
[4]Mean percent crude protein for all strains on each harvest date.

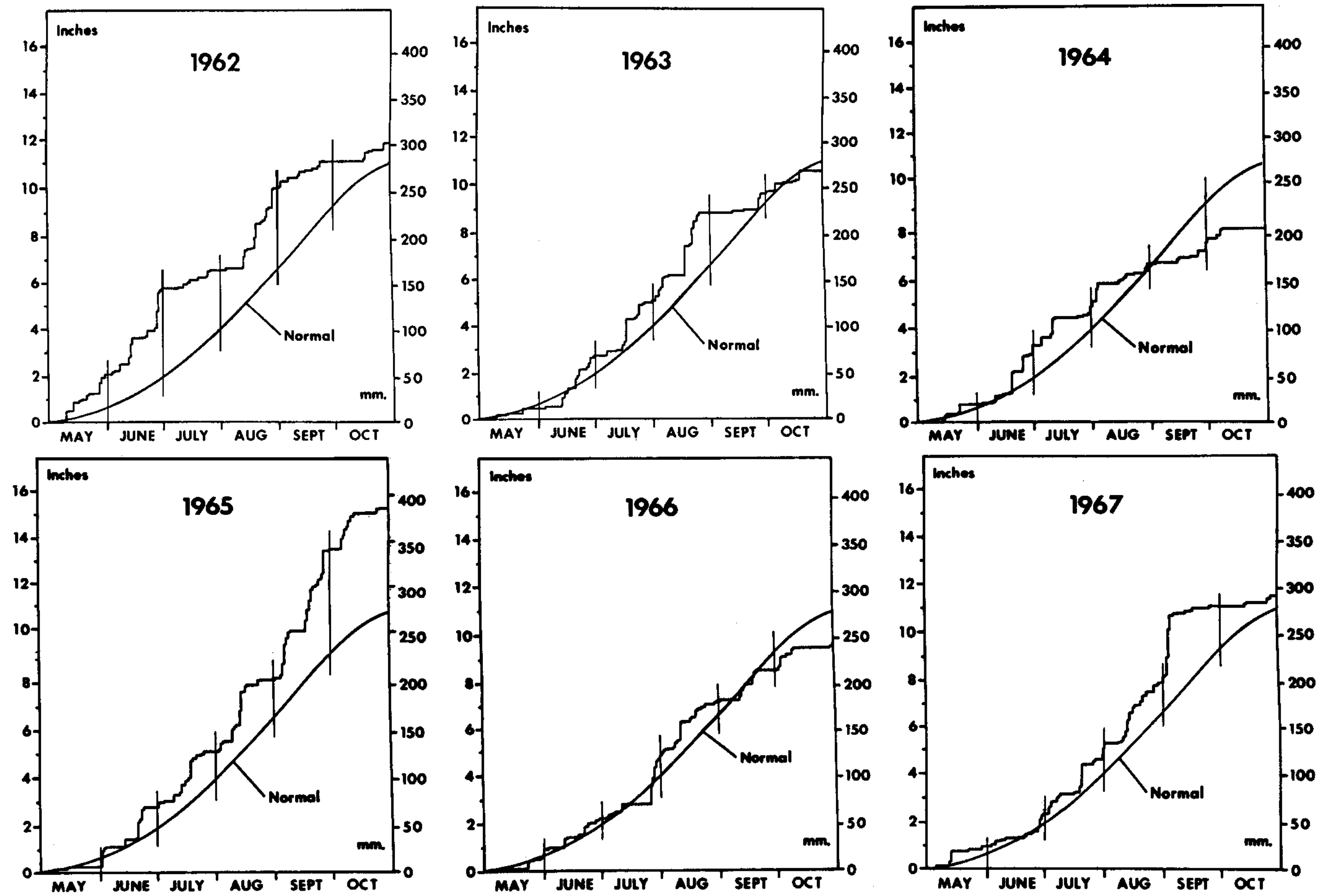


Figure 6. Graphic depictions of cumulative 6-month precipitation received at the Matanuska Research Farm during the six years involved in these experiments; also shown on each graph is the normal cumulative pattern of precipitation for the same location.

other three bromes indicating good stand recovery during that growing season.

Achenbach again sustained some winter injury during the second winter, but not as severe as during the first; therefore, the decision was made to proceed with the different harvest treatments during the third year. During that year, the still sub-optimal stands of native pumpelly bromegrass, and winter-injured stands of Achenbach resulted in generally lower forage yields than those of Polar and Manchar (Table 3). Season-total yields of all four strains were higher with two cuttings than with four or five cuttings.

Little winter injury was apparent in spring of the year following the different harvest frequencies. The combination of a relatively mild winter and the experiment's protected location resulted in highly unusual good winter survival of the southern-type cultivar Achenbach. Consequently, differences among strains in forage yields in the uniform-evaluation harvest in June of the final year were minor. The only statistically significant differences were that yields of Polar and Manchar that had been harvested either five or four times the previous year were higher than those of pumpelly and Achenbach that had been harvested twice.

Experiment IV: In this experiment, differential harvests were initiated in the year after establishment. However, the two 3-cut treatments planned for that experiment could not be completed as there was virtually no regrowth for a third harvest after the second harvest on 12 August in both treatments. The absence of appreciable regrowth may have been due in part to the relatively late second-harvest date. However, moisture deficit was believed to be a more dominant factor in preventing regrowth (see 1964, Fig. 6). Precipitation during August and September of that year was only about 50% of normal (2.8 vs. 5.3 inches). Forage yields for that year of incomplete harvests (2nd year of stands) are not shown.

During the next year (3rd year of stands), all plots in Exp. IV were harvested twice (25 June and 1 Sep.) to permit grasses to recover from any slight effects on stands from differential harvests during the previous year. In spring of the following year (4th year of stands), there were no discernible differences in growth or grass vigor as related to the different harvest schedules of two years earlier. Therefore, a new set of harvest schedules (5 cuts, 4 cuts, 3 cuts, and 2 cuts) was devised and initiated as shown in Table 4, and results are discussed below in combination with Exp. V.

Experiment V: This experiment utilized the same plots as were involved in Exp. I but without the cultivars Saratoga and Sac, stands of which had become too thinned from winter injury to be of use. During the year after

Table 4. Oven-dry forage yields of four northern-adapted smooth bromegrass cultivars as influenced by four different harvest schedules, and effects of those harvest schedules on grasses as measured by a uniform evaluation harvest of all plots on 22 June of the following spring. Differential harvests were conducted on 3-year-old uniform stands at the Matanuska Research Farm. (Exp. IV; pounds per acre N-P_2O_5-K_2O, respectively, applied during year of differential harvests = 126-96-48 on 14 April, plus 80-0-0 on 6 July; 126-96-48 applied 8 April of year of final harvest).

Harvest schedules and cultivars	Year of differential harvests						Uniform harvest subsequent spring
	Tons/acre						
5 cuts per year:							
	3 June	23 June	18 July	9 Aug	2 Sep	Season total	22 June
Polar	0.97 a[1]	0.32 a	0.31 a	0.45 a	0.07 a	2.12 de	1.88 ab
Carlton	0.69 a	0.33 a	0.23 a	0.50 a	0.04 a	1.79 e	1.68 a-e
Canadian[2]	0.79 a	0.21 b	0.36 a	0.38 a	0.09 a	1.83 e	1.75 a-e
Manchar	0.78 a	0.24 ab	0.38 a	0.41 a	0.08 a	1.89 e	1.51 def
Mean	0.81	0.28	0.32	0.44	0.07	1.91	1.71
(% D.M.)[3]	(17.4)	(19.5)	(18.4)	(14.1)	(17.1)		(27.6)
(% C.P.)[4]	(23.3)	(21.2)	(29.2)	(28.9)	(--.-)[5]		
4 cuts per year:							
	10 June	12 July		5 Aug	2 Sep		
Polar	1.72 a	0.33 a		0.49 a	0.16 a	2.70 c	1.83 abc
Carlton	1.41 a	0.29 a		0.47 a	0.13 a	2.30 cd	1.56 c-f
Canadian	1.66 a	0.34 a		0.45 a	0.19 a	2.64 cd	1.63 b-e
Manchar	1.59 a	0.31 a		0.44 a	0.17 a	2.51 cd	1.53 def
Mean	1.60	0.32		0.46 a	0.16	2.54	1.64
(% D.M.)	(17.9)	(17.3)		(18.2)	(17.2)		(27.6)
(% C.P.)	(18.0)	(30.8)		(28.7)	(27.1)		
3 cuts per year:							
		23 June	29 July		2 Sep		
Polar		2.87 ab	0.61 b		0.32 a	3.80 b	1.93 a
Carlton		2.46 b	0.67 ab		0.26 a	3.39 b	1.57 c-f
Canadian		2.59 b	0.70 ab		0.31 a	3.60 b	1.48 ef
Manchar		3.19 a	0.73 a		0.32 a	4.24 a	1.60 c-f
Mean		2.78	0.68		0.30	3.76	1.65
(% D.M.)		(23.3)	(18.7)		(17.1)		(27.6)
(% C.P.)		(10.3)	(24.2)		(29.9)		
2 cuts per year:							
		30 June			2 Sep		
Polar		3.44 a			1.25 a	4.69 a	1.94 a
Carlton		3.03 b			1.44 a	4.47 a	1.35 f
Canadian		3.10 b			1.09 a	4.19 a	1.76 a-d
Manchar		3.15 ab			1.29 a	4.44 a	1.81 abc
Mean		3.18			1.27	4.45	1.72
(% D.M.)		(28.2)			(22.1)		(27.6)
(% C.P.)		(9.7)			(17.3)		

[1]Means not followed by a common letter are significantly different (5% level) using Duncan's Multiple Range Test. For differential harvests, comparisons are within each 4-strain data set; for season totals and uniform evaluation harvest on 22 June, comparisons are among all 16 means in each column.
[2]Canadian commercial strain (not a cultivar).
[3]Mean percent dry matter for all strains on each harvest date.
[4]Mean percent crude protein for all strains on each harvest date.
[5]Data not available.

differential harvests reported for Exp. I (Table 1), all plots were harvested twice in the third year of those stands on the same dates; 24 June as a final-year evaluation harvest for Exp. I, and a second harvest on 2 September. Those two uniform harvests effectively dissipated any residual effects from different harvest schedules during the previous year on the three cultivars remaining with good stands—Polar, Carlton, and Manchar. The different harvest frequencies reported for Exp. V in Table 5 were then initiated in the fourth year of those grass stands.

Experiments IV and V: Both of these experiments included harvest frequencies of five, four, three, and two cuts per year, and, with all cutting frequencies in both experiments, the final harvests were on the same date (2 Sep.). This scheduling differed from Exps. I, II, and III where the final harvest of the different schedules occurred on different dates.

The different harvest frequencies engendered greater differences in total-year yields in Exp. IV (Table 4) than in Exp. V (Table 5). In Exp. IV, total-year yields were highest with two harvests and generally were progressively lower with each increased frequency of harvest. Similarly, in Exp. V, total yields were highest with two harvests but generally were similar for all cultivars with three, four, and five harvests per year.

In the uniform harvests in late June of the year following differential harvests, forage yields in both experiments differed little as affected by the different harvest frequencies. That lack of differences in harvest-frequency effects, as measured by yields in the final evaluation harvest in those two experiments, could be due to the fact that a final harvest on 2 September (with all treatments) left adequate time prior to termination of the growing season for all strains to recover from cutting-frequency effects and to prepare adequately for winter. It is possible also, however, that if winter conditions had been more severe during the final winters of those two experiments, any differences in winter survival that could have been caused by the different harvest frequencies would have been magnified beyond the small differences that occurred.

Yield differences among individual cultivars were relatively minor in the final-year evaluation harvest in Exp. IV (Table 4), with a general tendency toward higher yields for Polar than for the other cultivars. In Exp. V, however, that difference was more pronounced (Table 5); yields of Polar significantly surpassed the other cultivars in each harvest-frequency comparison. Final-year yields of Carlton and Manchar did not differ significantly for any harvest frequency of the previous year.

Distribution of Yield as Related to Bromegrass Development

The results of the five experiments illustrate that adapted bromegrasses possess a considerable capacity for forage production from initiation of spring growth in early May until about the end of June. In various experiments and years, dry-matter yields harvested in the first week of June ranged from about ¼ T/A (Table 3) to about ¾ T/A (Table 4). First-cut yields near mid-June ranged from about ½ T/A (Tables 1, 2) to more than 1½ T/A (Table 4).

Thereafter, however, a dramatic increase in dry-matter yield was invariably seen during the interval from mid-June to the end of that month. During that 2-week period, dry-matter yields often doubled (Tables 1, 2, 4), with yields near 1 July ranging from just over 1 T/A (Table 2) to over 3 T/A (Table 4), depending upon year and growing conditions.

Interruption of that very active period of growth (and dry-matter production) with forage harvests prior to late June or early July tended to curtail considerably the total-season yield of forage. Other investigators (Knievel *et al*. 1971; Kunelius 1979; Paulsen and Smith 1969; Reynolds and Smith 1962; Smith *et al*. 1986; Wright *et al*. 1967) similarly have noted reduced season-total yields with too-early harvest of the first cutting of bromegrass.

The specific sequence and progression of developmental stages in the spring growth of bromegrass helps to explain the response of the grass to different dates of harvest during that spring growth. The growth stages exhibited by bromegrass in Alaska are the same as occur in bromegrass in the midwest U.S. (Eastin *et al*. 1964; Paulsen and Smith 1969; Reynolds and Smith 1962); however, they occur somewhat later as related to calendar dates at this northern latitude where plant growth begins later (Compare Table 6 with above refrences).

The initial growth in spring, referred to as "tillering," involves the greening and leafing out of (a) tillers that had appeared above the soil surface, but had not elongated, during the previous autumn, and (b) newly appearing tillers that emerge from the soil surface in spring. During this early growth and proliferation of leaves, the terminal growing point within each tiller remains at or near the soil surface. Spring grazing or a very early harvest does not disturb or remove these growing points.

The process of tiller elongation into culms (stems) is called the "jointing" stage. As this stage progresses, the hidden terminal growing points inside the culms begin to elevate as internodes elongate. A very early forage harvest that clips above the level of the elevating growing points will be low in yield but will not deter continued growth of the culms.

In sharp contrast, however, a slightly later harvest that occurs after the hidden terminal growing points are elevated sufficiently to be removed in the harvest will profoundly interrupt the growing process. In that event, a considerable delay in growth may ensue before new basal tillers begin to grow to produce the next crop of herbage (Eastin *et al*. 1964; Paulsen and Smith 1968, 1969; Reynolds and Smith 1962; Smith and Nelson 1985).

To derive a better understanding of rate of herbage production as it relates to grass development, time during the growing season, and schedule and frequency of harvest, mean rates of dry-matter accumulation for all strains and for each growing period in Experiments I through V are presented in Figures 7 through 11, respectively.

The critical interrelationship of stage of grass development, time of harvest during June, and rate of herbage production was very evident in these experiments. The

Table 5. Oven-dry forage yields of three northern-adapted bromegrass cultivars as influenced by four different harvest frequencies, and effects of differential harvests on subsequent productivity of cultivars as measured by a uniform harvest of all plots on 29 June of the following spring. Differential harvests were conducted on 3-year-old uniform stands at the Matanuska Research Farm. (Exp. V; pounds per acre N-P_2O_5-K_2O, respectively, applied during year of differential harvests = 105-80-40 on 13 April, plus 80-0-0 on 6 July; 105-80-40 applied 23 March of year of final harvest).

Harvest schedules and cultivars	Year of differential harvests						Uniform harvest subsequent spring
	Tons/acre						
5 cuts per year:							
	2 June	15 June	2 July	20 July	2 Sep	Season total	29 June
Polar	0.39 a[1]	0.09 a	0.07 a	0.15 b	1.08 a	1.78 b	2.97 a
Carlton	0.34 a	0.10 a	0.08 a	0.23 a	1.27 a	2.02 b	2.27 cd
Manchar	0.52 a	0.05 b	0.09 a	0.25 a	1.15 a	2.06 b	2.03 de
Mean	0.42	0.08	0.08	0.21	1.17	1.95	2.42
(% D.M.)[2]	(29.5)	(30.6)	(23.7)	(23.6)	(22.5)		(25.7)
(% C.P.)[3]	(20.4)	(24.7)	(27.8)	(29.4)	(21.9)		
4 cuts per year:							
	8 June		2 July	27 July	2 Sep		
Polar	0.61 a		0.11 b	0.59 a	0.78 a	2.09 b	2.71 ab
Carlton	0.64 a		0.15 a	0.67 a	0.80 a	2.26 b	2.09 cde
Manchar	0.68 a		0.08 b	0.61 a	0.81 a	2.18 b	1.86 e
Mean	0.64		0.11	0.62	0.80	2.18	2.22
(% D.M.)	(30.3)		(23.6)	(22.8)	(21.5)		(25.7)
(% C.P.)	(20.7)		(25.6)	(26.4)	(24.1)		
3 cuts per year:							
		15 June		16 July	2 Sep		
Polar		0.79 a		0.31 a	0.90 a	2.00 b	2.76 ab
Carlton		0.82 a		0.38 a	0.99 a	2.19 b	2.19 cde
Manchar		0.83 a		0.34 a	0.98 a	2.15 b	2.13 cde
Mean		0.81		0.34	0.96	2.11	2.36
(% D.M.)		(29.9)		(24.3)	(20.7)		(25.7)
(% C.P.)		(19.3)		(26.9)	(24.9)		
2 cuts per year:							
			2 July		2 Sep		
Polar			1.33 a		1.52 a	2.85 a	2.99 a
Carlton			1.38 a		1.59 a	2.97 a	2.42 bc
Manchar			1.19 b		1.58 a	2.77 a	2.43 bc
Mean			1.30		1.56	2.86	2.61
(% D.M.)			(32.5)		(27.0)		(25.7)
(% C.P.)			(13.6)		(19.2)		

[1]Means not followed by a common letter are significantly different (5% level) using Duncan's Multiple Range Test. For differential harvests, comparisons are among each 3-cultivar data set in a column; for season totals and uniform evaluation harvest, comparisons are among all 12 means in each column.
[2]Mean percent dry matter for all cultivars on each harvest date.
[3]Mean percent crude protein for all cultivars on each harvest date.

first harvest on 2 June in the 5-cut treatment in Exp. III was taken when bromegrass was mostly 6 to 10 inches tall. It is believed that that very early harvest was prior to elevation of the growing points, for during the next 10-day growth period before harvest on 12 June, mean dry-matter production was at the very active rate of 54/lb/A/day (Fig. 9). The grass regrowth harvested on 12 June was mostly 10 to 16 inches tall; by that time the growing points undoubtedly had elevated and were removed in the harvest, for growth during the next growth period was at the rate of only 19 lb/A/day.

In Exp. V (Table 5, Fig. 11), first harvest in the 5-cut treatment also was on 2 June but grass growth was slightly taller (8 to 12 inches) at that cutting. Most growing points very likely were removed with that harvest, for dry-matter accumulation during the next two regrowth periods was at the very slow rates of 12 and 9 lb/A/day.

Similarly, in the 4-cut treatment in Exp. V, grass

Table 6. Typical growth[1] and development pattern for unharvested bromegrass in southcentral Alaska (year-to-year variations in weather hasten or delay development somewhat).

Calendar dates	Growth and developmental stages
25 April to 8 May	New tiller growth becomes apparent, 1-4 inches tall, reddish to purplish from anthocyanin pigmentation.
1-15 May	New growth becomes more leafy, 3-8 inches tall, = "tillering" stage.
15-31 May	More and taller leafy growth, 6-10 inches tall, culms begin elongating, = "jointing" stage.
1-10 June	Culms continue elongation, 8-24 inches tall, panicles (seed heads) begin emerging from "boot" (topmost leaf sheath). Panicle emergence of pumpelly brome is typically 4-8 days earlier than predominantly hybrid Polar, Polar 2-6 days earlier than introduced smooth brome cultivars.
10-20 June	Culm elongation and panicle emergence ("heading") continue, leaf height[2] = 22-42 inches, panicle height = 28-50 inches.
20 June - 10 July	Culm elongation continues, heading completed, leaf height[2] = 26-46 inches, panicle height = 30-60 inches.
4-20 July	Anthesis ("flowering") occurs; as in heading, pumpelly = earliest, Polar = intermediate, introduced smooth brome cultivars = latest.
12 Aug - 3 Sep	Seed mature; progression of seed maturity of pumpelly, Polar, and introduced cultivars follows general comparisons of heading and anthesis (see Klebesadel 1970).[1]With good soil, fertility, and moisture conditions.

[2]Height above soil surface of topmost leaves on culms.

growth at the first cutting on 8 June was 10 to 12 inches tall and the growing points had by then developed into fully differentiated panicles (seed heads), the emerging tips of which were becoming visible on 8 June (= late "boot" stage). That harvest, interrupting the early development of the grass before new basal tillers were prepared to elongate, was followed by a 24-day period (during June with very long photoperiods and normally very active growth) with accumulation at the rate of only 9 lb/A/day (Fig. 11). In a comparison of seasonal distribution of forage in four harvests of several grass species (Klebesadel 1992), bromegrass was more disposed to delayed regrowth than other species when the first harvest was taken near mid-June.

With progressively later dates of first harvest (at more advanced stages of grass development) in other treatments in the present experiments, recovery and regrowth from the then more active new basal tillers proceeded more vigorously and uniformly.

Later developmental stages in the continuing growth of bromegrass, if uninterrupted by harvest, include (in order of occurrence—see Table 6): "heading" (emergence of panicles above the last enclosing leaf sheath or "boot"), "anthesis" (appearance of pollen-shedding anthers in the flowering process), and finally "mature seed."

Forage Production During Second Half of Growing Season

The regrowth of bromegrass, after first harvest near late June or very early July, typically produces very few panicles. Therefore, the relatively clear-cut stages of development apparent in the initial growth of the season are poorly evident in the generally very leafy regrowth after mid-season harvest.

As noted earlier (Klebesadel and Helm 1992), seasonal distribution of bromegrass forage yield in harvests of two cuts and three cuts per year differ considerably in this subarctic area from patterns reported by several investigators in the northern states and Canada. Fortmann (1953) in New York obtained only about 15% of total-season forage yield in the second of two harvests per year. Fairbourn (1983) in Wyoming, despite irrigation, found Manchar bromegrass to be semi-dormant after a first cutting, producing little regrowth. Other investigators at more southern latitudes than Alaska also have reported similar small yields after first cuttings, some attributing the poor summer regrowth to summer drought and heat (Smith *et al*. 1986).

Conversely, relatively cool growing seasons with long photoperiods in Alaska's agricultural areas favor bromegrass regrowth during summer. Regrowth is promoted also by adequate soil moisture and thus is favored in this area because July, August, and September typically are relatively high rainfall months (Dale 1956; Watson 1959). Although that normal abundance of precipitation tends to discourage drying and curing of grass for haymaking (second cuttings often are ensiled), the usually adequate soil moisture during the latter half of

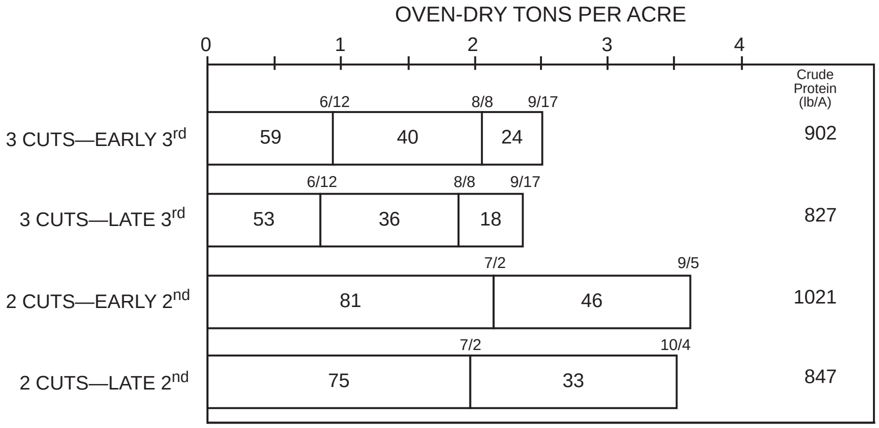


Figure 7. Graphic depiction of mean forage yields of three bromegrass cultivars for each harvest schedule in Exp. I (means for Polar, Carlton, Manchar only—Saratoga and Sac omitted due to winter injury). Number within each bar segment is mean dry-matter accumulation in pounds per acre per day during each growth period (arbitrary date of 10 May used for approximate start of spring growth to permit accumulation calculation for first growth period). Numbers to right of each bar are mean total yields of crude protein in pounds per acre.

the growing season promotes vigorous bromegrass growth, especially during July and August, prior to the shortening day-lengths and lowering temperatures of September.

The good productivity of bromegrass regrowth during the second half of the growing season in this area is obvious in the generally high second-cutting forage yields with all 2-harvest treatments in these experiments (Tables 1 through 5; Figs. 7 through 11). In the extreme cases of Exps. II and V, forage yield in second cuttings amounted to 53% to 66% of the annual total.

Conversely, however, occasional severe moisture deficit during the latter portion of the growing season can markedly restrict regrowth as occurred in the beginning of Exp. IV (Fig. 6—see 1964). To be assured of adequate moisture supply for optimum crop growth, some local growers with a good water supply have acquired systems to provide supplemental sprinkler irrigation.

Precipitation and Forage Production

Beyond the previously noted very slow rates of regrowth when early- to mid-June harvests interrupted the rapid first growth of bromegrass, considerable differences in rate of May + June dry-matter production also were noted among experiments when the first harvest was taken near the end of June (Figs. 7 through 11). The lowest rates of May + June dry-matter production (less than 50 lb/A/day) occurred in Exps. II and V; both of those experiments were conducted during the same year when April + May precipitation was 0.73 inches below normal (Fig. 6, 1965). Although June rainfall was 1.23 inches above normal, most came after mid-June, too late to adequately stimulate bromegrass growth to full capacity.

Rate of May + June dry-matter production in Exp. I was intermediate, averaging 78 lb/A/day for the two treatments harvested 2 July (Fig. 7). In that year (Fig. 6, 1963) May rainfall was 0.27 inches below normal, also curtailing herbage growth considerably.

Highest rates of May + June dry-matter production occurred in Exps. III and IV when spring rainfall was most abundant. In Exp. III, successive above-average rainfall amounts for April, May, and June of 0.69, 0.08, and 1.16 inches, respectively (Fig 6, 1964) fostered a high rate of dry-matter production of 102 lb/A/day prior to the 1 July harvest (Fig. 9). The very high rate of 127 lb/A/day for Exp. IV (Fig. 10) prior to the 30 June harvest was promoted by above-average April and May rainfall amounts of 0.43 and 0.21 inches, respectively, (Fig. 6, 1966); rainfall for June of that year (1.30 inches) was exactly normal.

These comparisons indicate that, with the relatively high fertilizer rates applied, rainfall amounts during April, May, and early June are critical to realizing the major forage-production potential of bromegrass during late May and all of June. Moreover, the results of Exps. II and V indicate that moisture abundance during April and May is especially critical, for moisture-stressed growth prior to June could not be "rescued" by a large rainfall surplus during the last half of June.

Crude Protein Concentrations and Yields

Percent crude protein in first-cutting forage decreased with progressively later dates of harvest (Tables 1 through 5). This decreasing concentration of crude protein in herbage with advancing plant growth and development

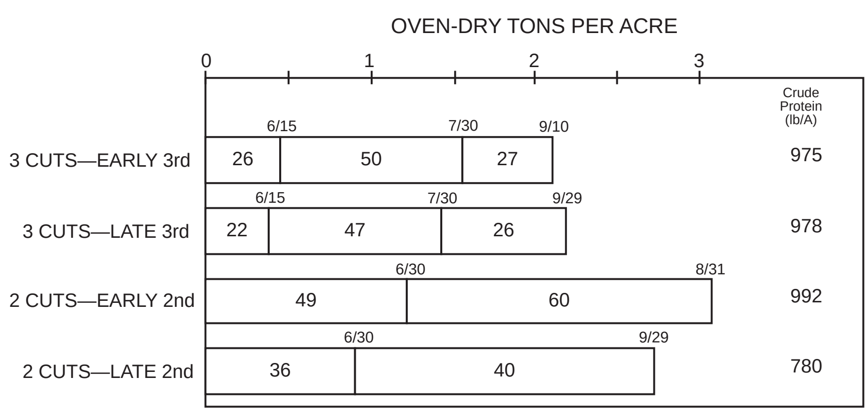


Figure 8. Graphic depiction of mean forage yields of five bromegrass strains for each harvest schedule in Exp. II. Number within each bar segment is mean dry-matter accumulation in pounds per acre per day during each growth period (arbitrary date of 10 May used for approximate start of spring growth to permit accumulation calculation for first growth period). Numbers to right of each bar are mean total yields of crude protein in pounds per acre.

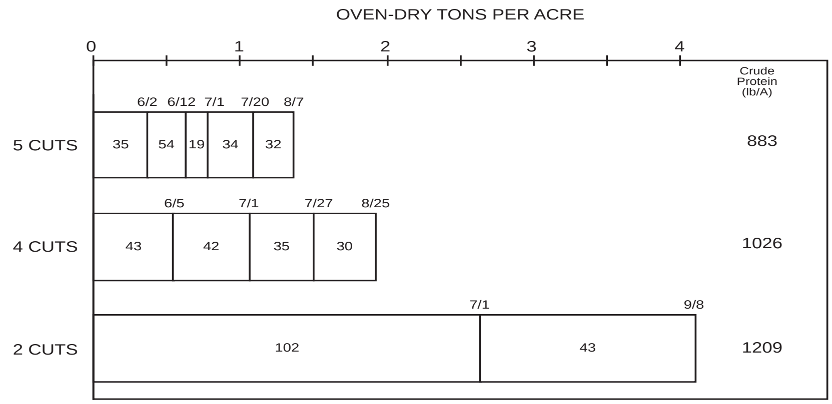


Figure 9. Graphic depiction of mean forage yields of two brome cultivars for each harvest frequency in Exp. III (means for Polar and Manchar only—pumpelly omitted for thin stands and Achenbach for winter injury). Number within each bar segment is mean dry-matter accumulation in pounds per acre per day during each growth period (arbitrary date of 10 May used for approximate start of spring growth to permit accumulation calculation for first growth period). Numbers to right of each bar are mean total yields of crude protein in pounds per acre.

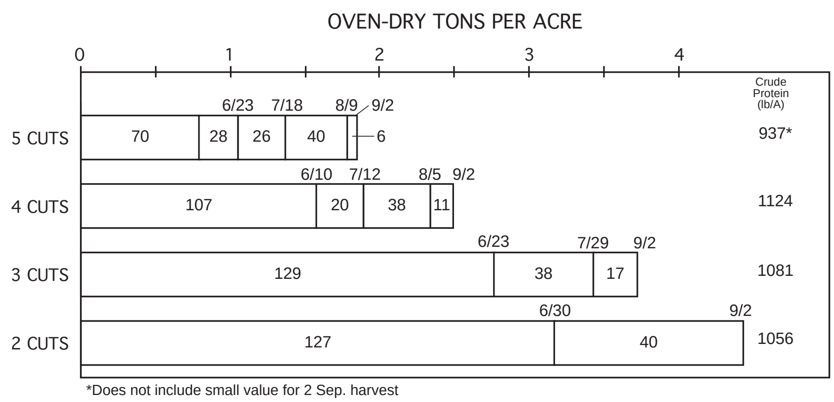


Figure 10. Graphic depiction of mean forage yields of four bromegrass strains for each harvest frequency in Exp. IV. Number within each bar segment is mean dry-matter accumulation in pounds per acre per day during each growth period (arbitrary date of 10 May used for approximate start of spring growth to permit accumulation calculation for first growth period). Numbers to right of each bar are mean total yields of crude protein in pounds per acre.

is a commonly recognized phenomenon that has been documented in many reports, including Bird (1943), Fairbourn (1983), Fortmann (1953), Kilcher and Troelsen (1973), Kunelius *et al*. (1974); Laughlin (1953), and Van Riper and Smith (1959).

The more frequent harvests in each of the present experiments, although lower in yield of forage, were higher in percent crude protein. Forage harvested frequently was more leafy than that in less frequent harvests; the latter understandably possess a higher ratio of stems to leaves, as stems elongate and the shaded, lower leaves turn brown and dry (Fig. 1). Kilcher and Troelsen (1973) reported that crude protein concentration in bromegrass leaves was usually 10 to 12 percentage points higher than that of stems.

The higher crude protein concentration but lower forage yields of the more frequent harvests, and the lower crude protein concentration but higher forage yields of the less frequent harvests, were counter-balancing effects, resulting in generally similar total annual yields of crude protein (Figs. 7 through 11). Total annual yields of crude protein ranged from 780 to 1209 lb/A.

There was little consistency or clear pattern among treatments in the ranking of total crude protein yields from experiment to experiment, except that the 5-cut treatments of Exps. III, IV, and V were lowest in total crude protein yield in each experiment. Kunelius *et al*. (1974) harvested bromegrass twice per year for three years with first cuttings at eight progressively later stages of primary growth; they reported similarly that the different harvest schedules had little effect on total annual yields of crude protein.

Percent Dry Matter in Herbage

Percent dry matter in herbage is a matter of concern in the utilization or preservation of forage. Succulent herbage generally is favored for pasture or green-chop feeding; however, high-moisture herbage requires more drying for preservation as hay. Conversely, when a grass forage is to be ensiled, a higher moisture content (lower percent dry matter) is desirable, the optimum moisture content being near 60% to 70%.

As the date of first harvest of bromegrass was delayed, percent dry matter in herbage generally increased (Tables 1 through 5). Moreover, percent dry matter in herbage of frequently harvested treatments was generally lower throughout the season than in treatments harvested only twice. For example, percent dry matter in the 5-cut treatments of Exps. III, IV, and V averaged 21.3%; in the 2-cut treatments of the same experiments, percent dry matter averaged 27.5%.

Precipitation, and therefore moisture availability to plants, also influences succulence of herbage. In Exp. IV, when precipitation was generally abundant (Fig. 6, 1966), mean percent dry matter in the 5-cut treatments was 17.3% (Table 4). In Exp. V, in contrast, lower precipitation, especially during the first half of the growing season (Fig. 6, 1965), not only curtailed herbage yields (Table 5) but also resulted in higher percent dry matter in the moisture-stressed herbage (mean percent dry matter in 5-cut treatment = 26.0%).

Effects of Time Between Harvests, and Final Harvest Date, on Subsequent Winter Survival and Uniform Evaluation-Harvest Yield

Figure 12 provides a visual comparison of forage yields at the uniform evaluation harvest in the final year of all experiments. Also shown, for the year prior to those evaluation harvests, are dates of harvests, growth periods between harvests, and the growth period from the

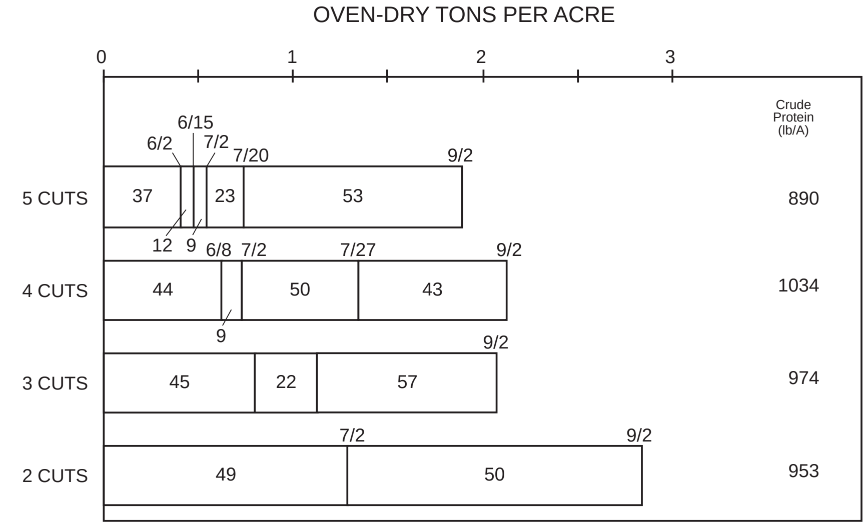


Figure 11. Graphic depiction of mean forage yields of three bromegrass cultivars for each harvest frequency in Exp. V. Number within each bar segment is mean dry-matter accumulation in pounds per acre per day during each growth period (arbitrary date of 10 May used for approximate start of spring growth to permit accumulation calculation for first growth period). Numbers to right of each bar are mean total yields of crude protein in pounds per acre

final harvest to approximate freeze-up date.

Results discussed earlier in this report indicate that both frequency and timing of harvests strongly influenced forage yields as well as predisposition to winter injury. There has been a general tendency in local farm practice toward more frequent harvests, thus subjecting stands to greater likelihood of winter injury. This hazard was clearly shown in Exp. II where both 3-cut schedules resulted in greater winter injury and lower final-year yields than either 2-cut schedule (Table 2 and Fig. 12).

However, the span of time between the final harvest and termination of the growing season also appears to influence strongly the subsequent vigor and yields of bromegrass stands as shown in Figure 12. There is some difficulty in defining precisely when a growing season ends, specifically when lethally low temperatures terminate bromegrass growth and leaf function. Moreover, considerable year-to-year variation often occurs. Watson (1959) reported mean dates of first autumn occurrence of temperatures of 32°, 28°, 24°, and 20°F for the Matanuska Research Farm are 12 September, 22 September, 7 Octo-

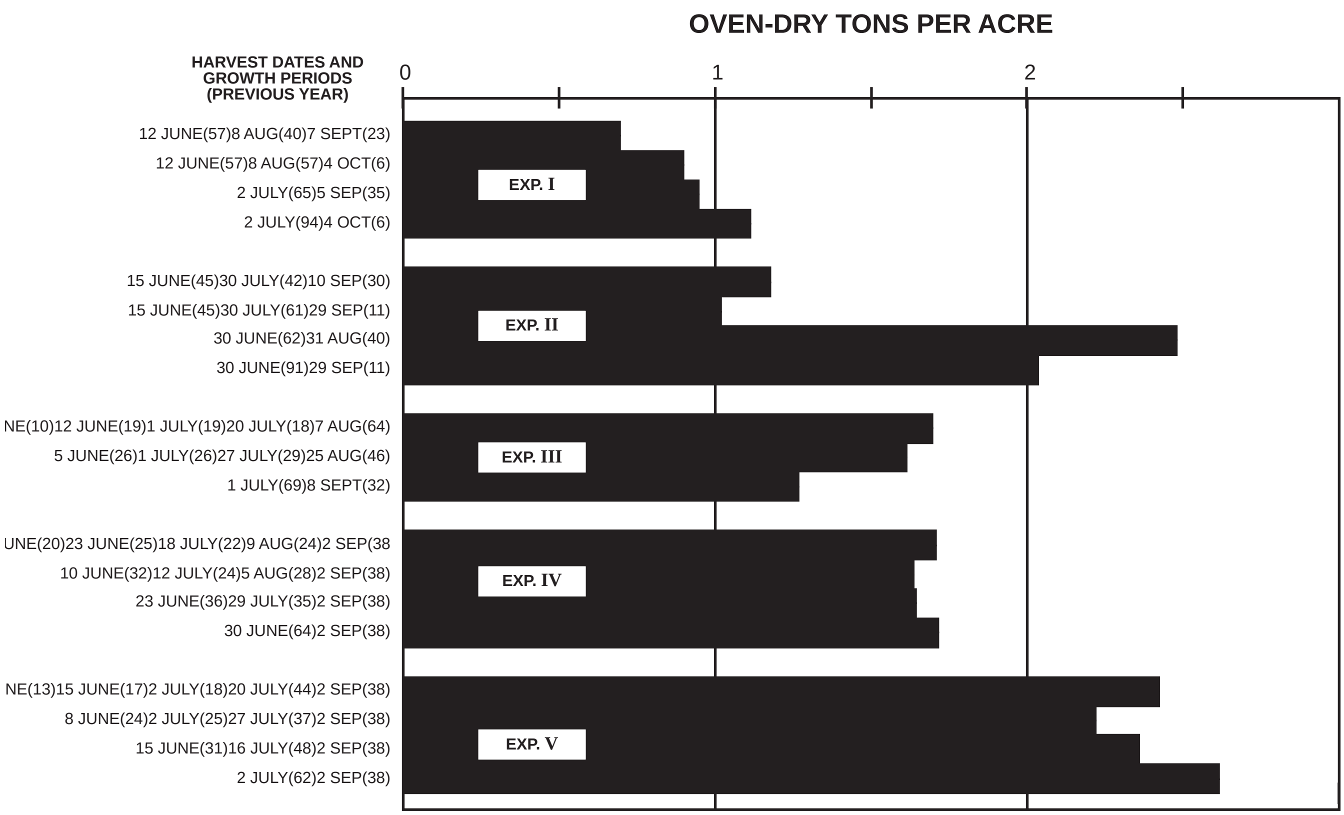


Figure 12. Graphic comparison of first-cutting evaluation-harvest yields in the final year of each of the five experiments. Dates of harvest during the previous year appear at left of each bar, and days of growth periods between harvests and between final harvest and 10 October (somewhat arbitrary but approximate date of frost-killing of foliage) appear in parentheses after harvest dates. Each graph bar represents mean of all strains included in experiment, except cultivars Sac and Saratoga were not included in yields shown for Exp. I because of extensive winter injury. Comparisons should be made among treatments within each experiment, rather than among experiments, because spring growing conditions, winter severities, and evaluation-harvest dates differed among experiments.

ber, and 20 October, respectively. A general and somewhat arbitrary date of 10 October for bromegrass growth termination in this area was selected for use in this discussion and in Figure 12.

In Exp. III, the 5-cut treatment (simulating pasturing or green-chop harvests) with last harvest on 7 August was not as detrimental to final-year yield as were the 4-cut and 2-cut treatments that imposed later last harvests (on 25 August and 8 September, respectively). Although the 5-cut treatment produced low forage yields (Table 3 and Fig. 9), and probably lowered energy levels of the grass stands by the time of the last harvest on 7 August, the approximately 9-week recovery period before growing-season termination obviously was adequate for restoration of vigor to the grass stands as indicated by high yields the following year in the uniform evaluation-harvest (Table 3, Fig. 12). Paulsen and Smith (1968) in Wisconsin also harvested bromegrass five times per year and found that the frequent harvesting prevented the grass from restoring high levels of reserves between cuttings. Nonetheless, with their final harvest on 29 August, a long pre-winter recovery period was available to the grass there also and they found a high level of food reserves (TAC) had been restored by 20 November.

In Exp. I of the present study, a third harvest in mid-September apparently interrupted the final growth period at a disadvantageous point, for that treatment resulted in the lowest forage yields in the uniform evaluation harvest the following year. In the same experiment, two cuts with the last taken after the September growth period (4 Oct.) and near the time of killing frost was least harmful as indicated by yields in the uniform evaluation harvest in the final year (Fig. 12).

In Exp. II, the 2-cut treatment with last harvest on 31 August left a 40-day regrowth period prior to 10 October. That treatment was superior to the 2-cut treatment with last harvest on 29 September (Fig. 12). In the same experiment, a final cut on 29 September was less harmful if two cuts rather than three had been taken with that final cutting date.

In Exps. IV and V, the last harvests were taken on 2 September with all treatments. With that last harvest date, the number of harvests prior to 2 September resulted in essentially no differences among treatments in evaluation-harvest yields in the final year of Exp. IV (Fig. 12). Differences in final evaluation-harvest yields differed little in Exp. V also, with a slightly higher yield where grasses had been cut only twice the previous year.

Peripheral Observation on Seed-Head Production

Seed production of bromegrass, and factors that affect heading and seed production, have become of considerable interest to agronomists and seed growers in Alaska. Moreover, growers of bromegrass principally for forage may opt to harvest a seed crop when forage supplies are abundant from other sources. Therefore, an observation on dramatic differences in panicle production in Exp. I merits recording here.

Panicle numbers produced by the five bromegrass cultivars in June of the final year of the experiment were strongly influenced by harvest schedules and frequencies during the previous year (Table 7). Both 3-cut schedules during the prior year markedly suppressed panicle production, compared with the 2-cut schedules. Moreover, with two harvests, a second cutting on 5 September strongly favored panicle production the following year over a second cutting taken on 4 October.

These results suggest that with second-cut harvest on 5 September, the uninterrupted and unshaded regrowth of bromegrass tillers from early September until freeze-up (typically near mid-October) favored heading the following year. Whether the 5 September (versus 4 October) harvest stimulated greater production of tillers and their growth during September is not known. Harvest of the herbage to remove shading of emerging tillers, thus exposing them fully to the effects of shortening photoperiods/lengthening nyctoperiods, is suspected as the dominant factor promoting panicle production the following year. Future studies may clarify this point.

Earlier reports from this location (Klebesadel 1971, 1985b) revealed that plant exposure to changing photoperiod/nyctoperiod during the pre-winter growing period (Sep. + Oct.) was important to heading the following year. For plants to respond fully during the late portion of the growing season to changing daily light/dark durations favorable to induction of floral primordia, plant receptor tissues (leaves) that respond to environmental stimuli logically should be continuously present for uninterrupted functional activity during that critical portion of the growing season.

Table 7. Percent panicle-bearing culms in spring growth of five bromegrass cultivars as influenced by harvest schedules during the preceding year. Each value represents mean of visual estimates on four plots in Exp. I.

Cultivars	Harvest dates during 1963				
	12 June 8 Aug 17 Sep	12 June 8 Aug 4 Oct	2 July 5 Sep	2 July 4 Oct	Mean
	Percent panicle-bearing culms in 1964				
Polar	11	21	50	24	27
Carlton	4	9	53	25	23
Manchar	4	5	25	8	11
Saratoga	1	5	6	5	4
Sac	—[1]	—	—	—	—
Mean	4	8	27	13	

[1]Grass stand virtually eliminated by winterkill; no panicles produced.

Conclusions

Grower Options

With adequate moisture and soil fertility, three major factors can influence stand persistence and forage production from bromegrass in southcentral Alaska. These are (a) the severity of winter stresses, (b) the inherent adaptation and winterhardiness of strains used, and (c) the frequency and scheduling of forage harvests.

The winter-severity factor is uncontrollable and unpredictable; however, choice of bromegrass strain to plant, and the frequency and scheduling of harvests, represent options that growers can choose among to insure against, or at least minimize, the harmful effects inflicted by the occasional occurrence of severe winters. The present results reveal that optimum grower objectives can be achieved within those options by (a) growing the most winterhardy strains available, and (b) harvesting on schedules and frequencies that return high yields of good quality forage but do not weaken and predispose stands to winter injury.

Bromegrasses

When winter stresses caused appreciable injury to stands in these experiments, the best adapted, extremely winterhardy strains (Polar and native pumpelly brome) were least injured. Of the several cultivars evaluated, the hybrid Polar clearly surpassed all others in survival when winter injury was most severe. Native pumpelly bromegrass, relatively unselected but inherently subarctic-adapted, surpassed Polar in winterhardiness but did not produce as much forage except following severe winters.

Other cultivars and strains generally suitable for use in this area in the absence of extremely stressful winters or harmful harvest scheduling include Carlton, Manchar, and Canadian commercial. The southern-type cultivars Saratoga, Sac, and Achenbach are poor choices for this area due to their marginal to poor winterhardiness.

Harvest Schedules and Frequencies

When winter injury was appreciable, three cuttings per year predisposed strains to greater winter injury than two cuttings. Moreover, a third cutting in mid-September was more harmful than a late-September or early-October third cutting.

With two harvests of bromegrass per year, the first is ideally taken in the interval of late June to very early July (when fully headed but pre-anthesis) in this area. That time of harvest (a) takes full advantage of the massive dry-matter production that occurs (with adequate moisture and fertility) with uninterrupted growth during May and June, (b) permits the grass to restore energy reserves to high levels that had been reduced to low levels to produce previous growth, (c) removes grass growth when new tillering at the base of plants has reached readiness to elongate and produce regrowth, (d) removes forage that, although somewhat lower in crude protein than at earlier stages of growth, represents a compromise of quite acceptable quality with high dry-matter yield, and (e) removes forage before further quality decline occurs.

Optimum time for the second harvest should be in late August to very early September; harvest throughout most of September should be avoided to prevent weakening the grass and predisposing it to injury should a stressful winter follow; moreover, taking a second cutting near the end of the growing season (late Sep./early Oct.) results in relatively low-quality forage.

These results indicate further that if a bromegrass stand is to be terminated, deliberate weakening of the stand during the final year of harvest can be achieved. A harvest schedule that would provide reasonably good yields of high quality forage, yet weaken the stand, should be three cuttings taken about 15 to 20 June, 1 to 8 August, and 10 to 15 September.

Moisture Supply and Forage Yields

The amounts of precipitation normally received in this area of Alaska are marginally adequate for realizing the production potential of bromegrass. Normal annual total at the Matanuska Research Farm is only 15.56 inches, while the normal amount received during the April through September period totals 10.17 inches.

In addition to those low totals, other factors that limit the moisture supply to crops locally are (a) poor distribution of precipitation with typically very low amounts received during the early portion of the growing season (April, May, and June normals = 0.63, 0.74, and 1.59 inches, respectively), and (b) the relatively shallow silt-loam mantle (18- to 24-inch depth where experiments were conducted) over glacial-outwash-deposited coarse sand and gravel. That coarse material under the silt-loam mantle retains little moisture; therefore the shallow silt layer provides only a modest reservoir of fine-textured soil material for moisture storage.

When precipitation is below normal, applied fertilizers are not utilized to maximum efficiency, first-cut herbage yields can be severely suppressed and, if moisture is deficient at mid-season or later (a relatively rare but occasional occurrence), regrowth during the latter portion of the growing season may be so meager as to be impractical to harvest.

This area's marginal total precipitation, and occasional dry spells that can greatly restrict forage productivity (as shown in these experiments), have caused some growers to acquire supplemental irrigation systems to assure dependable production regardless of precipitation vagaries.

Acknowledgments

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