

Bromegrass in Alaska. V. Heading and Seed Production as Influenced by Time and Rate of Nitrogen Fertilization, Sod Disturbance, and Aftermath Management

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SUMMARY

This report summarizes five primarily exploratory experiments conducted at the University of Alaska's Matanuska Research Farm (61.6°N) near Palmer in southcentral Alaska. The problem addressed was the rapid decline in Polar bromegrass seed yields with each year of production.

Objectives were to determine if management practices could be identified that would offset seed-yield decline, to evaluate several management procedures for influences on heading and on other components of seed yield from sods that developed from vegetative spread of Polar originally planted in rows, and to determine if low-producing stands could be returned by management procedures to high levels of seed production again.

- Sod disturbance in July markedly enhanced the effectiveness of subsequent nitrogen (N) topdressing in stimulating heading and increasing seed-weight-per-panicle the following year.

- Sod disturbance did not influence heading in the following year where no N was applied nor where N was applied in early spring of the year in which effects on heading were measured.

- After sod disturbance in July, N applied 19 August resulted in greater panicle numbers the following year than the same amount of N applied one month earlier, one month later, or the following spring.

- The greater effectiveness of N applied near mid-August in promoting panicle production the following year suggests that stimulated late-season tiller growth and/or adequate N supply within plants during occurrence of critical length photoperiods/nyctoperiods during September/October contribute significantly to induction of floral primordia.

- Inasmuch as spring application of N satisfactorily promotes good heading and seed production of smooth bromegrass during the same growing season at more southern latitudes, the relatively much poorer panicle production with spring application of N in Alaska (compared with application the previous August) suggests that induction of floral primordia occurs only during late summer/autumn at this latitude. This plant-behavior phenomenon, apparently unique to far-northern latitudes, occurs because critical-length photoperiods/nyctoperiods necessary for floral induction have occurred before new bromegrass growth begins in spring in this area.

- When the tall (12- to 24-inch) aftermath remaining after combine harvest of seed in August was left in place until spring, different rates of N and different times of N application had little effect on panicle numbers in the subsequent seed crop.

- Removal of the tall aftermath shortly after seed harvest markedly increased effectiveness of applied N in stimulating panicle production in the seed crop of the following year.

- With aftermath removal at the time of seed harvest, N applied shortly thereafter stimulated heading and seed production in the seed crop of the next year considerably more than N applied in spring of the year the seed crop was produced.

- With aftermath removal and N application shortly after seed harvest, 80 lb N/A resulted in more heading the following year than 40 or 120 lb/A. Inasmuch as the same rates of phosphorus and potassium were applied with the different rates of N, the highest N rate may have resulted in an inappropriate imbalance of fertilizer elements for maximum heading.

- Clipping and raking in late April to remove the tall aftermath remaining in spring after the previous year's seed harvest resulted in about twice as many panicles produced later that year as burning the aftermath in late April or mid-May.

- Leaving tall aftermath growth in place after seed harvest, or clipping the growth to a 6-inch stubble and leaving it in place, severely suppressed heading and seed yield the following year.

- Clipping aftermath to a 6-inch stubble and removing clippings, or clipping to a 2-inch stubble and leaving clippings in place, resulted in about equal and markedly increased heading and seed yields the following year over no treatment.

- Clipping aftermath to a 2-inch stubble and removing clipped growth shortly after seed harvest resulted in highest seed yield of all aftermath treatments.

- Sod disturbance of older stands, clipping aftermath short and removing it shortly after seed harvest, and applying N shortly after seed harvest all were found beneficial in stimulating heading and increasing seed yields the following year. Although the best combination of those treatments did not return older seed fields to original production levels, the aftermath treatment and timing of N fertilization, and perhaps other beneficial procedures not yet identified, should promote efficient seed production from younger bromegrass stands in Alaska.

- Occurrence of "white-top" panicles, a malady resulting from insect injury to bromegrass stems, can cause considerably reduced seed yield because those panicles produce no seed. Incidence of white-top in two study years was 18.4% and 25.5% of total panicles produced. Better understanding of factors that contribute to this problem and effective control measures are needed.

INTRODUCTION

Seed production of smooth brome grass (*Bromus inermis* Leyss.) has been little practiced or studied in Alaska. However, the importance of brome grass as a forage crop in Alaskan agriculture, the development of the subarctic-adapted, hybrid cultivar 'Polar' (Hodgson *et al.* 1971; Wilton *et al.* 1966), and the need to produce seed in Alaska of possible future cultivars, requires identification of desirable cultural procedures for maximum efficiencies in seed production at this high latitude.

Moreover, just as temperate-adapted brome grass cultivars often perform poorly in subarctic Alaska (Klebesadel 1970b, 1971, 1994; Klebesadel and Helm 1992; Wilton *et al.* 1966), so also are management procedures that were devised for other areas sometimes ill-suited for direct application in Alaska (Klebesadel 1970b). Furthermore, little information exists on seed production of a cultivar with such diverse genetic background as Polar; that cultivar incorporates germplasm of both smooth brome grass, introduced from Eurasia, and northern-adapted, North American pumpelly brome grass (*B. pumpellianus* Scribn.).

The Problem of Rapid Decline in Seed Yield

A field of Polar brome grass seeded on 2 June 1961 at this station produced seed at the rate of 198 lb/A in 1962, following one of the most stressful winters on plants during a 3-decade period. The following year (1963) the same field produced at the rate of only 106 lb/A, followed by 56 lb/A in 1964 (Fig. 1). It is now known that earlier planting than 2 June would have resulted in a higher yield in the first year after planting (Klebesadel 1970b); however, the much lower yields in the second, third, and fourth years were both disappointing and perplexing. A complete fertilizer topdressing had been applied prior to the initiation of grass growth each spring (Fig. 1).

The problem of rapid decline in brome grass seed yields with advancing age of stands has been reported by others (Anderson *et al.* 1946; Knowles *et al.* 1951; Waddington and Storgaard 1971).

Management Procedures and Seed Production

The very few investigations reported previously on brome grass seed production in Alaska have revealed that heading and seed yields of brome grass are very responsive to management practices. Time of planting markedly influenced seed yields the following year, with earliest planting of northern-adapted strains resulting in highest seed yield (Klebesadel 1970b).

Responses to nitrogen (N) topdressing provided circumstantial evidence that N supply during the late

Year	Spring fertilizer topdressed (pounds per acre)			Date of seed harvest
	N	P ₂ O ₅	K ₂ O	
1962	63	48	24	5 Sep.
1963	63	64	48	3 Sep.
1964	126	90	48	3 Sep.
1965	90	96	48	1 Sep.

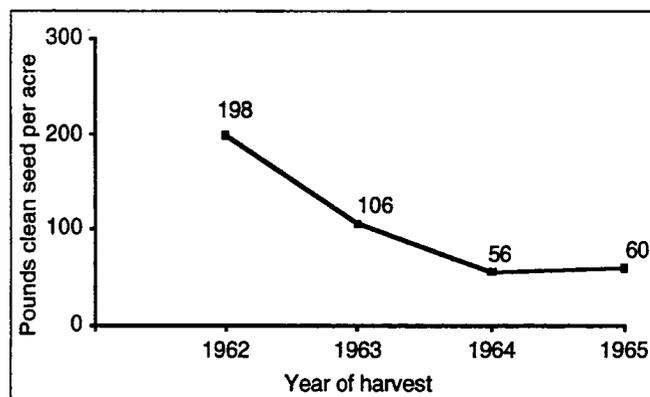


Figure 1. Seed yields of Polar brome grass harvested from field seeded in rows 24 inches apart on 2 June 1961, showing rapid decline in yields with increasing age of stand. Fertilizer applied and dates of harvest are listed above.

portion of the growing season was of critical importance to increasing production of panicles and seed the following year (Klebesadel 1970a). However, confirmation is needed, and optimum time and rate of N fertilization for brome grass seed production must be determined for these high latitudes.

Several other cultural practices, discussed later in this report, have been noted to influence brome grass seed production in more southern areas (Atkins and Smith 1967; Canode and Law 1978; Churchill 1944; Crowle and Knowles 1962; Fulkerson 1980; Knowles 1966; Knowles *et al.* 1951; Rumburg *et al.* 1980). However, the extent to which each is important at subarctic latitudes, and the optimum timing and proper execution of appropriate practices, should be determined.

Tillage Practices and Stand Rejuvenation

Atkins and Smith (1967) reported that highest sustained yields of brome grass seed in the Great Plains area can be obtained by maintaining the grass in rows. Buller *et al.* (1955) reported higher brome grass seed yields from rows than from broadcast stands in Pennsylvania. Unproductiveness of brome grass stands that have become "sodbound" has been considered due to nutrient deficiencies, unfavorable carbon/nitrogen ratio, or accumulation of growth-inhibiting substances (Benedict

1941; Myers and Anderson 1942; Watkins 1940).

In analyzing declining seed yields with advancing bromegrass stand age, Waddington and Storgaard (1971) stated: "Deterioration of the bromegrass stand to the 'sodbound' condition was accompanied by reductions in tiller density and growth rate."

Bromegrass sod disturbance to stimulate subsequent seed production has been accomplished by disking (Churchill 1944) and by shallow plowing (Knowles *et al.* 1951; Knowles 1958). Although sod disturbance in fall or spring increased seed production in subsequent years, seed yields in the first year following tillage were nil or reduced substantially (Churchill 1944; Crowle and Knowles 1962; Knowles *et al.* 1951). Oats often is sown in the bromegrass stand for a crop return in the year of no bromegrass seed production (Crowle and Knowles 1962; Knowles 1958).

These Experiments

Results reported here were derived from five experiments conducted on two different Polar bromegrass seed-production fields; one field had been planted in rows 24 inches apart on 2 June 1961 (used for Exps. I, II, III, IV), and the other in rows 18 inches apart on 14 June 1983 (Exp. V). By the time experiments I, II, III, and IV were initiated, rows had spread vegetatively to become an even sod. Experiment V was initiated before the spreading rows had fully coalesced. The five separate experiments were conducted to (a) explore the problem of rapid decline in seed yields with increasing age of stands, (b) attempt to identify cultural procedures that promote higher seed yields, (c) determine if seed production fields could be returned to their original much higher yields, and (d) delineate avenues for future research concerning this problem.

Results reported here were derived between the years 1965 and 1987 at the University of Alaska's Matanuska Research Farm (61.6°N) near Palmer in Southcentral Alaska.

EXPERIMENTAL PROCEDURES

Experiment I: Sod disturbance, time of second forage harvest, three rates of N.

This exploratory experiment sacrificed one year of seed production on a four-year-old stand in an attempt to stimulate seed production in the subsequent year. Spring topdressing in late April 1965 supplied N, P₂O₅, and K₂O at 90, 95, and 48 lb/A, respectively. The entire experimental area was harvested for forage 15 July 1965 leaving a 2 1/2-inch stubble and all clipped grass was removed immediately. On 19 July, one-half of the area was disked heavily one way, slicing the sod into ribbons, but with minor movement or turning of the sod strips. Three rates of N (0, 50, 100 lb/A) were applied 20 July in

linear strips along the entire length of both the disked and undisturbed sod areas.

Three equal divisions of the experimental area were established with borders perpendicular to and crossing both the tilled and untilled areas and the N strips. Grass regrowth was harvested 30 August on one section, 29 September on another, and the third was left unharvested. Final subplot size was 5 by 13 feet with the long axis of plots perpendicular to the original direction of the grass rows. Experimental design was a split-split-split plot with no replication. Effects of each treatment were measured over all other treatments.

At seed harvest on 26 August 1966, border effects were eliminated by harvesting and discarding a strip 15 inches wide from all four sides of each plot. Panicles counted within each plot at harvest were air-dried while hanging in cloth bags in a heated room. Panicles were then threshed, the seed cleaned and weighed, and seed weight per panicle derived from total panicles and total weight of seed per plot.

Experiment II: Sod disturbance, time of N application (120 lb/A).

Fertilizer topdressed on the experimental area on 3 May 1966 supplied N, P₂O₅, and K₂O at 126, 96, and 48 lb/A, respectively. Grass growth on the entire experimental area was clipped to about a 2-inch stubble and removed 19 July 1966. On 20 July, half of the plots were disked as in the previous experiment. In addition to an unfertilized check plot in both the disked and the undisturbed strips, ammonium nitrate supplying N at 120 lb/A was topdressed on a different plot in each strip on 21 July, 19 August, and 20 September of 1966, and on 22 March 1967. Individual plot size was 10 by 10 feet with three replications. Commercial fertilizer topdressed uniformly over all plots on 4 April 1967 supplied P₂O₅ and K₂O at 114 and 60 lb/A, respectively. Seed harvest procedures on 15 August 1967 and subsequent processing were as in Exp. I.

Experiment III: Aftermath management, time and rate of N application.

For two consecutive years, three rates of N (40, 80, 120 lb/A) were topdressed in summer after seed harvest or the following spring. Aftermath herbage remaining after seed harvest was clipped to a 2-inch stubble and removed either shortly after seed harvest or the following spring. Aftermath treatments were utilized as subplots in a split-plot experimental design with four replications. Subplot size was 10 by 10 feet.

Fertilizer topdressed on the experimental area on 3 May 1966 supplied N, P₂O₅, and K₂O at 126, 96, and 48 lb/A, respectively. Seed harvest just prior to initiation of the study was 15 September 1966. Seed harvests during the study were 16 August 1967 and 14 August 1968. Summer dates of aftermath removal were 15 September 1966 and 18 August 1967; spring dates were 28 March 1967 and 19 March 1968. Summer N topdressings were on 15 Sep-

tember 1966 and 21 August 1967; spring applications were on 28 March 1967 and 2 April 1968. Topdressings uniformly over all plots on 4 April in both 1967 and 1968 supplied P_2O_5 and K_2O at 114 and 60 lb/A, respectively. Border effects were removed just prior to panicle counts as in the previous experiments. Wind had caused much seed shattering prior to harvest; as a result, only very low seed yields were obtained that would be only broadly related to treatment effects; hence, only panicle numbers are presented.

Experiment IV: Influence of spring removal of aftermath by clipping and raking vs. burning.

Three treatments involving spring removal of aftermath remaining from the previous year's seed harvest were compared for effects on heading of a 5-year-old stand of Polar brome grass. In one treatment, the aftermath was clipped to about a 2-inch stubble and raked off. On the same date, a second treatment involved burning the aftermath. Fertilizer topdressed uniformly over the entire experimental area on 29 April 1966 supplied N, P_2O_5 , and K_2O at 126, 96, and 48 lb/A, respectively. The third treatment was a similar burning on 16 May. Individual plot size was 12 by 12 feet with four replications in a randomized complete block experimental design.

On 7 September 1966, a 2.5-foot-wide border was clipped to a short stubble and removed from all four sides of each plot. All panicles were then counted. Inasmuch as winds had caused a considerable amount of seed to shatter by that date, no accurate determination of seed yield was possible.

Experiment V: Aftermath management shortly after seed harvest.

Polar brome grass was seeded in rows 18 inches apart on 14 June 1983 where N, P_2O_5 , and K_2O had been disked into the plowed seedbed at 32, 128, and 64 lb/A, respectively. All aerial growth was clipped to about a 2-inch stubble and the area was raked clean on 8 December 1983. No spring fertilizer was applied in 1984 and seed was combine-harvested from all rows on 14 August 1984; seed yield over the experimental area plus a larger area of adjacent rows treated identically was at the rate of 262 lb/acre.

Ammonium nitrate supplying N at 100 lb/A was applied to the plot area in three consecutive years on 29 August 1984, 30 August 1985, and 26 August 1986. The 1985 seed crop was combine-harvested on 23 August leaving a 20- to 24-inch tall, leafy aftermath. On 30 August 1985, 20 plots measuring 7.5 by 10 feet were located within the brome grass rows and identified with stakes flush with the soil surface. A strip 15 inches wide was clipped to a 2-inch stubble on all borders of all plots and the clipped aftermath in those strips was raked and removed. A randomized complete block experimental design was used with five aftermath treatments and four replications. One treatment was left with no disturbance

of the tall aftermath. With two treatments, the aftermath was clipped to a 6-inch stubble and the other two treatments were clipped to a 2-inch stubble. With each stubble height, the clipped aftermath was left in place in one plot and in the other it was raked and removed. Plots were then left undisturbed until after killing frost and on 21 October 1985 all plots were clipped to a 2-inch stubble and the entire experimental area was raked clean to prevent uneven snow retention on plots over winter.

When seed was mature in 1986, brome grass growth was clipped to a 2-inch stubble and removed in a strip 15 inches wide on all borders of all plots. Seed heads were clipped and bagged from each plot, counted, dried at room temperature, threshed, and the seed cleaned and weighed.

The same aftermath treatments as described above were performed on the same plots on 26 August 1986. Again, as done the previous year, all plots were clipped to a 2-inch stubble and raked clean on 15 October 1986 after killing frost.

At seed maturity in 1987, all harvest procedures were repeated on 18 August as in 1986 and the experiment was terminated.

RESULTS AND DISCUSSION

Experiment I-Effects of sod disturbance, time of second forage harvest, 3 rates of N.

The objective of this exploratory experiment was to assess the desirability of sacrificing one year of seed production on a four-year-old grass stand in an attempt to stimulate seed production in the subsequent year.

Treatments evaluated precluded raising a grass seed crop the same year. The effects of taking one or two forage harvests, timing of the second cutting, sod disturbance, and three rates of N (0, 50, 100 lb/A), applied in July, were evaluated in the brome grass seed crop of the following year.

First-cutting, oven-dry forage yield from the experimental area on 19 July 1965 averaged 3.96 T/A. Yield data were not recorded for the much lower-yielding second cuttings harvested from different areas on 30 August and 29 September.

One-way disking of the brome sod on 19 July 1965 increased panicle numbers by 70% and seed weight per panicle by 83% in 1966 compared with undisturbed sod (Fig. 2). The combined effect of those two enhanced yield components more than trebled seed yield in 1966 over the yield obtained from undisturbed sod.

Harvesting the forage regrowth on 29 September 1965 increased panicle density markedly in 1966, as compared with harvest 30 August or leaving the regrowth in place until the following spring (Fig. 3). Panicle density on the areas harvested 30 August, and

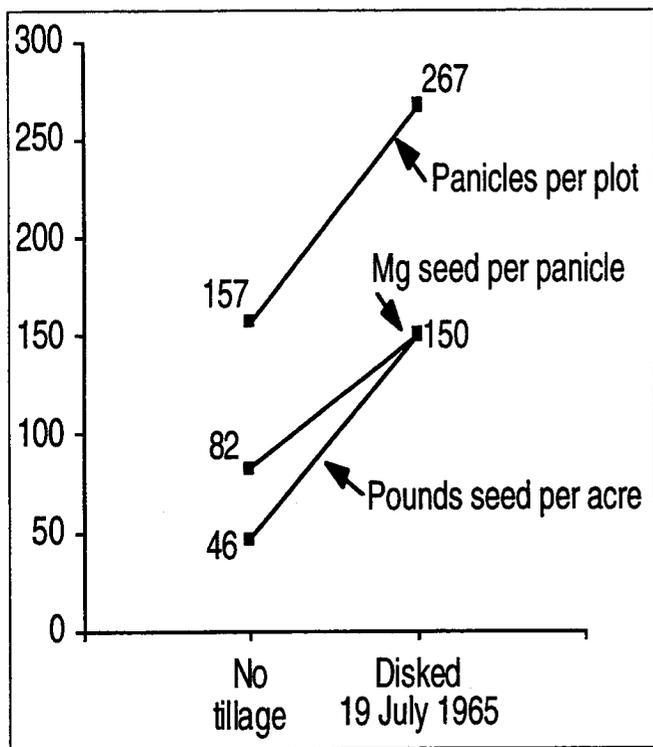


Figure 2. Influence of one-way disking of 4-year-old Polar bromegrass rows on 19 July on panicle density, seed weight per panicle, and seed yield at harvest on 26 August of the following year (Exp. I).

where no second cutting was taken, was quite similar in 1966.

These results are not in complete agreement with observations in a separate, unrelated study (Klebesadel 1994) wherein it was noted that approximately twice as many panicles were produced in plots of three brome cultivars that had been harvested for forage the previous year on 2 July and 5 September than in plots harvested 2 July and 4 October. The two experiments each had a second-cutting harvest date near 1 September (30 Aug. and 5 Sep.), yet those treatments resulted in the lower number of panicles in one experiment but the higher number in the other.

It could be expected that shading versus exposure of late-season tillers at the time of occurrence of critical-length photoperiods/nyctoperiods during September would be a contributory factor in panicle production the following year, yet it was not obviously so in this experiment comparison. One consistency between the two experiments was greater panicle density in both experiments where the interval between first and second cuttings in the year prior to the seed crop was near similar (65 and 76 days), rather than a shorter period of 46 days or a longer period of 94 days. Further investigation of growth intervals and resultant panicle production the following year could lead to a better understanding of this phenomenon than exists at present.

The effects on the 1966 seed crop of the 3 N rates, applied 20 July 1965 and averaged over all tillage and

forage-harvest treatments, are shown in Figure 4. Panicle density was increased 38% by N application at 50 lb/A compared with no N applied. Twice as much N (100 lb/A) resulted in virtually the same panicle density as did the lighter rate.

Seed weight per panicle increased slightly with each increment of applied N (Fig. 4). The cumulative effect of increased panicle density plus increased seed weight per panicle was an approximate doubling of seed yield with the 50 lb/A rate, compared with no N applied; an additional 50 lb of N/A caused an additional, but smaller, yield increase.

Experiment II-Effects of sod disturbance, time of N application (120 lb/A).

One-way disking of 5-year-old bromegrass rows on 20 July (by then rows had spread vegetatively and coalesced into a uniform sod), followed by N topdressing during the same growing season, increased markedly the density of panicles produced the following year (Fig. 5). Disking, followed by either no N application, or N topdressing early the following spring, had virtually no stimulatory effect on panicle density.

Nitrogen topdressing without sod disturbance had a greatly diminished stimulatory effect on panicle density (compared with N topdressing plus disking), regardless of time of application (Fig. 5). Although markedly different in relative effect, pattern of response to N was generally similar in both the disked and the undisturbed areas; panicle density was lowest with no N applied, highest with 19 August application, and intermediate with spring application. The sharp reduction in panicle density in the disked area with N applied 20 September, compared with 19 August (Fig. 5), indicates that N should be applied as soon as possible after seed harvest to stimulate maximum panicle density the following year.

Seed weight per panicle was consistently higher in the disked area, than where grass was undisturbed, at all levels of N application (Fig. 6). The pattern of response

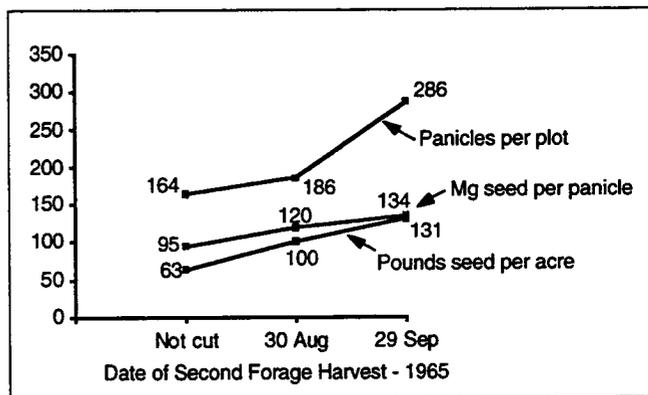


Figure 3. Influence of time of second forage harvest of a 4-year-old Polar bromegrass rows in 1965 (first cutting 15 July 1965) on panicle density, seed weight per panicle, and seed yield at harvest on 26 August 1966 (Exp. I).

to N rates was very similar both in the disked and in the undisturbed areas; seed weight per panicle was lowest with no N applied and higher with N applied in spring of the year of seed production than with application in mid- to-late summer of the year prior to seed production.

Disking of the 5-year-old stand in July (in a year when no seed crop was taken) promoted better seed yield in the following year (Fig. 7). The beneficial effects of disking, especially with N applied near the same time at 120 lb/A, indicated that sod disturbance should be done at some time during the growing season prior to the one in which beneficial effects are desired. Further work is needed to define more specifically the optimum time and frequency of sod disturbance as well as the most effective equipment and desired extent of disturbance.

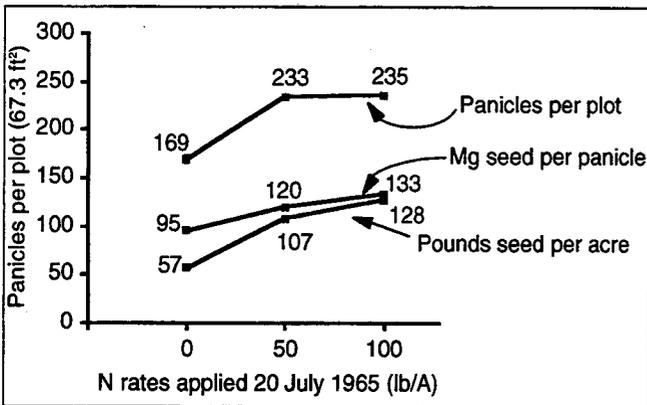


Figure 4. Influence of three rates of N, applied 20 July 1965 on 4-year-old Polar bromegrass rows, on panicle density, seed weight per panicle, and seed yield at harvest the following year on 26 August 1966 (Exp. I).

Other considerations beyond seed yields and economic returns also can influence the number of years that a bromegrass stand is used for seed production; these include class of seed produced, certification regulations, and desired crop rotation patterns. Moreover, Knowles (1958) found that rejuvenation by tillage could favor subsequent seed production by the most vigorously spreading plants, thus altering the genetic status of a cultivar.

Experiment III-Effects of aftermath management, 2 times of application of 3 rates of N.

A relatively tall (about 12- to 24- inch) leafy aftermath normally remains after combine harvest of a bromegrass seed crop because the sickle on the combine is elevated to a level that removes primarily only the panicles (that are positioned above most of the crop foliage). By selectively cutting above most of the stem and leaf growth, less extraneous material moves through the combine resulting in maximum seed recovery (Carlson and Newell 1985). That tall aftermath is modest in forage quality (Klebesadel 1970b) but can be fed to certain classes of

livestock that do not require maximum quality (Crowle and Knowles 1962; Knowles *et al.* 1951).

Removal of this aftermath immediately after seed harvest, versus the following spring when grass was yet dormant, were compared for effects on panicle density in the subsequent seed harvests during 1966-68. Similarly, N applications at 40, 80, and 120 lb/A, applied either shortly after seed harvest or early the following spring, were compared on both aftermath treatments for effect on subsequent panicle production.

Aftermath removal immediately after seed harvest resulted in markedly greater panicle production in the subsequent seed crop than where aftermath was left in place until the following spring (Fig. 8). Similarly, N application immediately after seed harvest was superior to topdressing the following spring as measured by subsequent panicle density.

The various N rates differed little in effect on panicle density when both aftermath removal and N application were performed in spring. With N applied shortly after seed harvest and aftermath removed in spring, the highest (120 lb/A) N rate resulted in a slight stimulation in panicle numbers over the lower N rates.

With aftermath removal shortly after seed harvest, panicle numbers in the next seed crop were enhanced considerably by different rates of applied N; however, greater panicle production at each N rate resulted from N application at the time of aftermath removal rather than the following spring. With aftermath removal shortly after seed harvest, the lowest rate of N (40 lb/A) applied at the same time was approximately as effective as three times that rate applied the following spring. Greatest stimulation of panicle production resulted from aftermath removal at seed harvest and with N applied at the same time at 80 lb/A.

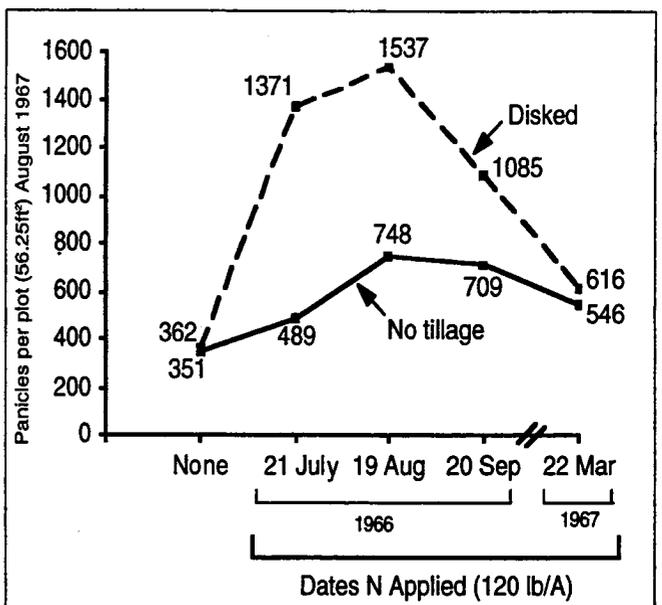


Figure 5. Influence of no tillage vs. disking 20 July 1966, and four dates of N application, on panicle numbers produced in 1967 (Exp. II).

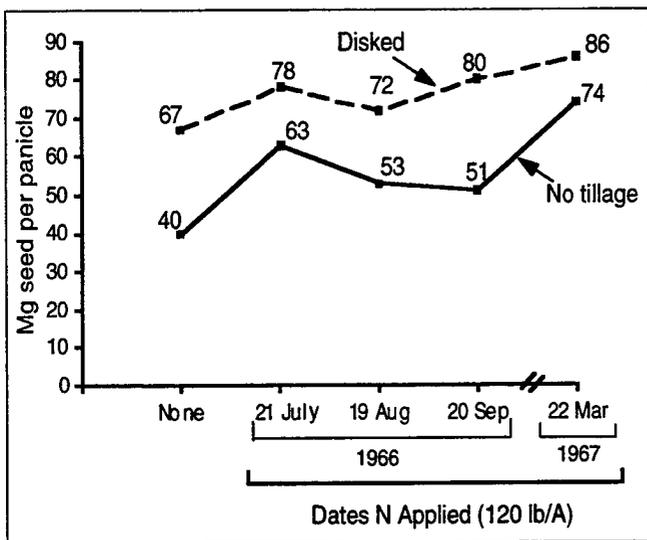


Figure 6. Influence of disking 5-year-old rows of Polar bromegrass on 20 July 1966, and five N treatments, on seed weight per panicle at harvest on 15 August 1967 (Exp. II).

The reason for the considerably lower panicle density with the 120 lb than the 80 lb/A N rate (with aftermath removal and N application near seed harvest) is not readily apparent; one possibility is that at the highest N rate an imbalance among the major nutrients occurred that was deleterious to panicle production. Topdressings of P_2O_5 and K_2O at 125 and 60 lb/A, respectively, were supplied with all N rates in both years. Canode and Law (1978) reported that N at 120 lb/A resulted in significantly lower seed yield than 80 or 100 lb/A in the second harvest year, but the highest N rate resulted in a significantly higher seed yield than the lower N rates in the fifth harvest year.

Another possibility is that the highest N rate fostered inordinate stimulation of growth that prevented maximum winterhardening, thus predisposing overwintering tissues to winter injury. Others have reported that imbalances or inappropriate ratios of the major nutritional elements (especially N and K) can predispose plants to winter injury (Smith *et al.* 1986, pp. 87-88). Future work concerning effects of nutrient rates and ratios should be pursued and may help to clarify this matter.

Atkins and Smith (1967) advocated early removal of aftermath remaining after seed harvest from cool-season grasses. Knowles (1966), in Saskatchewan evaluated time and method of removing aftermath remaining after bromegrass seed harvest, as measured by effect on the following seed crop. He found no advantage to removing the aftermath in mid-August or mid-October over leaving the growth in place until mid-April. Those findings are in sharp contrast to the present results where removal of aftermath shortly after seed harvest increased panicle production, and therefore seed yield, in the following seed crop.

Time of N Application

The differences found in various geographic areas for the optimum time of N application for bromegrass seed production apparently are related to latitude. Investigators at mid-temperate latitudes (Anderson *et al.* 1946; Atkins and Smith 1967; Churchill 1944; Harrison and Crawford 1941) reported negligible differences in seed yields as influenced by autumn versus spring application of N. Carlson and Newell (1985), summarizing general findings and practice in the U.S. Midwest, reported no preference between autumn and spring N application for bromegrass seed production, stating: "Fertilizer N should be applied in either the fall or very early spring."

Farther north in Canada, Crowle and Knowles (1962) and Knowles *et al.* (1951) reported an advantage from autumn application of N, although exceptions for Canada exist; Elliott (1967) at Beaverlodge, Alberta (55.2°N) stated that for N stimulation of brome seed production there, "fertilizing may be delayed until the early spring." Still farther north, at this location, the present results and earlier observations (Klebesadel 1970a) reveal that, for maximum seed yields, N should be applied during the latter portion of summer of the year before the one in which the seed crop is to be harvested.

Newell (1951) noted that an abundant supply of N should be available to brome plants during the time of short photoperiods (when floral induction occurs). He observed that N applied to brome seed fields in fall or very early spring (the two growth periods with short daily photoperiods) resulted in marked increase in the number of panicles produced. Similarly, when photoperiods and temperatures were manipulated artificially to induce heading, he noted that adequate N supply during the time of short photoperiods was important to subsequent heading.

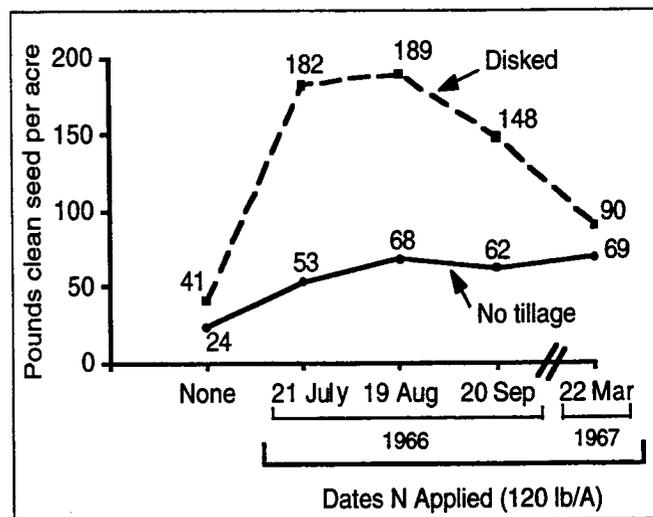


Figure 7. Seed yield in 1967 as influenced by no tillage vs. disking on 20 July 1966, and four dates of N application (Exp. II).

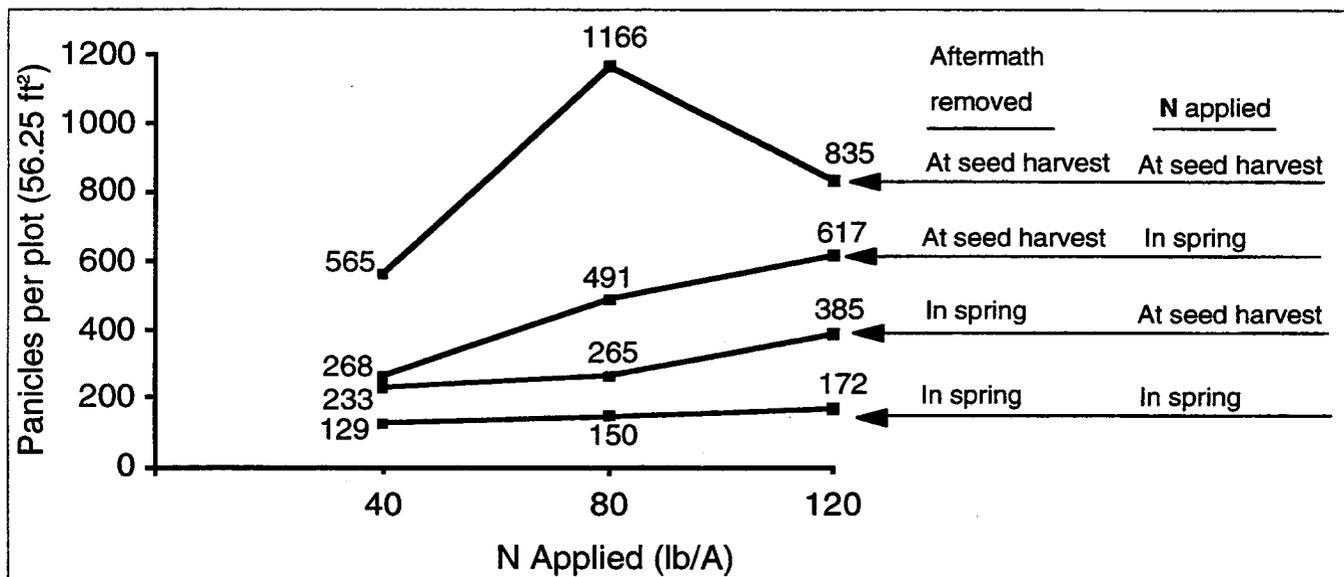


Figure 8. Influence of three N rates, two times of N application, and two times of aftermath removal on brome grass panicle density in the subsequent seed crop. Values are means of two years (Exp. III).

Floral Induction and Initiation

Possible reasons for the above stated different responses of brome grass to time of N fertilization have been discussed earlier (Klebesadel 1970a) but merit additional elaboration here.

Tillers that develop on a parent brome grass plant have been recognized to go through three developmental stages (Lamp 1952). Those stages may be generalized as: (a) growth into a short tiller from buds in axils of stems or rhizomes, (b) putting forth closely clustered green leaves near the soil surface to create a "rosette tiller," and (c) later elongation of internodes to produce an aerial culm while elevating the growing point up the interior of the culm. Rosette tillers formed in summer and autumn generally overwinter in unelongated form; during the following spring they elongate to produce tall culms that are either (a) leafy and totally vegetative with no seed head (panicle), or (b) with fewer leaves and producing a panicle. Certain conditions prior to or shortly after winter determine which type of culm will be produced (vegetative or panicle-bearing).

Development of seed heads from the growing points within tillers of cool-season grasses such as brome grass is also generally acknowledged to proceed through a sequence of stages (Canode *et al.* 1972; Elliott 1967; Hodgson 1966; Lamp 1952; Sass and Skogman 1951). Various investigators differ as to the specific names applied to those stages (Canode *et al.* 1972; Lamp 1952). However, one generally accepted version of those stages is: (a) *induction*, a chemical change fostered by specific stimuli that disposes the growing point, meristem, or apex (enclosed within a tiller and near the soil surface) to eventually become a seed head, (b) *initiation*, the early, microscopic morphological transformation of that veg-

etative growing point (still at or near the soil surface) into a floral primordium, and (c) *development*, as the growing point continues differentiation of tissues, is elevated upward through the stem or culm, emerges as a fully formed seed head, and continues through anthesis and seed formation to maturation.

Evans and Grover (1940) and Sharman (1947) relate in detail the phenomenon of initiation of floral primordia (transition of growing points from vegetative to reproductive condition) in perennial grasses.

Much of the stimulus that brings about induction of floral primordia is provided by nature, the principal factor being the occurrence in fall and spring of short daily photoperiods, or conversely, long nyctoperiods (Gall 1947; Newell 1951). The other major factor that promotes heading of brome grass is an adequate and timely supply of N, as discussed above.

The unique interrelationship of seasonal photoperiod pattern and growing seasons in subarctic regions apparently presents photoperiodic conditions conducive to brome grass floral induction only in autumn (Hodgson 1966; Klebesadel 1970a). Mean dates of first autumn occurrence of temperatures of 32°, 28°, 24°, and 20°F at the Matanuska Research Farm are 12 September, 22 September, 7 October, and 20 October, respectively (Watson 1959). The killing temperature for brome grass aerial growth is not known precisely; however, the above temperature pattern and general field observations indicate that frost killing of brome grass vegetation normally occurs shortly after the autumn equinox (when photoperiods and nyctoperiods are both 12 hours).

Of critical importance, spring growth of grasses in this area, does not begin until late April when much longer photoperiods, between 15 and 16 hours, generally exceed those required for induction of floral primordia.

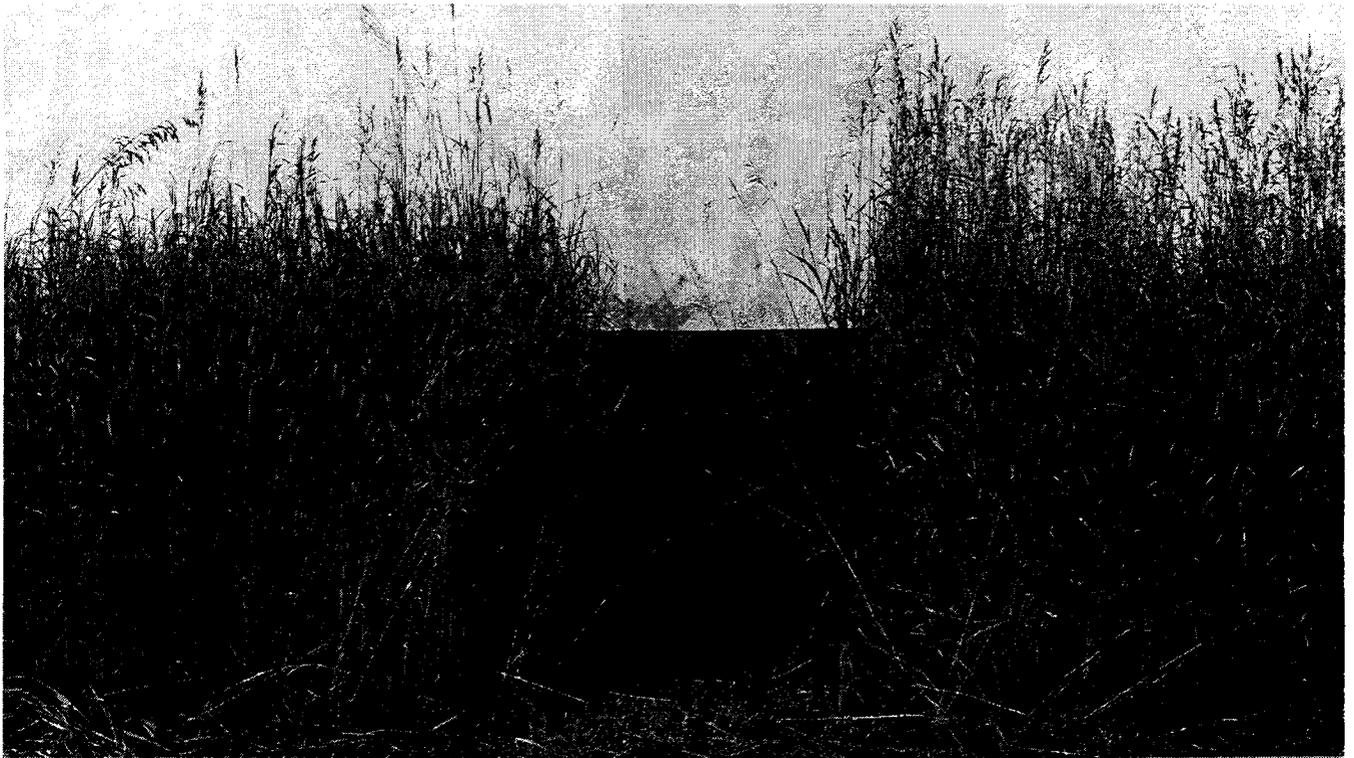


Figure 9. Two plots in Experiment III photographed August 1968 showing difference in Polar bromegrass panicle numbers as influenced by different times of aftermath removal (after seed harvest on 16 August 1967), and different times of N application.

	<u>Aftermath from 1967 seed harvest removed:</u>	<u>N at 80 lb/A applied:</u>	<u>Panicles per 56.25 ft² on 14 August 1968</u>
Left plot:	19 March 1968	2 April 1968	222
Right plot:	18 August 1967	21 August 1967	1215

In more southern areas, in contrast, grasses begin growth when photoperiods are significantly shorter, so inductive conditions occur there both in autumn and in spring (Clarke and Elliott 1974).

Beyond differences in growing conditions that change with latitude, peculiarities of the bromegrasses compared may also account for some of the differential response to time of N application. Lamp (1952) cited many reports that document the considerable variation in vegetative growth and reproductive activity of different clones and ecotypes of smooth bromegrass. As a far northern example, Romanova and Vasiliskov (1974) reported that at 67°44'N in northwestern Russia one variety of smooth bromegrass produced seed heads routinely while two other ecotypes studied (from ca. 59° to 60°N) remained vegetative. One of those was induced to produce panicles by shortening daily photoperiods (to 8 to 14 hours) for over 20 days, while the other could not be induced to produce seed heads.

Reports from this station (Klebesadel 1971, 1973) demonstrated that by exposing a normally nonhardy, southern-type cultivar of smooth bromegrass to artificially shortening photoperiods (lengthening nyctoperiods) for about eight weeks prior to freeze-up

(creating pre-winter photoperiod/nyctoperiod conditions resembling those that occur at more southern latitudes), that grass not only developed adequate freeze tolerance for good winter survival, but also produced many panicles the following year. Others (Howell and Weiser 1970) have noted the similarities between environmental stimuli (shortening photoperiods and lowering temperatures) that control both the development of freeze tolerance and flower initiation in plants.

In contrast, the artificially shortened pre-winter photoperiods caused subarctic-adapted pumpelly bromegrass to produce only 1/15 as many panicles the following year as were produced where it had been grown under normally shortening subarctic photoperiods. The start of the shortened-photoperiod treatment on 25 August abruptly shortened the normally occurring photoperiods from 15 hours on that date to 9 hours, and continued that daily photoperiod until frost killed bromegrass aerial growth near 20 October. Thus the plants were deprived of exposure to all durations of photoperiod between 15 and 9 hours that would have occurred with gradually shortening normal daily photoperiods between 25 August and 20 October.

The aforementioned disparate results with different

bromegrasses under different photoperiodic regimes indicates specific photoperiodic requirements for induction of floral primordia in bromegrasses, but also that those requirements may differ considerably among individual clones, cultivars, or ecotypes, especially those adapted at diverse latitudes.

All references herein concerning effects of time of N application on brome seed production at mid-temperate latitudes are based on smooth bromegrass which, according to many authorities, may undergo induction in autumn but commences floral initiation only in spring at those more southern latitudes.

Newell (1951) in Nebraska moved bromegrass plants from the field indoors to long photoperiods (that promote culm elongation and emergence of panicles); plants brought into the greenhouse in August produced no panicles, those brought indoors in mid-September produced some panicles, but most were produced on plants transferred indoors in mid-November and mid-December. Those results inform that brome plants were most effectively induced to produce panicles by the daily photoperiods occurring at that latitude after mid-September and prior to mid-November (photoperiods decreasing from about 12 1/2 to 10 hours) (List 1958).

Various investigators have examined growing points of smooth bromegrass periodically from autumn to spring to determine when actual initiation occurs. Canode *et al.* (1972) at Pullman, WA noted first indications of floral initiation on 12 February; Gall (1947) and Lamp (1952) reported initiation in early to mid-April at Chicago, IL; Sass and Skogman (1951) similarly observed its occurrence from early to mid-April at Ames, IA; Rumburg, *et al.* (1980) in Colorado, and Clarke and Elliott (1974) in Alberta, found no floral initiation in smooth brome in autumn but did in spring.

In contrast to those findings with smooth bromegrass, Clarke and Elliott (1974) and Hodgson (1966) reported autumn initiation of floral primordia in northern ecotypes of the closely related pumpelly bromegrass; moreover, the Canadian workers stated further that those fall-initiated primordia survived the winter to develop into inflorescences.

Those observations concur with determinations of comparative winterkill of subarctic-adapted versus introduced smooth bromegrasses in the field in Alaska (Klebesadel 1970b), as well as laboratory-determined comparative injury of rhizomes of different bromegrasses subjected to different levels of freeze stress (Klebesadel 1992). In both studies, from least-injured to most injured those grasses were: native Alaskan pumpelly brome, the hybrid Alaska cultivar Polar, the cultivar Manchar adapted in the northern 48 states, and the cultivar Achenbach adapted in mid-continent U.S.

Manchar bromegrass is adequately winterhardy for good vegetative survival during all but the most severe winters in this area (Klebesadel 1992, 1994), yet it has been noted that it consistently produces very few panicles

at this latitude (Klebesadel 1970b). At its more southern latitudes of adaptation, however, Manchar is described as "a high yielder of seed," and yields from 400 to over 600 pounds per acre are not uncommon (Stark and Klages 1949). Inasmuch as Manchar is adapted and commonly grown in the northern states where spring initiation is common, it is very poorly adapted for successful production of panicles at this latitude.

Referring to smooth bromegrass, Sass and Skogman (1951) in Iowa stated, "The rare inflorescence primordia that are formed in late autumn do not survive the winter." Implicit in that observation is the fact that floral primordia are more susceptible to cold injury than other overwintering plant tissues that do survive without injury.

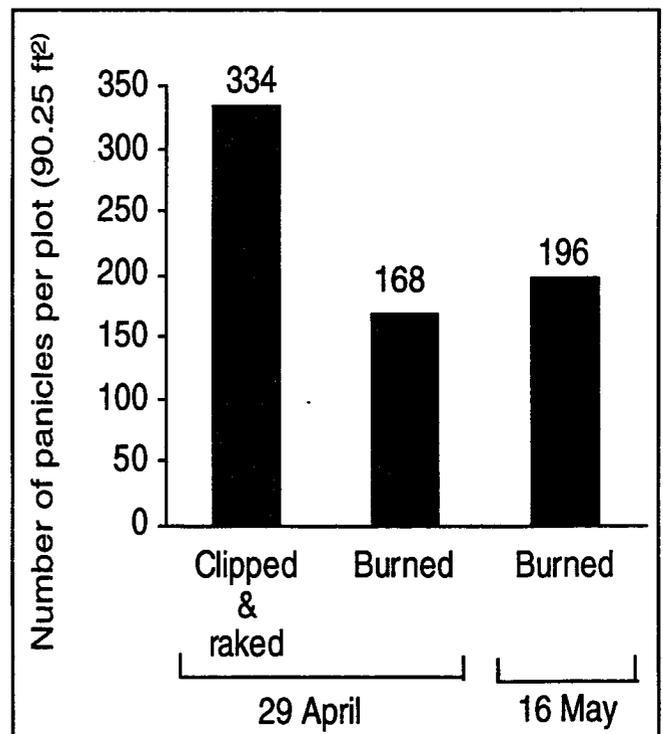


Figure 10. Number of panicles per plot in September 1966 as influenced by clipping and raking aftermath (left after previous-year seed harvest) on 29 April or burning it on two different dates (Exp. IV).

By subjecting Southland smooth bromegrass, a nonhardy, poorly adapted cultivar at this latitude, to short photoperiods (9 hr)/long nyctoperiods (15 hr) for eight weeks prior to winter, not only was good winter survival promoted, but many panicles were produced the following year (Klebesadel 1971, 1973). This suggests that not only did the short photoperiods/long nyctoperiods cause successful late-summer/autumn induction of inflorescence primordia, but the artificially altered pre-winter day/night regime also promoted development of adequate levels of freeze tolerance in overwintering tissues (Hodgson 1964; Klebesadel 1993), including the inflorescence primordia, for successful win-



Figure 11. Appearance of plots that received two of the five treatments in Experiment V when photographed 21 October 1985, shortly after a light snowfall. On the photo date, all plots were clipped to a 2-inch stubble and raked clean. Tall aftermath growth on left plot was left intact after combine-harvest of seed on 23 August; aftermath growth on right plot was clipped to a 2-inch stubble and raked clean on 30 August, the same day that all plots received N at 100 lb/A. Proliferation of new unelongated, leafy, unshaded tillers that developed during the 7 1/2 weeks since 30 August is visible in the snow on the right plot.

ter survival of those incipient panicles. As stated earlier, Howell and Weiser (1970) noted that similar environmental influences foster both floral initiation and development of cold hardiness in plants.

Experiments reported here utilized Polar, a cultivar predominantly of hybrid origin; 11 of the 16 clones in its genetic background represent hybridization between temperate-latitude-adapted smooth bromegrass that typically initiates floral primordia in spring, and northern-adapted pumpelly bromegrass that normally exhibits pre-winter initiation of floral primordia (Clarke and Elliott 1974; Hodgson 1966). Therefore, an adequate supply of N, provided by mid-to-late summer application, undoubtedly served to stimulate induction (and probably initiation) of panicle primordia of Polar prior to winter. This phenomenon, common both to the grass and to this latitude, resulted in greater panicle density and higher yields in the seed crop of the following year.

In addition to external stimuli acting upon plants to cause heading, Lamp (1952) believes that a tiller must also achieve a certain minimum stage of growth or development, referred to as "ripeness-to-flower," before the growing point can be induced to become a floral primordium. More study is needed of this concept for its applicability to seed production in Alaska; tagging of tillers of various stages of development and monitoring their eventual development as described by Lamp (1952) should be informative.

A further complicating factor, and one concerning which a more thorough knowledge would be helpful, is a given tiller's relative dependence upon, or indepen-

dence of, the parent plant from which it grew and to which it remains attached.

Experiment IV-Influence of spring removal of aftermath by clipping and raking vs. burning.

Clipping and raking on 29 April to remove aftermath remaining in place after the previous year's seed harvest resulted in about twice as many panicles per plot as burning the aftermath on either 29 April or 16 May (Fig. 10); this suggests that the heat from spring burning may have been injurious to the extent of reducing the numbers of panicles produced later that year.

This finding serves only to inform that spring burning is indicated to be harmful to the succeeding seed crop; the results of Exp. III demonstrated that the aftermath should be removed shortly after harvest of a seed crop, thus leaving none to be disposed of in spring. Therefore, the results of this experiment have no practical application for bromegrass seed production in this area, except to caution against spring burning of stands intended for seed production.

Canode and Law (1978) reported that residue burning between 15 August and 1 September resulted in significantly higher bromegrass seed yields than mechanical removal in the third, fourth, and fifth year of production in Washington. Knowles (1966) reported that burning either in mid-October or mid-April tended to reduce disease incidence, increased seed yields over non-removal of a 16- to 18-inch stubble, but resulted in generally lower seed yields than resulted from mechanical removal of the aftermath in mid-August, mid-October,

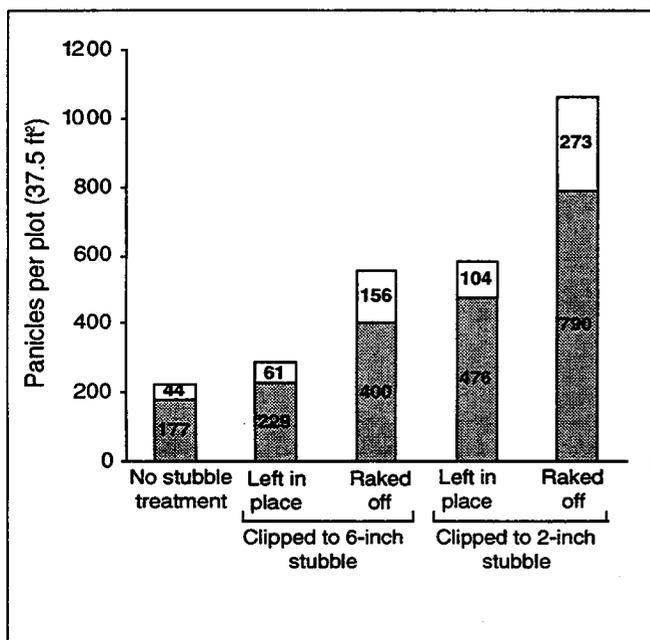


Figure 12. Two-year mean numbers of Polar bromegrass seed heads (panicles) produced per plot as influenced by management of aftermath following seed harvest in August of the previous year. Stippled portion of each bar is the number of fertile, seed-bearing panicles; open portion of bar is number of sterile, non-seed-bearing "white-top" panicles resulting from injury caused by an insect (Exp. V).

ber, or mid-April.

Late-summer or fall burning has little application for this area because of the normally frequent precipitation and poor burning conditions during late August and September.

Experiment V-Aftermath management shortly after seed harvest.

The five different procedures for managing the tall aftermath left standing after seed harvest in August (Fig. 11) had markedly different effects on the numbers of panicles (Fig. 12) and seed yields produced the following year (Fig. 13). With no treatment of the aftermath (until clipping and removal after killing frost), numbers of panicles produced the following year were few and seed yields averaged only about 40 lb/A over two years.

Clipping the aftermath to a 6-inch stubble and leaving the clipped material in place resulted in little improvement in panicle production, and seed yields averaged only 45 lb/A over two years. Removal of the clippings from the 6-inch stubble, however, resulted in more than doubling the amount of seed produced in the following year (2-year mean = 93.5 lb/A).

Clipping the aftermath to a 2-inch stubble and not removing the clipped growth resulted in a 2-year mean seed yield of 105 lb/A, a considerable improvement over no treatment or leaving the clipped material on a 6-inch stubble.

The best aftermath treatment for enhancing heading

and seed yield the following year, however, was clipping to a 2-inch stubble and removing the clipped growth; 2-year mean seed yield from that treatment was 154.5 lb/A, an almost fourfold increase over no treatment.

The marked differences in heading as influenced by the different aftermath treatments may be due largely to shading effects. Watkins (1940) reported that shading greatly reduced the numbers of fertile shoots (panicle-bearing culms) produced.

The tall, uncut aftermath (Fig. 11), and plots cut to 2- and 6-inch stubble but unraked, undoubtedly caused considerable shading of the newly developing tillers during the late portion of the growing season. The aftermath clipped to a 6-inch stubble and raked should have caused somewhat less shading than the aforementioned three treatments; however, it nonetheless suppressed panicle production the following year.

In contrast to all four other treatments, plots clipped to a 2-inch stubble with clippings removed resulted in production of many short, leafy, unshaded tillers prior to freeze-up (Fig. 11), and the greatest abundance of panicles and seed in the following year's seed crop (Figs. 12, 13). The vigorous growth of the new, leafy, unshaded tillers, stimulated by N application in late August, undoubtedly rendered them ideally receptive to photoperiods/nyctoperiods of critical duration for induction of floral primordia during September/October.

It is possible that clipping to a short, 2-inch stubble could have stimulated production of more new tillers and/or earlier, more vigorous growth of the new tillers; no counts or estimates of this were made. However, clipping to a 2-inch stubble without raking should also have stimulated tiller growth commensurate with the best treatment, but failure to remove the clipped material greatly suppressed panicle production the following year (Fig. 12).

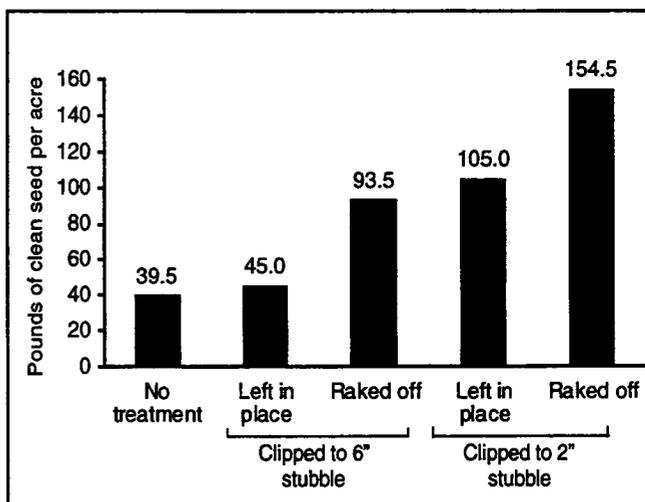


Figure 13. Two-year means of Polar bromegrass seed yields as influenced by management of aftermath following seed harvest in August of the previous year (Exp. V).

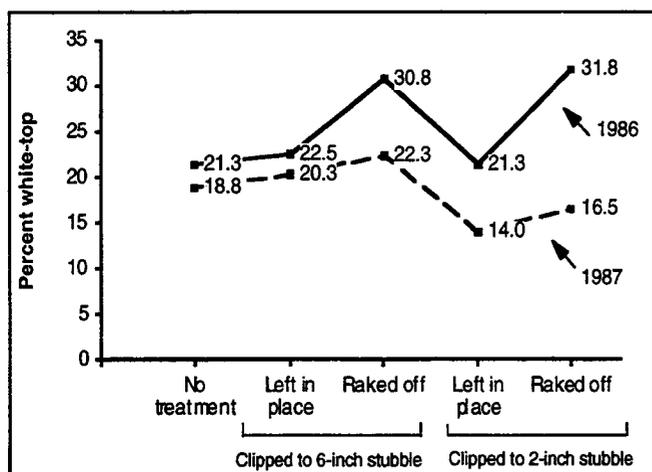


Figure 14. Percent of total *Polar bromegrass* panicles produced that were afflicted by white-top in 1986 and 1987 as influenced by various stubble-management treatments after seed harvest in August of the previous year (Exp. V).

It is also possible that several influences, including shading, differential numbers of new tillers produced, a combination of those, or other unknown factors, could have been operative in the different results produced by the treatments, but shading logically was a major influence. Whatever the cause(s), the influence had to be effective between the time that aftermath treatments were performed and killing frost because all plots were clipped uniformly to a 2-inch stubble and the entire experimental area was raked clean near mid-October.

Sterile "White-top" Panicles

"White-top" or "silvertop" are terms used to describe grass seed heads that emerge but are sterile and produce no seed, due to injury to plant culms by an insect (Duell 1985; Peterson and Veal 1971). This is probably the same malady referred to as "blind panicles" by Waddington and Storgaard (1971) in Manitoba. White-top, so-named because of the conspicuously whitish coloration of the affected seed heads, has been noted to occur commonly in several grass species in this area, including Kentucky bluegrass (*Poa pratensis*) (Klebesadel 1984), red fescue (*Festuca rubra*), timothy (*Phleum pratense*), quackgrass (*Agropyron repens*), Siberian wildrye (*Elymus sibiricus*), and bluejoint (*Calamagrostis canadensis*).

Considerable occurrence of white-top was noted in the panicles produced in both years in Exp. V (Figs. 12, 14). Percentage of panicles afflicted with white-top differed with the different aftermath management treatments (Fig. 14) and was more severe in 1986 (mean of all treatments = 25.5% of total heads were white-top) than in 1987 (mean = 18.4%).

Some degree of similarity was noted in the pattern of occurrence of white-top as related to aftermath-management treatments during the two years (Fig. 14); however, specific reasons for different percentages of incidence in

the two years, and how or why they may have been influenced differentially by the aftermath management treatments are not readily apparent.

The magnitude of the occurrence of white-top, however, was sufficient to have a considerable influence in suppressing seed yields in both years and with all treatments. In using the 2-year mean percentage incidence of white-top in the highest yielding treatment (= 24.2%), calculated total 2-year mean seed yield for that treatment would have been 204 lb/A instead of the 155 lb/A shown in Figure 13. Future work that identifies effective control strategies for the insect, leading to prevention of white-top occurrence, should be useful.

CONCLUSIONS

Apparently the growing point within each tiller of bromegrass will produce a leafy, non-heading stem unless induced to transform from vegetative to reproductive condition by (a) critical-length short daily photoperiods/long nyctoperiods and (b) adequate N supply prior to the time that the tiller begins elongation and when the growing point is still at or beneath the soil surface. Despite occurrence of short photoperiods and adequate N supply, however, significant shading and developing tillers apparently can reduce the number of panicles later produced from those tillers.

Seed yields of smooth bromegrass decline rapidly in the years immediately following the first year of production. Although certain management procedures tended to slow, halt, or even reverse somewhat those declining yields, none of the practices evaluated in these exploratory experiments returned 3-to-5-year-old stands of *Polar bromegrass* to original higher levels of seed production. However, each of the beneficial procedures, if employed earlier in the stand life of seed fields, may serve to slow annual declines in seed yield.

Seed yields are influenced principally by the numbers of panicles produced, except for the depressing influence of insect-damaged "white-top" panicles that produce no seed.

An additional factor important to seed production is the amount of seed produced per panicle; in these experiments it ranged widely, from 40 to 150 milligrams.

Management procedures that influenced the numbers of panicles produced and amount of seed per panicle on the bromegrass sods (that had developed from coalescence of rows seeded originally) included (a) sod disturbance by light disking, (b) date of a second forage harvest in the year before a seed harvest was taken, (c) time and rate of N application, (d) mechanical removal vs. burning of aftermath in spring, and (e) management of the tall aftermath growth in summer shortly after seed harvest.

Sod Disturbance

One-way disking (modest sod disturbance) in mid-July had a stimulatory effect on the seed crop of the following year; it (a) increased the effectiveness of N applied the same year, (b) increased the number of panicles produced the following year, (c) increased seed weight per panicle, and due to the cumulative effects of the foregoing factors, increased seed yields.

Other tillage implements and other extents of sod disturbance should be evaluated here for rejuvenation of bromegrass seed-production fields. The effects of cultivation to maintain bromegrass in rows (a practice employed elsewhere but not evaluated in this study) also warrants evaluation for its possible contribution to preventing decline in seed yields with advancing age of stands.

Date of Forage Harvest in Year Before Seed Crop

If a field harvested for forage is to be used for seed production the following year, results obtained indicate that a second forage harvest in late September would result in more panicles, more seed per panicle, and thus a greater seed yield than no second crop harvest or harvest at the end of August.

Time and Rate of N Application

Application of N shortly after seed harvest resulted in many more panicles produced the following year than N applied in spring of the year of seed production; however, spring-applied N resulted in more seed per panicle. Optimum rate of N was not determined, but from 80 to 100 lb/A apparently supplies the amount required for maximum panicle production. Additional studies should determine more precisely the ideal time and rate of N application. It may be found that the optimum rate increases with age of stand. Moreover, at higher N rates, it may be necessary to increase application rates of other nutrients (e.g. P and K) to achieve optimum balance of fertilizer elements for maximum heading and seed production.

Apparently photoperiods/nyctoperiods of critical duration for induction of bromegrass floral primordia (during bromegrass vegetative growth) occur only during late-summer/autumn at this latitude. For this reason, an adequate supply of fertilizer N must be applied in August to effectuate maximum induction of primordia prior to frost killing of foliage in mid-to-late October. Primordia that are induced to flower, and successfully survive the winter, produce seed heads the following year.

The relative ineffectiveness of spring-applied N (compared with August application during the previous year) in stimulating panicle production in the same year ap-

parently is due to the fact that initiation of spring growth of bromegrass at this latitude starts after photoperiods/nyctoperiods of critical duration to cause induction of floral primordia have occurred; thus, many more culms remain vegetative and do not produce panicles.

Mechanical Removal vs. Burning of Aftermath in Spring

Burning aftermath growth remaining after seed harvest, as is done in some other seed-producing areas, is believed a poor course of action here. Burning conditions in late summer generally are poor with normally moist conditions, and burning in spring reduced panicle numbers in the seed crop of the same year.

Management of Aftermath in the Year of Seed Harvest

The tall aftermath remaining after seed harvest should be clipped to a short stubble and removed from the field. Times of clipping and removal were not evaluated but, if to be fed, forage quality would be higher immediately after seed harvest than later; moreover, clipping and removal as soon as possible after seed harvest may stimulate more rapid tiller growth and would leave less time for harmful shading of late-summer developing tillers.

The Problem of White-top Panicles

The significant incidence of "white-top" in some years, an insect-caused damage to culms that results in panicles but no seed formation, can reduce seed yields considerably. The problem requires further study, and effective control measures should be identified.

ACKNOWLEDGMENTS

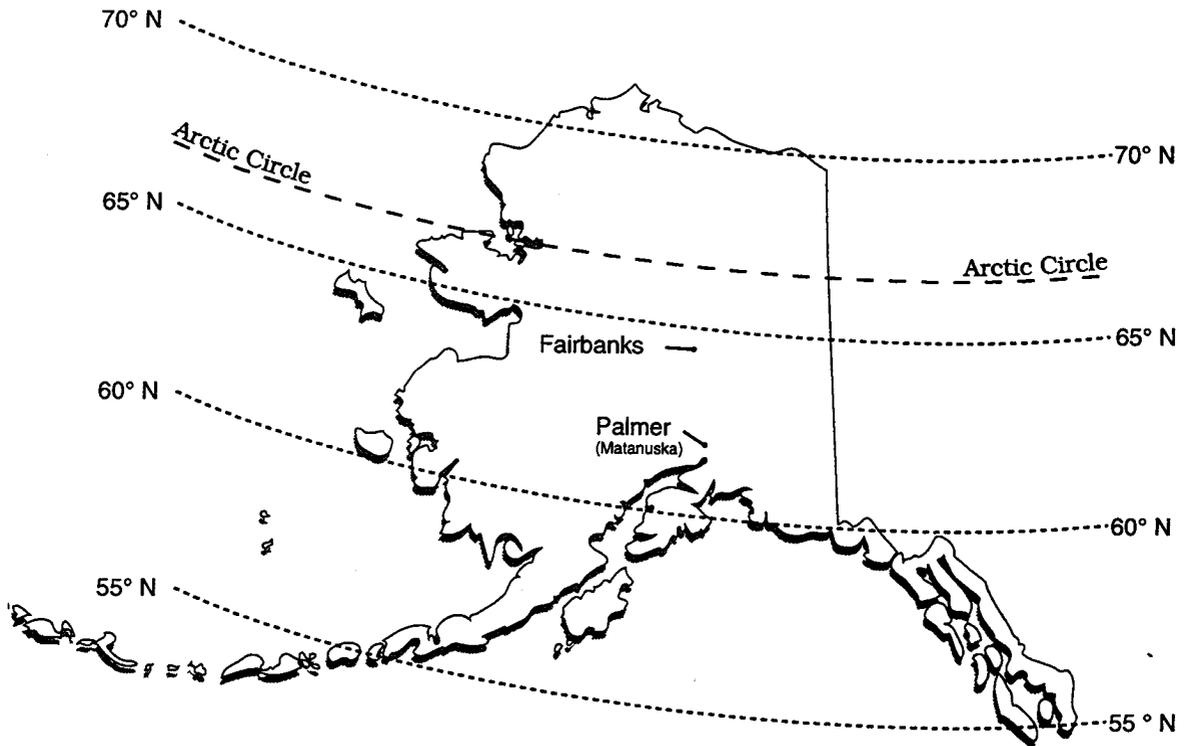
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