



Effects of timing of nitrogen fertilization and residue removal on seed yields of Regar meadow brome grass
by Susan Frances Upton

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Agronomy
Montana State University
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Abstract:

Seed yields of 'Regar' meadow brome grass (*Bromus biebersteinii* Roem and Schult.) are generally high the first year of production, but decline drastically in subsequent years. Three years is considered to be the maximum productive life of a Regar seed stand.

Experiments were conducted at Bozeman and Kalispell, Montana, to determine the effects of timing of nitrogen fertilization and residue removal on Regar seed yields. The experimental design was a randomized complete block with thirteen treatments and four replications. Treatments consisted of four different N application dates during the establishment year, four N application dates to established stands, and four dates of residue removal from established stands.

Nitrogen application in fall of the establishment year (1980) resulted in the highest seed yields the first year of production (1981) at Kalispell. There were no differences among treatments the first harvest year at Bozeman, where extreme lodging and excessive seed shattering occurred.

Fall N applications to established stands in conjunction with fall or after harvest plus fall residue removal from established stands resulted in the highest seed yields the second year of production (1982) at Kalispell. After harvest or fall N applications to established stands in conjunction with after harvest, fall, or after harvest plus fall residue removal from established stands resulted in the highest seed yields the second year of production at Bozeman.

These results suggest that nitrogen application in fall of the establishment year and to established stands in conjunction with fall or after harvest plus fall residue removal from established stands will produce highest Regar seed yields at these two locations. Experiments should be conducted at other Montana locations before statewide recommendations for Regar seed production are made. In addition, studies at Bozeman and Kalispell should be continued for a minimum of two additional years to determine the effects of timing of N application and residue removal on Regar seed stand longevity.

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AND RESIDUE REMOVAL ON SEED YIELDS OF
'REGAR' MEADOW BROMEGRASS

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

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in

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APPROVAL

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Susan Frances Upton

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for admission to the College of Graduate Studies.

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ABSTRACT

Seed yields of 'Regar' meadow bromegrass (*Bromus biebersteinii* Roem and Schult.) are generally high the first year of production, but decline drastically in subsequent years. Three years is considered to be the maximum productive life of a Regar seed stand.

Experiments were conducted at Bozeman and Kalispell, Montana, to determine the effects of timing of nitrogen fertilization and residue removal on Regar seed yields. The experimental design was a randomized complete block with thirteen treatments and four replications. Treatments consisted of four different N application dates during the establishment year, four N application dates to established stands, and four dates of residue removal from established stands.

Nitrogen application in fall of the establishment year (1980) resulted in the highest seed yields the first year of production (1981) at Kalispell. There were no differences among treatments the first harvest year at Bozeman, where extreme lodging and excessive seed shattering occurred.

Fall N applications to established stands in conjunction with fall or after harvest plus fall residue removal from established stands resulted in the highest seed yields the second year of production (1982) at Kalispell. After harvest or fall N applications to established stands in conjunction with after harvest, fall, or after harvest plus fall residue removal from established stands resulted in the highest seed yields the second year of production at Bozeman.

These results suggest that nitrogen application in fall of the establishment year and to established stands in conjunction with fall or after harvest plus fall residue removal from established stands will produce highest Regar seed yields at these two locations. Experiments should be conducted at other Montana locations before statewide recommendations for Regar seed production are made. In addition, studies at Bozeman and Kalispell should be continued for a minimum of two additional years to determine the effects of timing of N application and residue removal on Regar seed stand longevity.

INTRODUCTION

'Regar' meadow brome grass (*Bromus biebersteinii* Roem and Schult.) is an improved forage cultivar selected for its vigorous regrowth characteristics. Regar is moderately drought tolerant, winterhardy, and exhibits good forage quality and high yields. Since its introduction in 1959, Regar has gained popularity throughout the northern U.S. and Canada.

Seed yields of Regar are generally high the first year of production, but exhibit a marked decline in subsequent years. This decline in seed production associated with age of stand is characteristic of many cool-season perennial grasses. Nitrogen fertilization and post-harvest residue removal are two cultural practices which in some cases have resulted in increased seed yields and seed stand longevity of cool-season perennial grasses.

Objectives of this research were to determine the effects of timing of nitrogen fertilization and residue removal from established stands on seed yields of Regar meadow brome grass.

LITERATURE REVIEW

'Regar' meadow brome grass (*Bromus biebersteinii* Roem and Schult.) is a forage cultivar which was selected from the Turkish accession PI-172390 for its vigorous regrowth characteristics. Regar was tested and released by the USDA Plant Introduction Station Agricultural Research Service in 1959, and has since gained popularity as an improved grass cultivar throughout the northern U.S. and Canada (Cooper et al., 1978; Foster et al., 1966).

Morphological Characteristics of Regar Meadow Brome grass

Regar is classified as a long-lived perennial bunchgrass; however, a considerable amount of vegetative spreading has been observed, especially under irrigated conditions. Regar plants produce an abundance of crown and root material (Foster et al., 1966).

Plants of Regar exhibit numerous, dominantly basal, slightly pubescent leaves which are light green in color. The erect seed stalks extend in an open panicle above the leaf mass. Seeds resemble those of smooth brome grass (*Bromus inermis* Leyss.) except for the presence of a short awn (Foster et al., 1966).

Agronomic Characteristics of Regar Meadow Brome grass

Regar is generally adapted to the same soil types and geographic areas as smooth brome grass; however, the adapted range of Regar may extend into zones of less precipitation and slightly lower elevations than that of smooth brome grass (Foster et al., 1966; Wiesner, 1982). Regar is drought tolerant and exhibits excellent winter hardiness. Regar

may be grown under irrigation or under dryland conditions if the average annual precipitation and the elevation are above 36 cm and 1,220 m, respectively (Foster et al., 1966).

Regar can be seeded alone, in mixtures with perennial grasses, or with legumes such as alfalfa (*Medicago sativa* L.), Ladino clover (*Trifolium repens* L.), birdsfoot trefoil (*Lotus corniculatus* L.), or cicer milkvetch (*Astragalus cicer* L.) (Cooper et al., 1978; Foster et al., 1966).

Regar has good forage production throughout the growing season. It starts growth early in the spring and is ready for grazing at an early date. Regar produces seed heads and matures seven to ten days earlier than smooth brome grass. The plants continue growth after seed maturation and, with favorable soil moisture, the leaves remain green late into the fall (Foster et al., 1966).

Regar exhibits good regrowth after grazing or clipping due to rapid growth of new shoots and elongation of old shoots which have been removed (Cooper et al., 1978; Foster et al., 1966).

Nutritional quality of Regar forage is similar to smooth brome grass (Foster et al., 1966). The forage appears to be palatable to all classes of livestock, both as green forage and as cured hay (Cooper et al., 1978; Foster et al., 1966). In some cases, semimature standing forage of Regar has been more completely utilized by livestock than comparable forage of smooth brome grass (Foster et al., 1966).

Forage yields of Regar have consistently equalled or exceeded those of 'Manchar' smooth brome grass (Cooper et al., 1978; Foster et al., 1966). Total yields of irrigated Regar-legume mixtures over three years at three Montana locations exceeded yields of Manchar-legume mixtures by an average of 3.54 megagrams per hectare (Cooper et al., 1978). In Idaho, the difference in forage yields of Regar and Manchar increased after four years. This was attributed to Regar meadow brome grass not becoming sodbound as rapidly

as Manchar smooth brome grass or other strongly rhizomatous forage grasses (Foster et al., 1966).

Seed Production Characteristics of Regar Meadow Bromegrass

Regar seed yields are generally high the first production year with a pronounced decline in subsequent years (Cooper et al., 1978; Foster et al., 1966). In Idaho, dryland seed yields decreased from 336 kg/ha in the first harvest year to 112 kg/ha in the third harvest year (Foster et al., 1966). Experiments conducted in Montana indicate that seed yield decline in Regar may be related to available soil moisture. Under dryland conditions, seed yields declined from 572 kg/ha in the first harvest year to 265 kg/ha in the third harvest year, a 54% decrease. Seed yields in stands irrigated every two weeks decreased from 470 kg/ha in the first harvest year to 18 kg/ha in the third harvest year, a 96% decrease. The denser stand and larger amount of forage in the irrigated plots suggested a sodbound condition. More root and vegetative growth was produced at the expense of seed production (Cooper et al., 1978).

Seed yields of most perennial cool-season grasses decline with stand age. This decrease is generally more pronounced with rhizomatous, vigorous sod-forming grasses than with bunchgrasses or moderate sod-forming grasses (Canode and Law, 1975). Seed yield declines with increasing stand age have been observed with smooth brome grass (Anderson et al., 1946; Canode, 1968), intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.) (Canode, 1965), Kentucky bluegrass (*Poa pratensis* L.) (Evans and Canode, 1971), mountain brome grass (*Bromus marginatus* (Nees ex Steud.) (Klages and Stark, 1949), orchard-grass (*Dactylis glomerata* L.) and meadow fescue (*Festuca pratensis* Huds. syn *F. elatior* L.) (Green and Evans, 1956).

Seed yield decline of Manchar smooth brome grass is due to a reduction of seed weight and number of seed heads per unit area in aged stands (Canode, 1968).

Effect of Post-Harvest Residue Removal on Seed Production
of Cool Season Perennial Grasses

Early research showed that fall grazing or clipping of smooth brome grass seed stands did not reduce subsequent seed yield, and "judicious pasturing" following seed harvest was recommended (Churchill, 1944; Metcalfe, 1951). Recent research indicates that post-harvest residue removal is essential to maintaining high seed yields of smooth brome grass, and that complete residue removal results in the highest seed yields (Canode and Law, 1978; Knowles et al., 1951 rev. 1969).

Knowles et al. (1951 rev. 1969) reported that removal of post-harvest residue by burning or mowing and removal of all cut material increased smooth brome grass seed yields up to 30% over untreated controls, with no significant differences between the two methods. However, Canode and Law (1978) showed that mechanical removal of smooth brome grass straw and stubble resulted in an average seed yield reduction of 24% as compared to open burning. Clipping and removal of both straw and stubble resulted in higher seed yields than removal of straw alone.

Metcalfe (1951) observed seed yield reductions in smooth brome grass of up to 50% following spring clipping due to decreased panicle length, number of florets per panicle, and weight of threshed seed per panicle. In contrast, Knowles et al. (1951 rev. 1969) found that differences in seed yields following residue removal in either August, October, or April were not significant.

Post-harvest residue removal is essential in maintaining high seed yields of Kentucky bluegrass (Canode, 1972; Canode, 1980; Canode and Law, 1975; Canode and Law, 1977; Pumphrey, 1965). Thatch accumulation is the primary factor causing decreased seed yields

of older stands (Canode and Law, 1975). Thatch accumulation suppresses autumn regrowth, resulting in decreased numbers of large tillers capable of being florally induced (Canode, 1980). Residue removal methods which completely remove straw and stubble discourage thatch accumulation, and are most effective in maintaining high seed yields (Canode, 1980; Canode and Law, 1975; Pumphrey, 1965).

In situ residue burning (open burning) is the most effective residue removal method in maintaining high seed yields of Kentucky bluegrass. Mechanical thatch removal following straw and stubble removal resulted in seed yields almost equal to those obtained with open burning in some experiments, but significantly decreased seed yields in other experiments (Canode, 1980). Pumphrey (1965) reported that August residue removal by either burning or mechanical means was equally effective in maintaining high seed yields, but later studies by Canode and Law (1977) showed average seed yield reductions of up to 60% when straw and stubble were mechanically removed compared to burning. Other studies found that burning lowered seed yields of Kentucky bluegrass in the second and third seed crops when compared with mechanical residue removal, but higher yields were obtained in the fourth and fifth seed crops (Canode, 1972).

Mechanical removal of straw and stubble resulted in higher seed yields of Kentucky bluegrass than mechanical removal of straw alone (Canode and Law, 1977; Pumphrey, 1965). Pumphrey (1965) showed that partial residue removal, consisting of baling the straw which had passed through the combine and removing the bales from the plot (stubble remains on plot) had an intermediate effect between no removal and complete removal. Canode and Law (1977) showed that chopping and removing the stubble following straw removal resulted in increased seed yields compared with removal of straw alone.

Post-harvest residue removal increases the value of autumn nitrogen applications in Kentucky bluegrass. Post-harvest burning and fertilization with 112 kg N/ha increased seed

yields 62 and 284 kg/ha, respectively. A combination of these two practices increased seed yield 528 kg/ha when compared with the untreated controls (Pumphrey, 1965).

While post-harvest residue removal is essential to maintaining high seed yields of Kentucky bluegrass, delaying residue removal until after the initiation of fall growth severely reduces seed yields the following year (Pumphrey, 1965).

Autumn defoliation of perennial ryegrass (*Lolium perenne* L.), either by grazing or by mechanical means, may increase or decrease the number of fertile tillers and seed yield depending on cultivar, age of stand, and availability of spring moisture (Evans, 1962; Roberts, 1958; Roberts, 1965; Roberts, 1966).

October defoliation of perennial ryegrass cultivar 'S.24' (an early type) significantly decreased seed yield the first production year. This effect was largely negated by nitrogen applied as late as anthesis. October defoliation and N application significantly increased seed yields of S.24 the second and third harvest years (Evans, 1962; Roberts, 1965). These results agree with earlier studies which indicated that seed yields of perennial ryegrass cultivars were not decreased following October to January grazing with N application and adequate spring moisture (Roberts, 1958).

September grazing of mature stands of several perennial ryegrass cultivars significantly increased seed yields by increasing fertile tiller numbers as much as 15% (Roberts, 1966).

Grazing or defoliation of perennial ryegrass after the onset of reproductive development in the spring can decrease seed yield (Roberts, 1958; Roberts, 1966). Spring or winter plus spring grazing of perennial ryegrass cultivar 'S.101' did not reduce seed yield if defoliation occurred before mid-April. Seed yields were significantly decreased, however, when spring grazing was delayed until May and drought occurred (Roberts, 1958). Seed yield reduction following grazing or defoliation after inflorescence initiation is due to the direct removal of the apices of advanced tillers. This practice results in decreased fertile tiller number and size (Roberts, 1958; Roberts, 1966).

Delayed spring grazing reduces seed yields of timothy. Roberts (1958) observed significant seed yield reductions of 'S.50' timothy for three consecutive harvest years following spring and winter plus spring grazing, even with the addition of N (Roberts, 1958). Decreased seed yields following grazing of timothy after inflorescence initiation are due to reduction in size and number of fertile tillers (Roberts, 1958; Roberts, 1965).

Post-harvest residue removal increased seed yields of meadow fescue. Green and Evans (1956) showed that seed yields of meadow fescue were increased by grazing in October, December, or March. Roberts (1965) reported that average seed yields of 'S.215' meadow fescue were generally improved by residue removal prior to inflorescence initiation. Residue removal after inflorescence initiation of S.215 resulted in reduced fertile tiller numbers and seed yields. Grazing of 'S.53' meadow fescue in September and December reduced seed yields (Roberts, 1965).

Spencer (1950) reported seed yield reductions of up to 50% following post-harvest residue removal of 'Kentucky 31' tall fescue (*Festuca elatior* var. *arundinacea* Schreb.).

Post-harvest residue removal prior to the initiation of fall growth of red fescue (*Festuca rubra* L.) results in increased seed yields. Highest seed yields are obtained when the residue is thoroughly removed (Chilcote et al., 1980; Kim, 1973; Pumphrey, 1965).

Burning of straw and stubble is the most effective method of maintaining high seed yields in red fescue (Chilcote et al., 1980; Kim, 1973). Burning results in increased tiller numbers, vigorous root growth, and more fertile tillers (Kim, 1973).

Pumphrey (1965) reported that similar seed yield increases in red fescue were obtained by either burning or mechanical removal of residue. Close-clipping and sweeping of the residue resulted in seed yields comparable to, but generally inferior to those obtained by burning (Chilcote et al., 1980; Kim, 1973). Complete residue removal by either burning or mechanical means resulted in increased early season tiller development (Kim, 1973).

Partial mechanical removal of the residue (leaving short stubble and some organic residue on the soil surface) resulted in significantly lower seed yields than either burning or close-clipping, but yields were significantly greater than with no residue removal (Chilcote et al., 1980; Pumphrey, 1965). Residue removal following the initiation of fall growth resulted in marked reduction in red fescue seed yields in the subsequent harvest (Pumphrey, 1965).

Post-harvest residue removal slowed the decline in seed production associated with stand age in orchardgrass (Canode, 1972; Green and Evans, 1956; Rampton and Jackson, 1969; Roberts, 1965). However, delayed spring grazing or cutting resulted in reduced seed yields (Green and Evans, 1956; Roberts, 1965).

Green and Evans (1956) showed that grazing of orchardgrass between October and April increased the production of fertile tillers compared with ungrazed treatments. The additional fertile tillers induced by grazing maintained significantly higher seed yields than ungrazed controls as the stands aged. April or May grazing treatments resulted in significantly lower seed yields than ungrazed controls. Roberts (1965) found that seed yields of 'S.26' orchardgrass were increased by residue removal in October, prior to inflorescence initiation. However, delaying residue removal until after inflorescence initiation in the spring reduced fertile tiller number and seed yields.

Burning and mechanical removal of post-harvest residue were equally effective in maintaining high seed yields in orchardgrass (Canode, 1972; Rampton and Jackson, 1969).

Post-harvest aftermath grazing of Russian wildrye (*Elymus junceus* Fisch.), Altai wildrye (*Elymus angustus* Trin.), and green needlegrass (*Stipa viridula* Trin.) significantly increased seed yields compared with ungrazed controls (Lawrence and Lodge, 1975). Grazing prevents the development of long mesocotyls which elevate the shoot apices to a height where they are exposed to frost damage (Lawrence, 1973; Lawrence and Ashford, 1964; Lawrence and Lodge, 1975).

Experiments in New Zealand with 'Massey Basyn' Yorkshire fog (*Holcus lanatus* L.) showed that date of discontinuation of grazing had a major effect on subsequent seed yields (Hill et al., 1974). Highest seed yields (323 kg/ha) were obtained when grazing was discontinued early (June 30), but lodging occurred. With later discontinuation of grazing (July 31 and August 31), lodging did not occur and seed yields averaged 247 kg/ha. Very late discontinuation of grazing (September 30) drastically reduced the number of inflorescences per unit area and seed yield (111 kg/ha). Researchers concluded that since the seed yield difference between early and mid-late discontinuation would probably be reduced under commercial conditions, grazing of Massey Basyn Yorkshire fog in New Zealand should be discontinued in late July or August (Hill et al., 1974).

Effect of Timing and Rate of Nitrogen Application on Seed
Production of Cool Season Perennial Grasses

Application of nitrogen fertilizers increases seed yields of smooth brome grass and slows the decline in seed production associated with increasing stand age. Nitrogen application increases the number of panicles per unit area, panicle length, total number of florets per panicle, and weight of threshed seed per panicle, but decreases the percentage of fertile florets (Metcalf, 1951).

The greatest increase in smooth brome grass seed yield per kilogram of nitrogen applied is obtained with relatively low rates. Knowles et al. (1951 rev. 1969) found that approximately one kilogram of additional seed was produced for each kilogram of ammonium nitrate (33% N) applied.

Early researchers recommended spring application of from 47 to 71 kg N/ha annually (Buller et al., 1955; Churchill, 1944). Anderson et al. (1946) reported that seed yields of smooth brome grass were increased with rates of N up to 112 kg/ha, but that higher rates became less effective in increasing yields. In Saskatchewan, the most profitable rate of N

application to smooth brome grass was approximately 37 kg/ha, supplied as ammonium nitrate (Crowle and Knowles, 1962).

More recent research shows that smooth brome grass seed yields are not increased by rates of N exceeding 67 kg/ha. Application of 112 kg N/ha results in reduced weight per seed when compared with an application rate of 67 kg N/ha. High rates of N neither prevent the decline in seed yields of Manchar smooth brome grass associated with stand age nor compensate for the reduction in seed yield associated with mechanical residue removal (Canode, 1968).

Harrison and Crawford (1941) reported that April or May N applications resulted in higher seed yields the first harvest year than the controls, while June applications did not consistently stimulate seed yields. In the second year of production, April applications were found to significantly increase seed yields while May and June applications were not as effective.

Metcalf (1951) showed that fall application of N was more effective than spring application in increasing smooth brome grass seed yields the first year of production. However, spring application of N to older, sodbound stands resulted in greater seed yields than fall or fall plus spring applications. Buller et al. (1955) reported that spring N applications were superior to fall applications in one year, while fall applications were more effective the following year. Polovii (1974) reported that early autumn-spring split N applications resulted in the highest average seed yields of smooth brome grass over three years.

Current research suggests that fall N application results in highest seed yields in smooth brome grass. Knowles et al. (1951 rev. 1969) and Crowle and Knowles (1962) indicated that fall applications of N resulted in much higher smooth brome grass seed yields than spring applications. Mid-September applications resulted in higher seed yields than mid-August or mid-October applications.

Rumberg et al. (1980) reported that fall application of nitrogen to smooth brome-grass stimulated early spring growth and increased the relative abundance of fertile tillers up to 15% compared with unfertilized and spring-fertilized treatments.

Fertilization of mountain brome-grass with N is essential in maintaining high seed yields. Early spring applications of 18 to 21 kg N/ha produced highest seed yields when mountain brome-grass was grown in rows under irrigation (Klages and Stark, 1949).

The application of high rates of N increases seed yields of Kentucky bluegrass (Cedell, 1978; Evans and Canode, 1971). Evans and Canode (1971) showed that seed yields of Kentucky bluegrass were increased when N was applied in conjunction with burning or gapping (removal of alternate 30-cm sections of plants) treatments. Fall application of 202-246 kg N/ha resulted in the highest seed yields. Seed yield was increased over 200% due to a nitrogen-induced increase in panicle numbers and seed weight. No N rate totally prevented the decline in Kentucky bluegrass seed yield associated with stand age.

Cedell (1976) showed that autumn-spring split N applications resulted in high seed yields in Kentucky bluegrass. Yields were reduced when N was applied in spring only.

Increasing the quantity of fall-applied nitrogen does not prevent the decline in seed production associated with stand age in intermediate wheatgrass. Canode (1965) showed that application of 89.6 kg N/ha increased seed yields of intermediate wheatgrasses compared with 67.2 kg/ha, but that application of 112 and 134.4 kg N/ha produced no further seed yield increases.

Early studies with perennial ryegrass showed that application of 94 kg N/ha significantly increased fertile tiller number and seed yields when compared with unfertilized controls. Seed yields resulting from spring or fall applications, or from spring-spring or autumn-spring split applications, or from application of 25% of the N in the autumn and the remaining 75% in spring were not significantly different (Evans, 1954).

Research indicates that timing of N application may be more important in perennial ryegrass than was previously supposed. Roberts (1965, 1966) showed that spring application of N significantly increased fertile tiller number and seed yield of perennial ryegrass compared with autumn application. Evans (1962) found that seed yield of the first harvest crop was significantly increased by N application even when N was applied as late as anthesis. One application in spring resulted in higher seed yields than two applications made the previous summer and autumn. Furthermore, application of N at anthesis of the first crop and again the next spring before harvest of the second seed crop increased perennial ryegrass seed yields more than applications made in summer or autumn.

Hebblethwaite and Ivins (1978) found no significant differences among seed yields of 'S.23' and 'S.24' perennial ryegrass when N was applied at different times from inflorescence initiation to emergence. Splitting the N between inflorescence initiation and emergence did not produce higher seed yields than a single application. Seed yields were significantly reduced when N application was delayed until 70 to 80% of the inflorescences had emerged.

Spring application of N fertilizers may be more effective in increasing timothy seed yields than fall applications; however, seed yields are not greatly affected by increasing the amount of N applied (Evans, 1954; Lambert, 1967; Roberts, 1965). Although Austenson and Peabody (1964) reported no significant differences in timothy seed yields obtained with fall, spring, or split applications, other research suggests that spring application is superior to fall application. Evans (1954) observed that fall N application reduced seed yields slightly each year, while spring application slightly increased seed yields, when compared with the unfertilized control. Split fall-spring or split spring applications both increased seed yields compared with application of the entire quantity in autumn. Roberts (1965) also reported that spring N application produced higher seed yields in timothy than fall application.

Lambert (1967) showed that timothy seed yields were increased by split fall-spring applications of 97.5 kg N/ha, but that higher rates of N produced no further increase in yield. Under dryland conditions, application of 292.5 kg N/ha significantly increased seed yields compared with the unfertilized control, but significantly decreased seed yields compared with application of 97.5 kg N/ha. The increase in yield of plots receiving 97.5 kg N/ha was due to increased numbers of florets per head and increased weights of both seed per head and seed per unit area. While head length increased with increasing rates of N under both irrigated and dryland conditions, application of 292.5 kg N/ha to irrigated plots resulted in the production of fewer fertile tillers than no N fertilization. Evans (1954) found that application of 94 kg N/ha reduced fertile tiller numbers of timothy at all application dates.

Roberts (1965) found that application of N in conjunction with post-harvest residue removal had no effect on fertile tiller numbers or on seed yields in timothy.

Meadow fescue seed yields were increased by spring application of 47 kg N/ha, but applications of higher rates resulted in no further increase in yield (Green and Evans, 1956). Roberts showed that N applied in conjunction with autumn residue removal had no significant effect on seed yield of S.215 meadow fescue.

Timing of N application appears to be important with meadow fescue. Roberts (1965) found that spring applications of N resulted in higher seed yields of S.53 meadow fescue than fall applications. Green and Evans (1956) reported no significant difference between seed yields resulting from a single N application in March and the same quantity split equally between March and May applications.

Nordestgaard (1974) concluded that a total of 100-110 kg N/ha should be applied annually for maximum seed production of the meadow fescue cultivar 'Senu Pajbjerg'. Highest seed yields were obtained the first year of production when one-third of the N was applied in autumn and the remainder applied the following spring. Application of a

greater proportion of the total N in autumn resulted in highest seed yields for second year or older seed stands. Increased N application in spring did not fully compensate for failure to apply N the previous autumn.

Highest seed yields of red fescue and colonial bentgrass (*Agrostis tenuis* Sibth.) were obtained when all or a portion of the nitrogen was spring applied (Austenson and Peabody, 1964). However, Nordestgaard (1980) suggests that N application in mid-September prior to the first year of seed production results in highest seed yields in red fescue.

Application of 74 kg N/ha almost doubled seed yields of Kentucky 31 tall fescue in comparison with untreated controls. Autumn and spring applications were equally effective. When soil moisture was excessive, however, application of this rate resulted in considerable lodging, especially when application was delayed until late spring (April 1) (Spencer, 1950).

Application of N increases seed yields in orchardgrass. Spencer (1950) reported that application of 74 kg N/ha effectively doubled seed yields of orchardgrass in comparison with unfertilized controls. Evans (1954) attributed increased orchardgrass seed yields with N fertilization to an increase in fertile tiller production, but Lambert (1963) suggests that seed yield increases in orchardgrass are due to increased seed weight per panicle.

Spring applications are more effective in increasing orchardgrass seed yields than fall applications (Evans, 1954; Green and Evans, 1956; Rampton and Jackson, 1969; Roberts, 1965; Spencer, 1950). Spencer (1950) reported that spring application of 74 kg N/ha significantly increased seed yields compared with autumn application of the same quantity. When soil moisture was excessive, however, application of this rate resulted in considerable lodging, especially when application was delayed until late spring (April 1). Evans (1954) showed that application of 94 kg N/ha in March resulted in higher orchardgrass seed yields than the same quantity applied in September. Splitting the spring application of fertilizer did not significantly increase seed yields compared with a single spring application (Evans,

1954; Green and Evans, 1956). Application of 25% of the N in September and the remaining 75% in March was as effective as application of the entire amount in March. Splitting the applications between autumn and spring decreased seed yields compared with spring applications but increased seed yields compared with fall applications (Evans, 1954; Ramp-ton and Jackson, 1969).

Results of studies by Austenson and Peabody (1964) disagree with those of other researchers. They reported that spring-fall split N applications produced highest orchard-grass seed yields when stands were planted in rows and that fall N applications produced highest yields with solid stands.

Roberts (1965) reported that N applied in conjunction with residue removal had no significant effect on the number of fertile tillers or on orchardgrass seed yields.

Application of N increased seed yields of Massey Basyn Yorkshire fog by an average of 30% compared with unfertilized controls, irregardless of timing of application. Seed yield increases were attributed to an increase in fertile tiller numbers when N was applied at the discontinuation of grazing and to an increase in number of seeds per head when N was applied at inflorescence initiation (Hill et al., 1974).

MATERIALS AND METHODS

Experiments were conducted at the Arthur Post Field Research Laboratory, Bozeman, Montana, and at the Northwestern Agricultural Research Center, Kalispell, Montana, to determine the effects of timing of residue removal and nitrogen fertilization on seed production of Regar meadow brome grass.

Bozeman soils are mainly Amsterdam silt loam, classified in the fine-silty mixed family of Typic Haploborolls. The 15-year precipitation average is 42.70 cm. Precipitation for production of the first seed crop was 49.84 cm, or 7.14 cm above average. Precipitation for production of the second seed crop was 45.80 cm, or 3.10 cm above average.

Kalispell soils are mainly Flathead very fine sandy loam, classified in the coarse-loamy mixed family of Pachic Udic Haploborolls. The 25-year precipitation average for the Kalispell location is 49.68 cm. Precipitation for production of the first seed crop was 63.88 cm, or 14.20 cm above average. Precipitation for production of the second seed crop was 45.85 cm, or 3.83 cm below average.

Regar was seeded in 6.1 m rows in May, 1980, at both locations. Seeding rate was 66 pure live seeds per meter row in accordance with recommendations by Cooper et al. (1978). Row spacing was 60.96 cm, with four rows per plot.

The studies were conducted under irrigation with moisture provided as necessary during the year of establishment. Established stands were irrigated in spring, immediately after harvest, and in fall.

Prior to seeding, 336 kg/ha P_2O_5 (0-45-0) was disked into the seedbed. Weeds were controlled during the year of establishment by hand hoeing.

The experimental design was a randomized complete block with four replications. Thirteen different nitrogen fertilization and residue removal schemes comprised the treatments (Table 1).

Table 1. Description of Treatments Applied to Regar Meadow Bromegrass at Bozeman and Kalispell for Seed Production.

Treatment number	Nitrogen seeding year	Nitrogen established stand	Residue removal established stand
1	0 ¹	0	F
2	0	F	F
3	F	0	F
4	F	F	F
5	0	0	0
6	F	F	0
7	0	F	0
8	F	0	0
9	F	A H	F
10	2 wks	F	F
11	2 wks	S	F
12	F	F	A H
13	F	F	A H + F

¹ 0 = none, F = fall, S = spring, A H = after harvest, 2 wks = two weeks after seedling emergence.

Nitrogen fertilization treatments in both seeding year and for established stands were applications of 84 kg N/ha supplied as ammonium nitrate (34-0-0), hand broadcast onto the soil surface.

Nitrogen was applied two weeks after seedling emergence on May 28, 1980, at the Kalispell location and on June 4, 1980, at the Bozeman location. Fall N was applied during the year of establishment on October 22, 1980, at Kalispell and November 4, 1980, at Bozeman.

Spring, after harvest, and fall N applications in 1981 were made on April 10, August 3, and October 2, respectively, at the Kalispell location. These same applications at Bozeman were made on April 21, August 13, and October 22, respectively.

Spring N applications in 1982 were made on April 23 at the Kalispell location and on May 3 at Bozeman.

Residue removal was accomplished by cutting residue to approximately 5 cm with a flail type forage harvester (Rem Mfg. Co., Swift Current, Saskatchewan). Residue was removed from all plots in fall of the establishment year. After harvest and fall residue was removed from established stands in 1981 on August 3 and October 2, respectively, at Kalispell, and on August 13 and October 19, respectively, at Bozeman.

Seed was harvested on July 22 and 23 in both 1981 and 1982 at Kalispell and on August 2 and 3 in both 1981 and 1982 at Bozeman. Only three replications were harvested at Bozeman in 1981 due to excessive lodging.

Seed was hand-harvested from 4.88 m of the center two rows of each plot. Stems were cut close to the seed head for ease of threshing.

Straw on all plots was swathed to a height of approximately 15 cm following seed harvest. Cut straw was baled and removed from the plots. Two weeks after seed harvest, specific plots were fertilized and all plots were irrigated.

Seed was threshed and cleaned to a minimum purity of 90% using a Hannaford "Seedmaster" resilient taped thresher (Alf Hannaford and Co. Pty. Ltd., Welland, So. Australia). Seed was weighed and yields were calculated in kilograms per hectare.

Data were analyzed using standard randomized complete block procedures. In addition, treatments 1 through 8 were analyzed as a factorial to detect differences due to nitrogen applications in the establishment year, nitrogen applications to established stands, and residue removal from established stands.

RESULTS AND DISCUSSION

Nitrogen application in fall of the establishment year (treatments 3, 4, 6, 8, 9, 12, and 13) resulted in highest Regar seed yields harvested the first seed production year (1981) at Kalispell (Table 2, Figure 1). Regar fertilized two weeks after seedling emergence and in spring preceding the first harvest (treatment 11) produced significantly lower seed yields than fall-fertilized Regar, but significantly higher yields than Regar only fertilized two weeks after seedling emergence (treatment 10) and unfertilized Regar (treatments 1, 2, 5, and 7). Lowest seed yields were produced with no N application during the establishment year (treatments 1, 2, 5, and 7).

Table 2. Mean Seed Yields of Regar Meadow Bromegrass Produced by Different N Application Treatments at Kalispell and Bozeman (1981).

Treatment Number	NSY ¹	NES	RRES	Seed Yield (kg/ha)	
				Kalispell	Bozeman
1	0 ²	0	F	543.62	1,447.59
2	0	F	F	636.71	1,273.57
3	F	0	F	1,326.87	1,401.22
4	F	F	F	1,358.99	1,318.08
5	0	0	0	538.32	1,170.64
6	F	F	0	1,349.36	1,418.77
7	0	F	0	557.83	1,468.95
8	F	0	0	1,365.05	1,415.63
9	F	AH	F	1,288.31	1,421.91
10	2 wks	F	F	919.65	1,118.89
11	2 wks	S	F	1,194.76	1,345.61
12	F	F	AH	1,344.70	1,420.34
13	F	F	AH + F	1,316.36	1,268.13
Mean				1,056.96	1,345.33
LSD (0.05)				193.93	NS
CV (%)				11.91	10.15

¹ NSY = nitrogen seeding year, NES = nitrogen established stand, RRES = residue removal established stand.

² 0 = none, F = fall, S = spring, AH = after seed harvest, 2 wks = two weeks after seedling emergence.

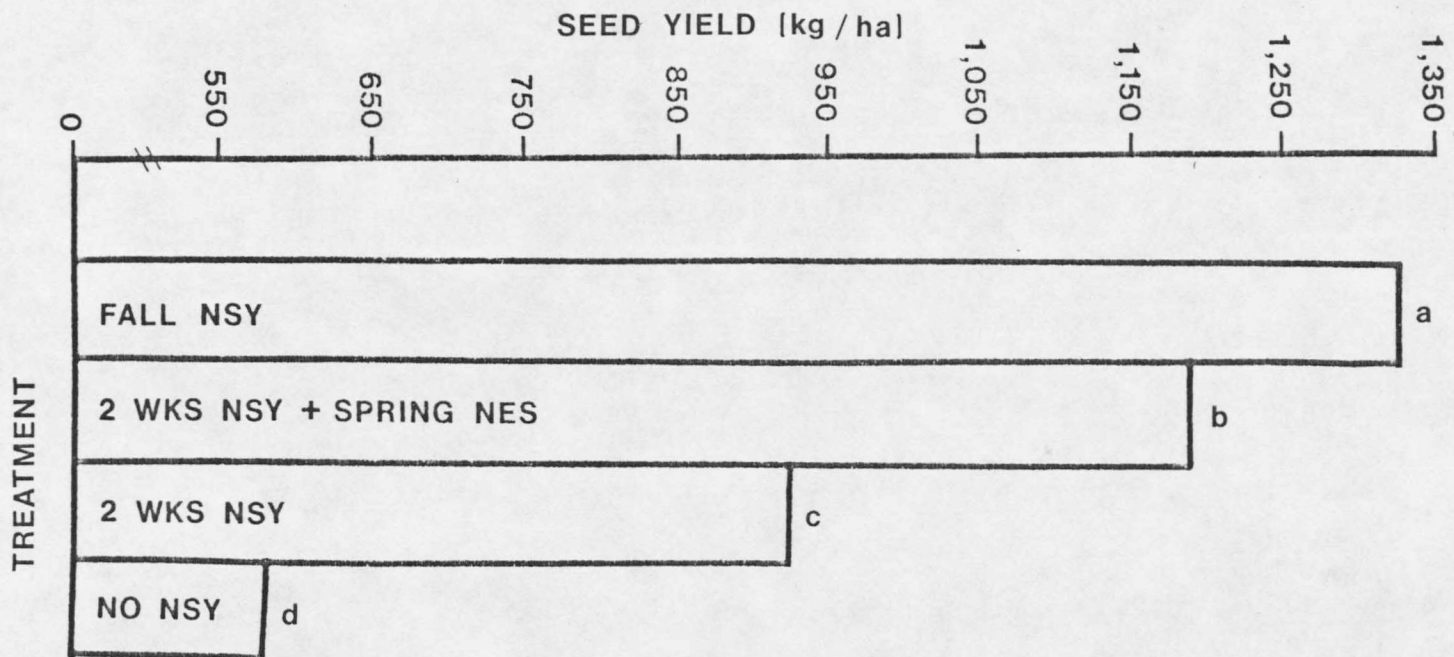


Figure 1. Mean seed yields of Regar meadow brome grass produced by different N application treatments (Kalispell, 1981). NSY = Nitrogen Seeding Year, NES = Nitrogen Established Stand. Means followed by the same letter are not significantly different at the 5% probability level.

Timing of N application during the establishment year was critical in producing high seed yields the first year of production at Kalispell. A single fall application of 84 kg N/ha produced significantly higher seed yields than two 84 kg applications, one applied two weeks after seedling emergence and another in spring preceding the first seed harvest (Figure 1, Table 3). These results are similar to those obtained by Metcalfe (1951), who found fall N application to be more effective than spring application in increasing smooth brome grass seed yields the first seed production year.

Table 3. Mean Squares Showing Significant Effects of Different N Application Treatments on Seed Yields of Regar Meadow Bromegrass (Kalispell, 1981).

Source of Variation	D.F.	MS
Blocks	3	45,610.0
Treatments	12	514,723.9*
F vs 2 wks + S ¹	1	69,487.7*
F vs 2 wks	1	605,733.4*
F vs 0	1	5,982,713.7*
0 vs 2 wks + S	1	1,252,561.3*
0 vs 2 wks	1	393,188.1*
2 wks vs 2 wks + S	1	151,371.0*
Error	36	15,841.4

*Denotes significance at the 5% probability level.

¹ F = fall, 2 wks = two weeks after seedling emergence, S = spring, 0 = none.

Seed yields produced by different N treatments the first year of production at Bozeman were not significantly different (Table 2). Since soil tests were not conducted at either location prior to planting or during the course of the experiment, residual soil nitrate levels during the establishment year are unknown. Soil nitrates may have been adequate to stimulate high seed yields in all plots the first seed production year at Bozeman.

All Regar plots at Bozeman lodged severely approximately one week after anthesis. Lodging was caused by high winds accompanied by heavy rainfall. Excessive vegetative growth induced by residue removal and applied N may also have contributed to the high degree of lodging at Bozeman.

Average seed yields the first harvest year were significantly higher at Bozeman than at Kalispell (Table 2). Differences in precipitation and soil type may account for the difference in seed yields between the two locations. Precipitation for production of the first seed crop at Bozeman exceeded the annual average by 7.14 cm, while precipitation at Kalispell exceeded the annual average by 14.20 cm. Kalispell soils contain a greater proportion of sand than Bozeman soils and are more subject to leaching of nitrates and other mobile nutrients. More soil nitrates may have been leached out of the soil at Kalispell than at Bozeman. A higher initial level of residual soil nitrates at Bozeman than at Kalispell would further increase the difference in seed yields between the two locations.

A lower initial level of residual soil nitrates and/or increased leaching at the Kalispell location might also account for the differences observed between seed yields produced by different N treatments at Kalispell and the lack of differences produced by those same treatments at Bozeman. The effects of differentially applied N on seed yield would become more evident if residual soil N at Kalispell was initially low or made unavailable to the developing root system due to excessive leaching. In contrast, the effects of differentially applied N would be minimal if residual soil N at Bozeman was initially high and remained available to the root system for production of the first seed crop.

Highest seed yields the second production year (1982) at Kalispell were obtained when N was fall applied to established stands in conjunction with fall or after harvest plus fall residue removal (treatments 2, 4, 10, and 13) (Table 4). These results are in accordance with those of Knowles et al. (1951 rev. 1969) and Crowle and Knowles (1962), who reported significant increases in smooth bromegrass seed yields following fall N application and residue removal. Similarly, Evans (1962) and Roberts (1965) found that October residue removal and N application significantly increased seed yields of S.24 perennial rye-grass the second and third seed production years.

Table 4. Mean Seed Yields of Regar Meadow Bromegrass Produced by Different N Application and Residue Removal Treatments (Kalispell, 1982).

Treatment Number	NSY ¹	NES	RRES	Seed Yield (kg/ha)
1	0 ²	0	F	68.91
2	0	F	F	415.76
3	F	0	F	50.96
4	F	F	F	460.54
5	0	0	0	56.47
6	F	F	0	246.60
7	0	F	0	282.55
8	F	0	0	55.67
9	F	AH	F	269.06
10	2 wks	F	F	395.32
11	2 wks	S	F	228.90
12	F	F	AH	355.46
13	F	F	AH + F	458.94
Mean				257.32
LSD (0.05)				99.32
CV (%)				25.05

¹ NSY = Nitrogen seeding year, NES = nitrogen established stand, RRES = residue removal established stand.

² 0 = none, F = fall, 2 wks = two weeks after seedling emergence, S = spring, AH = after seed harvest.

There were no significant differences among seed yields resulting from a single defoliation in fall (treatments 2, 4, and 10) as compared to defoliation after harvest and again in fall (treatment 13) as long as N was fall applied. However, seed yields were significantly lower when residue was removed after harvest only (treatment 12) and N was fall applied (Table 4). Knowles et al. (1951 rev. 1969) reported that seed yields of smooth bromegrass were not significantly different regardless if residue was removed in August, October, or April. Timing of residue removal appears to have been more critical in Regar the second year of production at Kalispell.

Seed yields obtained with fall N application without residue removal (treatments 6 and 7) were significantly lower than those produced by fall N application combined with after harvest (treatment 12), fall (treatments 2, 4, and 10), or after harvest plus fall (treatment 13) residue removal. However, these yields were not significantly different from

those produced by after harvest (treatment 9) or spring (treatment 11) N fertilization and fall residue removal (Table 4).

Factorial analysis of data from treatments one through eight showed significant differences among seed yields the second year of production at Kalispell due to N application and residue removal from established stands (Tables 5 and 6).

Table 5. Mean Seed Yields of Regar Meadow Bromegrass Produced by Different N Application and Residue Removal Treatments (Treatments 1-8) (Kalispell, 1982).

Treatment Number	NSY ¹	NES	RRES	Seed Yield (kg/ha)
1	0 ²	0	F	68.91
2	0	F	F	415.76
3	F	0	F	50.96
4	F	F	F	460.54
5	0	0	0	56.47
6	F	F	0	246.60
7	0	F	0	282.55
8	F	0	0	55.67
Mean				204.68
LSD (0.05)				96.11
CV (%)				31.93

¹ NSY = Nitrogen seeding year, NES = nitrogen established stand, RRES = residue removal established stand.

² 0 = none, F = fall.

Seed yields from established stands receiving fall N (treatments 2, 4, 6, and 7) averaged 351.36 kg/ha, while yields from stands receiving no N (treatments 1, 3, 5, and 8) averaged only 58.00 kg/ha (Figure 2). Similarly, seed yields resulting from fall residue removal (treatments 1, 2, 3, and 4) averaged 249.04 kg/ha, while yields from established stands from which residue was not removed (treatments 5, 6, 7, and 8) averaged only 160.32 kg/ha (Figure 3).

A significant N fertilization by residue removal interaction indicated that seed yields the second year of production at Kalispell were not increased by residue removal from established stands unless residue removal was accompanied by fall N application to established stands (Table 6).

Table 6. Mean Squares Showing Significant Main Effects of Fall Residue Removal and Fall N Application to Established Stands and Significant Interactions on Seed Yields of Regar Meadow Bromegrass (Kalispell, 1982).

Source of Variation	df	Mean Square
Blocks	3	9,037
Treatments	7	116,600*
Fall residue removal vs No residue removal	1	62,970*
Fall nitrogen established stand vs no nitrogen established stand	1	688,500*
Fall residue removal × Nitrogen established stand	1	57,600*
Error	21	4,270

*Denotes significance at the 5% probability level.

Fall residue removal without N fertilization (treatments 1 and 3) resulted in a non-significant increase in seed yields of 3.87 kg/ha over untreated controls (treatments 5 and 8) (Figure 4). Fall N application without residue removal (treatments 6 and 7) resulted in a significant seed yield increase of 208.51 kg/ha over untreated controls (Figure 4). A combination of fall residue removal and N application (treatments 2 and 4) increased seed yields by 382.08 kg/ha over untreated controls, and resulted in a significant seed yield increase of 173.57 kg/ha over yields of stands receiving fall N without residue removal (treatments 6 and 7) (Figure 4). These results agree with those of Pumphrey (1965), who showed that residue removal from established stands of Kentucky bluegrass increased the value of fall N application.

Nitrogen fertilization and residue removal did not prevent the decline in Regar seed yields associated with stand age in Kalispell. Mean seed yields decreased from 1,056.96 kg/ha the first year of production to 257.32 kg/ha the second year of production, a 75% decrease (Figure 5). These results are similar to those obtained by Canode (1968) who found that N neither prevented the decline in Manchar smooth bromegrass seed yields associated with stand age nor compensated for the reduction in seed yield associated with mechanical residue removal.

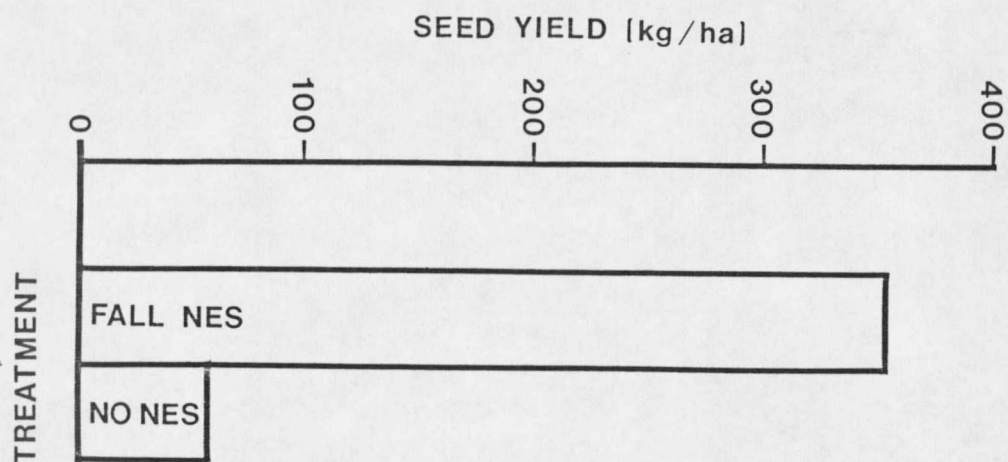


Figure 2. Main effects of fall N application to established stands on Regar meadow brome-grass seed yields (Kalispell, 1982). NES = Nitrogen Established Stand.

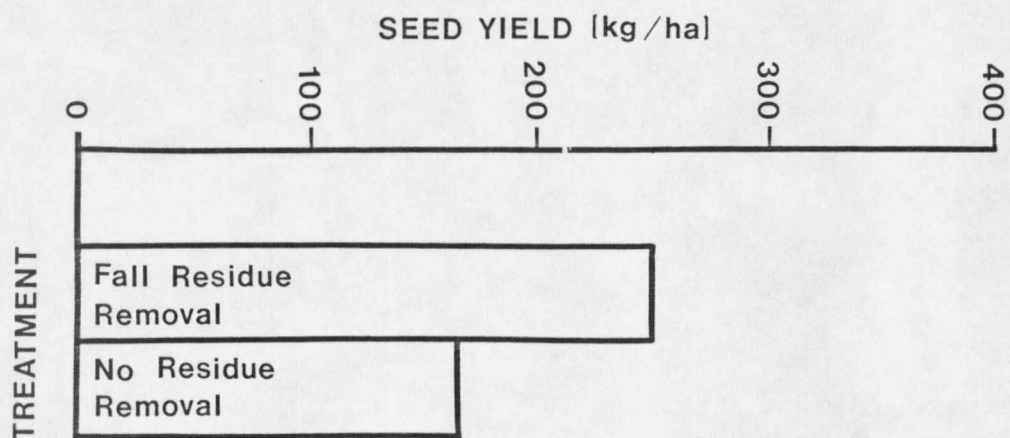


Figure 3. Main effects of fall residue removal from established stands on Regar meadow brome-grass seed yields (Kalispell, 1982).

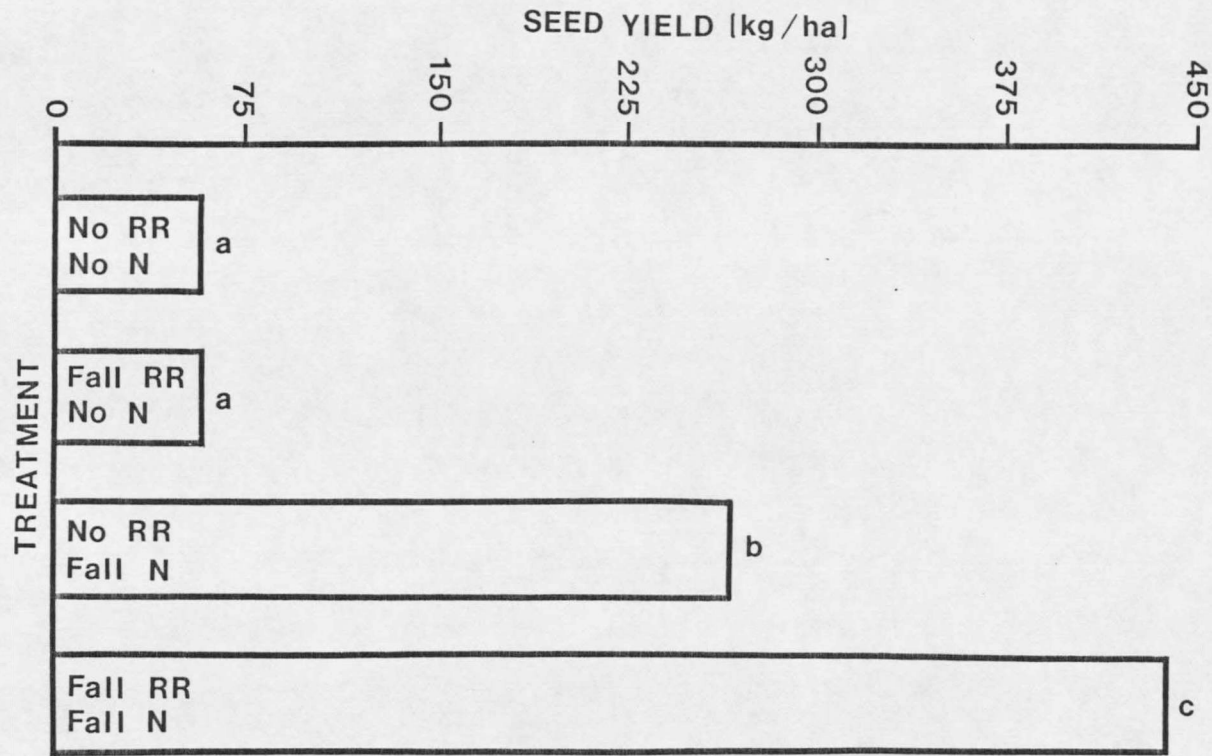


Figure 4. Main effects and interactions of fall residue removal and fall N application to established stands on Regar meadow bromegrass seed yields (Kalispell, 1982).
 RR = Residue Removal from Established Stands, N = Nitrogen Application to Established Stands.
 Means followed by the same letter are not significantly different at the 5% probability level.

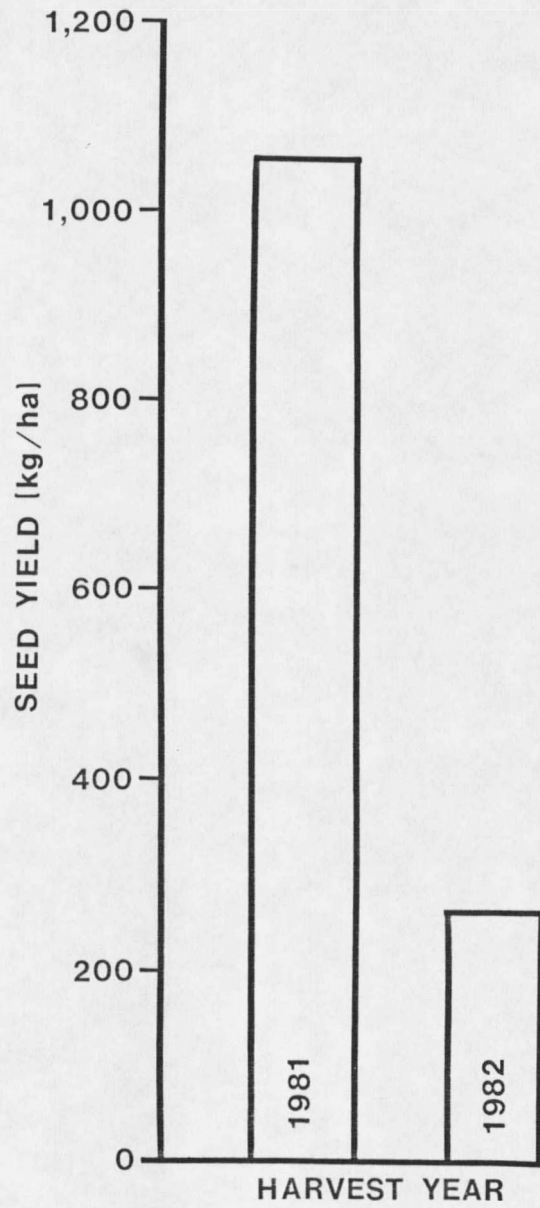


Figure 5. Average Regar meadow brome grass seed yields for two harvest years (Kalispell).

