AN ABSTRACT OF THE THESIS OF

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Title: SEED YIELD AND YIELD COMPONENTS OF PENNFINE PERENNIAL RYEGRASS (*Lolium perenne* L.) AS INFLUENCED BY TIME AND RATE OF SPRING NITROGEN AND CHEMICAL DWARFING

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Abstract approved:
Dr. Harold W. Youngberg

Seed yield in perennial ryegrass is the product of yield components that develop during the life of the plant. Crop yield potential is defined by the number of fertile tillers, spikelets per spike, and florets per spikelet. It has been shown that perennial ryegrass realizes only a small percentage of the potential as harvested seed, and is an inherently poor seed producer as cultivars have been selected primarily for vegetative production or desirable turf characteristics.

The Willamette Valley of Oregon produces nearly all of the perennial ryegrass seed grown in the United States. Environmental conditions during plant growth control potential yield development and the efficiency with which it is used. To increase the efficiency of seed production, it is important to understand the effects specialized cultural management techniques have in this producing region.

In these studies on perennial ryegrass, the effects of varying the amount and time of spring applied nitrogen (N), and the effects of the plant growth retardant paclobutrazol were investigated under field conditions using the cultivar Pennfine. In addition, the influence of high levels of early spring N, combined with growth retardant use was investigated.

Increased tiller densities, the result of higher N level, can result in a greater seed yield potential. However, as tiller densities become greater, the components of seed yield on individual tillers become smaller. In addition, earlier and more severe lodging result in greater tiller mortality and harvest dry weight losses. Split spring applications totaling 120 to 150 kg N ha^{-1} appeared to provide a better balance between compensating yield components, while maintaining an economic seed yield.

Spring application of paclobutrazol delayed the onset and severity of lodging, resulting in an increased number of fertile tillers in the stand, and a greater number of potential seed sites per unit area. Earlier dates of application had a greater effect in reducing lodging in 1983, but no difference was observed between two spring growth stages in 1984. Reduced lodging appears to enhance seed set, resulting in a greater number of seeds recovered at harvest and a higher floret site utilization (FSU). Harvest index was also increased with paclobutrazol.

Application of paclobutrazol significantly increased seed yield, a result of improved seed recovery due to more seeds per spike. However, the increased yield potential resulting from higher N rate was not recovered by application of paclobutrazol where severe lodging conditions occurred prior to the completion of seed filling. Under more normal environmental conditions, 120 kg N ha^{-1}, followed with a growth retardant application, had a significantly greater seed yield than the other treatments.

Seed Yield and Yield Components of Pennfine Perennial Ryegrass (*Lolium perenne* L.) as Influenced by Time and Rate of Spring Nitrogen and Chemical Dwarfing

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William C. Young III

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Professor of Crop Science in charge of major

Redacted for privacy

Head of Department of Crop Science

Redacted for privacy

Dean of Graduate School

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Seed Yield and Yield Components of Pennfine Perennial Ryegrass (Lolium perenne L.) as Influenced by Time and Rate of Spring Nitrogen and Chemical Dwarfing

INTRODUCTION

The Willamette Valley of Oregon is a major producing region for seed crops of cool season grass species. Mild winters and adequate moisture during the growing season favors the survival and early regrowth of perennial grasses following establishment or post-harvest burning. In addition, dry weather in the early summer insures good conditions for pollination, seed filling and maturation, and harvest of high yields. Nearly all the perennial ryegrass seed grown in the United States is produced here.

Perennial ryegrass varieties have been selected primarily for vegetative production or desirable turf characteristics, while seed production has occupied a secondary position. Selection for seed productivity may incur some reduction in the qualities for which the varieties were bred; thus, increases in seed yield will continue to be based upon improvements in agronomic technique. Therefore, it is necessary to know how various cultural practices influence seed yield and yield components.

Estimates of yield potential made by determining the number of floret sites per unit ground area of the crop at peak anthesis, and assuming that each one has the capacity to set a seed, have shown that perennial ryegrass realizes only a small percentage of the potential as harvested seed. The importance of understanding these factors is necessary if the physiologist and the seed grower are to find improved agronomic techniques which result in greater seed yields.

The following three papers examine the effects of varying the amount and time of spring applied nitrogen, and the plant growth retardant paclobutrazol under Oregon conditions. The objectives of these studies were to describe the resulting effects on potential and actual seed yield characteristics, and to identify opportunities for greater efficiency in seed crops through improved management.

REVIEW OF THE LITERATURE

INTRODUCTION

The Willamette Valley of Oregon is a major producing region for seed crops of cool season grass species. Nearly all the perennial ryegrass (*Lolium perenne* L.) seed grown in the United States is produced here. Perennial ryegrass is used for both pasture and turf throughout the world.

Seed yield in grasses is the product of yield components that develop during the life of the plant. Hebblethwaite, Wright and Noble (1980) divided the development of a grass seed crop into two stages: (1) the establishment of the yield potential, and (2) utilization of the yield potential. Yield potential is defined as the number of potential seed sites per unit ground area of the crop at anthesis, and is a function of the number of fertile tillers, spikelets per fertile tiller and florets per spikelet. The utilization of yield potential is determined by events at and after anthesis, i.e., pollination, fertilization and seed growth. These processes determine the number of seeds per spikelet and the mean weight per seed, which together comprise the actual seed yield per unit ground area at harvest.

DEVELOPMENTAL PHYSIOLOGY

Vegetative growth. At the base of each grass tiller, situated at or slightly below the ground level, is the growing point of that tiller. This terminal growing point of the shoot is an apical meristem (Evans and Grover, 1940). The apical growing point and elongating meristematic cylinder of the shoot are for convenience regarded as a "vegetative point" until the inception of the first protuberances of the nascent inflorescence (Evans and Grover, 1940). As growth proceeds the apical meristem begins to elongate and new leaf initials are laid down (Cooper, 1951). Soper and Mitchell (1956) have described the initiation of the perennial ryegrass leaf as a bulge on the side of the apex, and followed the lateral expansion of the bulge to form a collar around the apical culm. Further marginal growth results in a hood overtopping the culm and cell division becomes confined to the base of the young leaf, thus delineating the leaf intercalary meristem (Soper and Mitchell, 1956). During this period of vegetative growth an elongated meristem with lateral primordial ridges may be built up in advance of the expanding leaves (Cooper, 1951). Although this depends on the relative rates of elongation of the shoot apex and expansion of leaf primordia, accumulation of as many as 17 rudimentary leaf fundaments were found in perennial ryegrass (Evans and Grover, 1940).

While the shoot is in the young vegetative condition a tiller bud arises in the axil of each leaf (Mitchell, 1953b). Thus at the same time the earlier leaf primordia are expanding, giving rise to leaf blade and sheath, their axillary buds may grow out as new vegetative tillers (Cooper, 1951). Mitchell (1953b) has shown that with young ryegrass plants in the vegetative phase of development there is little inhibition of lateral buds when the plants are in conditions favoring vigorous growth. When conditions favored a high rate of tillering the axillary bud at each node grew out to a visible tiller when there was one mature and one developing leaf above it (Mitchell, 1953a). Mitchell (1953b) has shown that the inhibition of lateral buds tends to be induced by shading or a reduction of the period of illumination, high temperature or partial defoliation, and concludes that in ryegrass the lateral buds can be regulated by the general level of the energy substrate in the plant.

Reproductive growth. The time when the growing point undergoes the morphological change that definitely marks the initiation of the inflorescence varies with the age of the tiller, with the nutritive and seasonal conditions, with the length of the daily period of illumination, with latitude, and with other factors (Evans and Grover, 1940). The first sign of spikelet initiation is the appearance of spikelet buds in the axils of the leaf primordia, forming the typical "double ridges" (Cooper, 1951). After the appearance of "double ridges," spikelet development extends both up and down the apex, accompanied by suppression of the subtending leaf primordia (Cooper, 1951). The development of florets as secondary buds on the spikelets soon begins, and the apical meristem is transformed into the terminal spikelet of the inflorescence, thus limiting the total number of spikelets (Cooper, 1951). Once reproductive development occurs, tillering virtually ceases and increased plant weight is achieved only by growth of existing tillers (Silsbury, 1966). Furthermore, Evans (1960) has shown that perennial ryegrass has an obligate requirement of at least two weeks vernalization at 4° C before flowering can take place.

Increasing day length or temperature accelerated the development of the inflorescence (Ryle 1965). When long days and high temperature were given together, ears emerged less than two weeks after spikelet initiation. However, rapid initiation of the spike reduced the number of spikelets per spike and florets per spikelet. Spikelet numbers are determined soon after spikelet initials are first visible, and lower temperature appears to increase the number of spikelets developed, possibly because of delay in spikelet initiation. Similarly, lowering the temperature increased the number of florets per spikelet. However, the availability of metabolites presumably sets an upper limit to the number of florets that can be developed by any tiller. When many spikelets are laid down at the onset of reproduction, some restriction on the number of florets each produces may develop during the course of spike differentiation.

Floret site utilization. Although the establishment of yield potential may be considered to be complete at first anthesis, the utilization of yield potential is determined by crop development at and after anthesis (Ryle, 1966). Furthermore, by determining the number of floret sites per unit ground area of the crop at anthesis and assuming that each one has the capacity to set a seed, it has been shown that perennial ryegrass realizes only a small percentage of the potential as harvested seed (Ryle, 1964; Griffiths, Roberts and Lewis, 1973).

Successful pollination does not guarantee seed set, for unless cell division occurs, the ovules eventually shrivel and die. Burbidge, Hebblethwaite and Ivins (1978) showed that, for two varieties of perennial ryegrass, the percentage of florets which set seed reached a maximum value of about 60% three weeks after peak anthesis. However, after reaching this maximum value, the percentage decreased to about 20-30% by final harvest. This is consistent with results reported by Anslow (1963), who observed that only two-thirds of all florets set seed, and by Gangi (1984), who reported initial floret fertility of 61%

and found this to decrease to 20-32% by final harvest. Anslow (1963) further showed that floret site utilization was lower in later emerging heads than in those emerging earlier. In addition, within each inflorescence there was a slight fall in floret fertility in the upper spikelets, compared with those in the middle and at the base of the spike, and a marked reduction in fertility in the outer florets of each spikelet (Anslow, 1963). Anslow (1963) further suggested that lower fertility of florets on the last heads to emerge may result from differences in microclimate (lower illumination and temperature) within the crop.

Seed set, shown by early growth of the embryo and endosperm, indicates the presence of cell division following successful fertilization. However, not all florets are capable of developing seed as anthesis in cross-pollinated grasses is subjected to the environmental conditions at the time of dehiscence (Hill, 1980). Emecz (1961) has shown that threshold values of 14-17^{o} C and 2000-4400 foot-candles for 1.5-2.5 hours are required before anthesis commences. Thus, both light intensity and temperature measured in the vicinity of the plant have a positive effect on anthesis. In addition, Hill (1980) summarized that humidity had no measurable effect on anthesis in grasses except when it altered light conditions, or when it was accompanied by precipitation. Furthermore, poor seed set observed in some grass species may be due to the susceptibility of stigmas to damage by high temperatures and to the desiccation of pollen (Jones and Brown, 1951).

Burbidge, Hebblethwaite and Ivins (1978) have suggested that the loss of seed from the maximum may be attributable to one or both of the following factors: (1) loss of light seed in cleaning and harvesting, and (2) abortion of developing seeds. Anslow (1964) has shown that seed in early heads was 67% heavier than that in late heads, and that the basal florets in each spikelet contained heavier seed than more distal ones. Thus, some light seed would be lost during threshing and cleaning. Burbidge, Hebblethwaite and Ivins (1978) identified two possible reasons why some developing seed may abort: (1) seed growth may be inhibited hormonally, and (2) the crop may be unable to support seed growth at all the pollinated sites and some may abort, enabling the remainder to form viable seeds. During seed development, cell division continues until the embryo has a fully developed scutellum, a stem apex and root initials; a limitation to the supply of assimilates, water and minerals available for transfer to the seed could limit the number of viable seed produced. Furthermore, perennial ryegrass gives a high priority to other sinks in direct competition with developing seeds (Ryle, 1970). Thus, stems, leaves and secondary vegetative tillers are storage sites of assimilate storage, even during the seed development phase (Clemence and Hebblethwaite, 1984). However, it is likely that under conditions for seed crop production, assimilates might not be limiting, but rather the translocation to the seed from storage or directly from photosynthesis of the flag leaf or ear during seed development may be. As previously seen (Anslow, 1964), basal florets are in a more favored position in relation to assimilate supply, as are those inflorescences first to emerge. Thus, intra-plant competition under field culture will influence floret site utilization.

Environmental conditions during seed development are important in maximizing seed filling. Hebblethwaite (1977) has shown perennial ryegrass to be sensitive to soil moisture conditions at a number of growth stages. Irrigation to alleviate moisture deficits which coincided with anthesis increased seed yield by 16% due to an increase in number of seeds per unit area at harvest. Akpan and Bean (1977) conclude that year to year variation in the yield of perennial ryegrass is partly caused by the efficiency with which florets are able to set seed and the size to which each seed develops. Floret fertility was highest at an intermediate temperature regime of 20° C day/15° C night, but the highest seed weight resulted from the lowest temperature regime (15° C/10° C). Thus, air temperature of approximately 20° C should be suitable for efficient floret fertilization, whereas lower temperatures will subsequently be required for seed formation.

Thus the yield of perennial ryegrass is under the control of the environment, and final seed yield is dependent upon time of tiller origin, the proportion of these tillers reaching the reproductive state and the number of fertile florets formed by each inflorescence.

CULTURAL MANAGEMENT

Langer (1980) stated that specialized management techniques required for successful seed production in grass must be based on a sound understanding of the physiology of the plant. The main characteristic of grass seed production is brought about by prolonged periods of tillering, and any management system that is designed to stimulate early tillering and tiller survival should result in improved yields (Langer, 1980). Even though the effect of other yield components should not be underestimated, fertile tiller number is the most important component of seed yield.

Effects of nitrogen (N) fertilizer. If all other elements are not limiting, N is the main nutritional determinant of seed yield in grasses

(Rolston et al., 1985). Most workers have shown positive effects of N fertilizer application on ryegrass seed yield (Ryle, 1966; Hill, 1970; Spiertz and Ellen, 1972; Hebblethwaite, 1977; Hebblethwaite and Ivins, 1977; Brown, 1980, 1981; Hebblethwaite, Wright and Noble, 1980). Youngberg (1980) reported that fertilizer programs have contributed greatly to high seed yield in Oregon, and that N was the most critical element affecting seed production.

Wilson (1959) investigated the influence of time of tiller origin and N level on the floral initiation of perennial ryegrass under high and low N levels. He found that the range of tiller origin from November 29 to February 12 (75 days) was reduced to a range of only nine days in floral initiation. Most tillers originating after March 5 failed to initiate floral structures. Furthermore, high N promoted earlier floral initiation, and under the low N level spike emergence was delayed one week. Thus, while the number of days to floral initiation and ear emergence decreased with later dates of tiller origin, the interval from floral initiation to ear emergence was relatively constant. Lastly, leaf number at ear emergence decreased with later dates of tiller origin.

Ryle (1964) conducted experiments to determine the influence of time of tiller origin and N level on the development and size of the inflorescence in perennial ryegrass. The youngest shoots had about a third fewer primordia than the oldest shoots just prior to spikelet initiation. Nitrogen slightly increased the number of vegetative primordia within date of origin groupings. Differences in the number of primordia before spikelet initiation generally persist throughout inflorescence differentiation; thus, there was a significant decrease in number of spikelets with later date of origin. The influence of date of origin on the total number of florets per inflorescence was also large; tillers arising in the early spring developed only about half as many florets as those originating in autumn and early winter. The rate of N also significantly influenced the number of florets per spikelet; almost every spikelet in the main-stem ear developed two or three more florets than comparable spikelets formed under low N conditions. Thus the initiation of leaf primordia appears unlikely to be affected by shortage of N unless it is acute, while the number of florets per spikelet are more easily influenced by external conditions.

Hill and Watkins (1975) examined the effect of tiller age on tiller survival, ear emergence and seed head components. They reported that tillers formed during the first four months following an autumn sowing in the first year, and also in the immediate post-harvest period in the second year, made the major contribution to the population of seed heads. Tillers formed in March and April produced only 2% of the seed heads. In addition, there was a reduction in spikelet number from early-emerged to late-emerged inflorescences possibly due to a greater number of leaf primordia accumulated on the shoot apices of older tillers, inferring that more sites are available for spikelet initiation. Similarly, early-emerged heads contained more florets than late-emerged heads. Application of N also exerted a strong positive effect on the number of florets formed on individual heads.

Many experiments have studied N application in relation to crop management in an effort to influence the number of tillers that produce heads, and seed number per head. Hill (1970) observed that N application in the spring encouraged the production of new tillers, but did not greatly influence the number of heads produced. However, application at the time of initial seed head formation did influence seed number per head, and later applications increased individual seed weight. Furthermore, delaying part or all of the N to the later stages of inflorescence development could decrease the level and intensity of lodging and increase floret site utilization (Hebblethwaite and Ivins, 1978).

Nordestgaard (1980) has shown that the autumn N requirements for perennial ryegrass are small and that all N should be applied at one time in the spring. In trials which were unfertilized in September, delaying N application in the spring from February 25 to April 29 decreased the number of fertile tillers per unit area. However, this decrease was compensated for by an increase in the calculated number of seeds per fertile tiller, while individual seed weight and seed yield were not significantly affected. The mean of the level of N application across spring dates indicated an optimum level of 135 kg ha^{-1} for perennial ryegrass. Increased seed yield resulting from higher levels of N was mainly attributed to a slight, but often nonsignificant, effect on individual seed weight.

Brown (1980) investigated treatments designed to test whether N applied at stem elongation (nodes 2 cm above tiller base) or at autumn sowing affected seed yield. He found significantly higher seed yields in plots receiving N at elongation than from plots with N only at sowing. However, seed yields did not differ significantly between the N at elongation only treatment and the N at sowing plus elongation treatment. Furthermore, these results indicated that vegetative differences did not necessarily manifest themselves as similar reproductive differences, and that large differences in floret populations were not reflected in similar differences between seed yields. He concluded that a low to moderate population of large seed heads with relatively few florets per spikelet but with high rates of seed recovery would seem ideal for increasing seed yield.

Hebblethwaite and Ivins (1977) investigated the level of application of N at 0, 40, 80, 120, 160 and 200 kg ha^{-1} at spikelet initiation in perennial ryegrass. Maximum seed yields were achieved at about 80-120 kg N ha^{-1}; further increases in application decreased seed yield. A number of possible reasons were cited for reduced seed yields at higher levels of N. Although the number of spring produced tillers increased, the number of fertile tillers was not significantly affected; thus, those tillers destined to become fertile had to compete with vegetative tillers that subsequently died. Secondly, growth tended to be more lush and lodging started earlier and was more severe, especially at anthesis. Lodging created a micro-climate within the crop canopy that was not favorable for pollination and percent seed set was decreased. Increasing the level of N up to 160 kg ha^{-1} significantly increased the number of florets per spikelet; however, this increased potential was only reflected in increased seed number per spikelet and per unit area up to 120 kg ha^{-1}. Earlier and more severe lodging and greater competition among tillers were again listed as reasons for poor seed set at high levels of N. Correlation coefficients between all seed yield components and seed yield found only seed numbers per spikelet and per unit area were significantly related. In these experiments the individual seed weight was remarkably stable. Hebblethwaite and Ivins

(1977) concluded that improvement in seed set is the most important single factor which is likely to increase yield.

Hebblethwaite and Ivins (1978) continued their N studies in perennial ryegrass by investigating the timing of nitrogen application. In this study, N rate was held constant at 120 kg ha^{-1}, while six different times of application were employed: 1) spikelet initiation, 2) floret initiation, 3) 30% ear emergence, 4) 70-80% ear emergence, 5) peak anthesis and 6) split between spikelet initiation and 30% ear emergence. When N was applied at spikelet initiation the maximum production of vegetative tillers was higher and occurred earlier in the season than in treatments where N application was delayed until 70-80% ear emergence. However, the later the date of application, the greater the reduction in fertile tiller numbers. In addition, delaying the application of N fertilizer in the spring slightly reduced the number of spikelets per spike, but significantly decreased the number of florets per spikelet. Florets per unit area, and therefore yield potential similarly decreased, although the percentage seed set was increased. Increased seed set where N application was delayed may be due to delays and decreases in the severity of lodging, or a reduction in competition for metabolites between developing seeds. Individual seed weight was found to increase with delayed N application. However, evidence from the final seed harvest suggested that if N application was delayed until 30% ear emergence or later, yields were reduced. Thus any advantages obtained by delaying N application are outweighed by decreases in other yield components. No advantages were found by splitting N application between initiation an 30% ear emergence.

Chemical control of lodging. Lodging results from the development of tillers which have insufficient stem strength to support their own weight. In perennial ryegrass seed crops lodging can decrease the efficiency with which potential yield is utilized (Hebblethwaite, Burbidge and Wright, 1978; Burbidge, Hebblethwaite and Ivins, 1978). In Oregon, lodging reduced seed yield due to greater fertile tiller mortality and a fewer number of seeds per spike (Hunter 1985).

Hebblethwaite, Burbidge and Wright (1978) investigated the effects of lodging on seed yield and yield components of perennial ryegrass by mechanically supporting the crop with wire. Prevention of lodging increased seed yield up to 61% due to a higher number of seeds per unit ground area. In addition, where the onset of lodging was delayed by supporting the crop only until the end of anthesis, the seed yield increase obtained was intermediate between the naturally lodged treatments and those treatments supported throughout. These results indicate that lodging may affect both pollination and seed development.

Concurrent with the above study, Burbidge, Hebblethwaite and Ivins (1978) investigated the influence of lodging on floret site utilization. Examination of florets between peak anthesis and harvest revealed that, whereas up to 60% of the potential seed sites (florets) at anthesis may be pollinated, less that 25% of these ultimately contain a seed at harvest. However, this proportion was always higher when the crop was erect than when it was lodged.

If a stand is lodged at anthesis, pollen dispersal can be inhibited, resulting in a poor seed set (Anslow, 1963). The microenvironment in a lodged canopy facilitates fungal attack on the inflorescence, reducing seed yield (Griffiths, 1967). Lodging also is thought to restrict light interception, reducing current photosynthate to the developing head and contributing to sterile florets (Spiertz and Ellen, 1972).

Plant breeders have been very successful in recent years in improving production under intense management conditions with the introduction of semi-dwarf cultivars in a number of crop species (Jennings, 1976). The reduction in plant height associated with semi-dwarfism and the subsequent decrease in lodging is thought to be the major reason for increased yields in small grains (Marshall and Murphy, 1981). In contrast, however, grass breeders are primarily concerned with forage or turf qualities, which are not always well correlated to seed yield (Griffiths, Lewis and Bean, 1980).

Cultural practices to control lodging, such as altering the amount and time of N application (Hebblethwaite, 1977), and grazing and defoliation (Green and Evans, 1956; Roberts, 1965) have been examined, but results have been variable. Thus, the only alternative appears to be the use of growth retardant chemicals which will decrease straw length and consequently lodging (Hebblethwaite, Burbidge and Wright, 1978).

Hebblethwaite and Burbidge (1976) successfully decreased lodging in perennial ryegrass with maleic hydrazide, a chemical that inhibits cell division and suppresses apical dominance. However, it also was found to inhibit the formation of reproductive organs, and thereby reduced all yield components, seed yield and germination percentage.

The effect of chlorocholine chloride (CCC) has also been investigated in a series of field experiments on perennial ryegrass (Hebblethwaite and Burbidge 1976). CCC is a growth retardant that inhibits gibberellin biosynthesis, and reduces cell division in internode regions without affecting the apical meristem (Harada and Lang, 1965). Although it is widely used in Europe to prevent lodging in cereal grains, results with perennial ryegrass showed that CCC had no significant effect on lodging or total straw length, thus no effect on yield was observed (Hebblethwaite and Burbidge, 1976).

Wright and Hebblethwaite (1979) found greater success with an application of the growth retardant compound ancymidol, which reduced culm length and delayed lodging in perennial ryegrass. The result was a seed yield increase of up to 60% by increasing the number of seed per unit ground area. The application of ancymidol on a commercial scale is not practical, however, due to the high cost of the chemical, which is formulated for use on nursery ornamentals (Hebblethwaite, Hampton and McLaren, 1982).

More recently evidence has been accumulating for the plant growth retardant paclobutrazol. Unlike CCC or ancymidol, which are mainly foliage active chemicals, paclobutrazol is a soil active, xylem mobile compound which inhibits gibberellin biosynthesis (Shearing and Batch, 1982). Foliar uptake is regarded as being of little importance as paclobutrazol accumulates in leaf tissue and little reaches the meristematic area of cell division and extension (Froggatt, Thomas and Batch, 1982). Hampton and Hebblethwaite (1984) have shown the requirement for water before paclobutrazol is taken up by the root system and growth retardant properties are exhibited in perennial ryegrass.

Hebblethwaite, Hampton and McLaren (1982) found paclobutrazol to have effects similar to ancymidol upon lodging and seed yield of perennial ryegrass. Application of paclobutrazol at the floret initiation stage resulted in 27% to 50% increases in seed yield, attributed to more seeds per spikelet and seeds per unit area. Fertile tiller number was not affected by paclobutrazol at any stage of development. Straw weight was not significantly affected by paclobutrazol but harvest index was increased which implies a more efficient partitioning of dry matter into seed yield. Yield component responses to paclobutrazol application differ according to the crop growth stage and rate of chemical, and the year in which application is made. However, in all cases seed yield increases are a direct result of increases in seeds harvested per unit area (Hebblethwaite, 1987).

Hampton and Hebblethwaite (1985a) found that paclobutrazol applied to perennial ryegrass at the spikelet initiation stage of growth increased seed yield due to an increased production of fertile tillers in two years (1981 and 1982), and an increased number of seeds per spikelet in the second year. Seed yield increases were significantly greater at a rate of 2.0 kg a.i. ha^{-1} than at lower rates. Lodging was prevented completely by the 2.0 kg rate, delayed until after anthesis by the 1.0 kg rate, and began before anthesis with the 0.5 kg rate. In addition, paclobutrazol reduced stem internode length and strengthened the base of the stem. These data showed that fertile tiller survival did not differ markedly between lodged and non-lodged plots, and that differences at final harvest resulted from increased tiller production following paclobutrazol application.

Hampton and Hebblethwaite (1985b) reported that an application of the growth retardant paclobutrazol, at 2.0 kg a.i. ha^{-1} to plots of perennial ryegrass at spikelet initiation, significantly increased the number of seeds per spikelet present at final harvest by reducing the number of seed aborted during seed development. Both basal and penultimate spikelets contained more florets and seeds than did those of untreated plants. Assimilate recovery was significantly lower from the terminal section of the ear in the untreated plants. And in a subsequent study, Hampton, Clemence and Hebblethwaite (1987) reported that prevention of lodging with paclobutrazol increased assimilate movement to the ear from the flag leaf.

Seed yield increased 49% to 109% on a six year old and first year crop of Pennfine perennial ryegrass, respectively, following paclobutrazol application during floret initiation stage of growth at 0.67 kg a.i. ha^{-1} (Chilcote, Youngberg and Albeke, 1982), primarily due to increased numbers on fertile tillers and more harvested seeds per inflorescence.

Hunter (1985) studied the effects of paclobutrazol upon tillering, lodging, dry matter partitioning in perennial ryegrass; he observed delayed lodging by restricting stem elongation. This effect was concentrated in the basal internodes where both internode length and weight were reduced. Paclobutrazol significantly delayed lodging and reduced tiller mortality, which resulted in more fertile tillers at harvest in treated plots.

Hampton, Clemence and Hebblethwaite (1983) investigated the influence of N rates and paclobutrazol upon seed yield. N application increased the number of fertile tillers in one study (1981) but spikelets per tiller were reduced as N applications increased. Seed number per spikelet usually decreased with increased N applications. Seed yield increased by the same amount in paclobutrazol treated plots regardless of N levels when compared to untreated plots at the same N rate.

CONCLUSIONS

Griffiths, Roberts and Lewis (1973) in their review on the seed potential of grasses state that:

> The maximizing of seed yields is very much a matter of synchronizing management practices with environmental influences. Cold, dry weather in the early spring militates against the beneficial effects of timely nitrogen application, whilst wet periods, if they coincide with the critical phases of anthesis and seed set, can act against the effectiveness of all previous good managements. It is only when the seed producing plant is in harmony with its natural and imposed environment throughout the growing and harvesting seasons that the grower will be ensured of high yields.

Thus, the overall problem of seed production remains one of continuing to research specialized cultural management techniques to help insure profitable production for seed growers.

MANUSCRIPT I

The Influence of Time and Rate of Spring Applied Nitrogen on Seed Yield and Yield Components of *Lolium perenne* L. cv. Pennfine

The Influence of Time and Rate of Spring Applied Nitrogen on Seed Yield and Yield Components of *Lolium perenne* L. cv. Pennfine

INTRODUCTION

Seed yield in grasses is determined by the number of reproductive tillers per unit area, number of spikelets per inflorence, number of florets per spikelet, and the individual seed weight (Hebblethwaite, Wright and Noble, 1980). By determining the number of potential floret sites per unit ground area of crop at anthesis and assuming that each one has the capacity to set a seed, it has been shown that perennial ryegrass realizes only a small percentage of the potential as harvested seed (Ryle, 1964; Griffiths, Roberts and Lewis, 1973). Therefore it is important to develop more detailed knowledge of the plant, and to identify management practices appropriate for environmental and soil conditions found in Oregon, if economic yields of perennial ryegrass seed are to be obtained.

In perennial ryegrass floral induction occurs under the influence of low temperatures and short days (Evans, 1960). As temperature and day lenght increase, induced tillers begin initiating reproductive structures (Cooper, 1951). The onset of floral initiation depends on the photoperiodic requirement of each cultivar, but it may be modified to a certain extent by temperature levels in the spring (Langer, 1980). Although external factors are capable of affecting the physiological events leading up to seed formation, the question from the point of view of the producer is to what extent the components of yield can be modified by appropriate management.

Nitrogen (N) is the most critical element affecting seed production in Oregon (Youngberg, 1980). Seed crop yields of perennial ryegrass are increased by N fertilization, regardless of the time of application; however, the size of the response, and more particularly the efficiency of a given amount of N can vary with timing (Brown, 1980; Hebblethwaite and Ivins, 1978; Hill, 1970; Nordestgaard, 1980). Optimum levels of N for perennial ryegrass have been quoted between 70-120 kg ha^{-1} (Hebblethwaite and Ivins, 1977), 135 kg ha^{-1} (Nordestgaard, 1980), and 124-157 kg ha^{-1} (Youngberg, 1980). Hebblethwaite and Ivins (1977) reported that increasing the level of N applied to perennial ryegrass increased the potential yield, but not necessarily the actual seed yield. Severe lodging, competition of a large number of vegetative tillers, and lower percentage floret site utilization (FSU) contributed to reduced efficiency.

Nitrogen fertilizer management used in perennial ryegrass seed production should be related to the morphological and physiological stage of the crop (Hill, 1972). Hill (1972) reported increased seed yield from splitting N between an autumn and spring application; however, Brown (1980) and Nordestgaard (1980) both recommend that N be applied in the early spring for maximum seed yield. Langer (1980) has reported that it is the number of spikes at harvest which have the most importance influence on seed yield, and that it is possible for a reasonably large proportion of spring-formed tillers to become fertile. Other researchers have observed an increased floret density via a greater number of florets per head following N at floret initiation (Brown, 1980), and increased seed weight following later spring N applications (Griffiths, Roberts and Lewis, 1973). However, Hebblethwaite and Ivins (1978) found no advantage for splitting applications of spring N between apex initiation and ear emergence.

Seed growers in the Willamette Valley of Oregon traditionally apply 34-45 kg N ha^{-1} in the autumn and 90-112 kg N ha^{-1} in the spring split 50% in March and 50% in April (Youngberg, 1980). The level of autumn applied N is usually increased if fields are to be grazed during the winter, and may be eliminated if soil tests indicate sufficient residual from previous N is available.

This research was designed to study the time and rate of spring N application in relation to two developmental growth stages: (1) before apex initiation, during vegetative growth, and (2) after spikelet initiation, during reproductive development. Objectives were to determine for Pennfine perennial ryegrass grown in the Willamette Valley of Oregon, USA.:

(1) the contribution of spring formed tillers to final seed yield;

(2) the effect on yield components per tiller (spikelets per spike, florets per spikelets, and individual seed weight);

(3) the efficiency of seed production by describing the resulting effects on potential and actual seed yield.

MATERIALS AND METHODS

Experiments were conducted for two years on a first (1982) and second (1983) year seed crop of perennial ryegrass, using the cultivar Pennfine. The stand was located on a Woodburn silt loam soil at Oregon State University's Hyslop Crop Science Field Laboratory, approximately 10 km northeast of Corvallis. Soil in this series has 0-3% slope with an available water capacity of 30-33 cm. Permeability is slow, and rooting depth is somewhat restricted by a seasonal water table in the winter and spring. In a representative profile the surface layer is a very dark greyish-brown and dark-brown silt loam about 40 cm thick. The subsoil is dark-brown silt loam and silty clay loam that extends to a depth of 150 cm or more (Knezevich, 1975).

The experimental site, which had been fallowed for two years, was disked, harrowed, and rolled in May 1981. Oregon Certified Pennfine perennial ryegrass was seeded with a John Deere precision plate planter in rows 30 cm apart at a seeding rate of 6.0 kg ha^{-1} on 29 May. Irrigation was used on 9 July and 13 August (10 cm at each date) to insure a uniform stand establishment. Standard weed control practices used during establishment included bromoxynil at 0.56 kg a.e. ha^{-1} on 23 June, and a tank mix of 2,4-D low volatile ester at 0.56 kg a.e. ha^{-1} plus dicamba at 0.28 kg a.e. ha^{-1} on 13 July 1981. All other weed management followed cultural practices of Willamette Valley seed growers. These broadcast applications included atrazine at 1.35 kg a.i. ha^{-1} in mid-October of 1981 and 1982, and a tank mix of 2,4-D low volatile ester at 0.56 kg a.e. ha^{-1} plus dicamba at 0.28 kg a.e. ha^{-1} mid-February of 1982 and 1983. In addition, the fungicide triadimefon at 0.28 kg a.i. ha^{-1} was applied to all plots during mid-May and early-June of 1982 and 1983 for control of rust (*Puccinia* spp.).

Broadcast applications of ammonium phosphate-sulfate fertilizer (16-20-0-15) were used in late-October at a rate of 300 kg ha^{-1} in the establishment year (1981), and 200 kg ha^{-1} following harvest of the first year seed crop (1982). The soil profile was sampled in early-February, before spring N treatments were applied in both 1982 and 1983, at three horizons: 0-30, 30-60 and 60-90 cm. In 1982, seven soil cores were randomly taken from each of four blocks and bulked. Laboratory analysis showing pH and ppm P, K, NH_4-N, and NO_3-N for the 0-30 cm profile, and ppm NH_4-N and NO_3-N for the 30-60 and 60-90 cm profiles are presented in Table I.1.

Spring N treatments included all possible combinations of four rates of nitrogen (0, 60, 90 and 120 kg N ha^{-1}) at two spring dates of application, based on morphological stage of development (vegetative and spikelet initiation). Thus, 16 factorial treatments were arranged in randomized complete blocks and replicated six times in both 1981-82 and 1982-83 crop years (Table I.2.). Plot size was 2.5 x 6.0 m. All N treatments were applied using a calibrated, hand driven Gandy spreader. Calendar dates for N applied during the vegetative growth stage (Veg. N) were 4 March 1982 and 24 February 1983. Similarly, N after spikelet initiation (S.I. N) was applied on 29 March 1982 and 24 March 1983. Ammonium nitrate (34-0-0) was the source of all spring applied N in both years.

Straw residue was removed immediately following seed harvest in 1982, and stubble was subsequently removed to a height of 2.5 cm using a close-clipping technique described by Young, Youngberg and Chilcote

Table I.1. Soil test values from the experimental site, February 1982. Values are the mean of four blocks.

Profile	pH	P	K	NH_4-N	NO_3-N
(cm)			------------ (ppm)	----------------	
0-30	5.6	81	255	1.7	1.3
30-60	-	-	-	1.6	1.2
60-90	-	-	-	2.4	2.8

Table I.2. Factorial presentation of time and rate of spring applied N treatments in 1982 and 1983.

		S.I. N[2] (kg ha^{-1})			
		0	60	90	120
Veg. N[1] (kg ha^{-1})	0	0 + 0	0 + 60	0 + 90	0 + 120
	60	60 + 0	60 + 60	60 + 90	60 + 120
	90	90 + 0	90 + 60	90 + 90	90 + 120
	120	120 + 0	120 + 60	120 + 90	120 + 120

[1] Veg. N = N applied during the vegetative growth stage.
[2] S.I. N = N applied after spikelet initiation growth stage.

(1984). Before spring N treatment in 1983, soil cores were randomly taken, as described above, from three treatments made in the previous spring totaling 0, 120, and 240 kg N ha^{-1} (0 + 0, 60 + 60, and 120 + 120 kg N ha^{-1}, respectively) in all four blocks. No significant differences were observed (Table I.3); thus, 1983 N treatments were made using the same randomization within each block as for the previous year.

The growth stages were determined by microscopic examination of the shoot apex following dissection of the apices of 10 primary tillers. The timing of these stages was recorded when seven of the 10 tillers were at the appropriate stage.

Peak anthesis was determined by examining fertile tillers in the field when anther exertion began, and was defined as the time when seven of 10 randomly selected fertile tillers had exerted anthers. The tiller population at peak anthesis was described by cutting, at the soil level, all plant material from two 0.1 m^2 quadrats. Samples were placed in large paper bags and put into a forced air drier at 50° C for approximately 48 hours. Subsequently, tillers were removed and separated into classes based on their maturity. Tillers were described as fully-emerged reproductive, late-emerged reproductive (spikes not fully emerged from the boot), and vegetative. The number of spikelets per spike was counted on a subsample of 10 randomly selected late-emerged and full-emerged tillers. Floret number per spikelet was determined by counting the florets in two spikelets positioned at the bottom, middle, and top of four randomly selected fully-emerged spikes. The mean number of florets per spikelet from all locations (bottom, middle, and top) was taken as the number of florets per spikelet. The number of fertile tillers at maturity was determined from two additional

Table I.3. Soil test values from the experimental site, February 1983. Values are the mean of four observations.

Profile 1982 N rate	pH	P	K	NH_4-N	NO_3-N
(kg N ha^{-1})		------------	(ppm)	--------------	
0-30 (cm)					
0	5.6	70	218	2.5	1.5
60	5.6	76	199	2.1	1.7
120	5.6	67	213	2.1	1.9
LSD .05	NS	NS	NS	NS	NS
30-60 (cm)					
0	-	-	-	2.0	0.7
60	-	-	-	2.4	0.7
120	-	-	-	3.0	0.7
LSD .05				NS	NS
60-90 (cm)					
0	-	-	-	2.8	0.6
60	-	-	-	2.9	0.6
120	-	-	-	3.0	0.8
LSD .05				NS	NS

0.1 m^2 quadrats cut immediately before seed harvest. Potential yield, defined as the number of florets per unit area, was calculated as:

florets per spikelet x spikelets per spike
x fertile tillers (per unit area) at maturity.

Beginning with the onset of lodging, visual estimates of lodging were made. Lodging was scored in both severity and area affected. Lodging severity rated the degree of leaning in the lodged portion of the plot, with a lodging score of "1" indicating an upright canopy and "5" indicating a totally flat canopy. The area lodged was estimated as the percentage of the total plot area affected.

The fate of all tillers between peak anthesis and maturity was evaluated by expressing the number of fertile tillers at maturity as a percentage of the total number of tillers at anthesis:

$$\frac{\text{total tillers at peak anthesis}}{\text{total fertile tillers at maturity}} \times 100$$

Seed yield was determined by harvesting a 1 x 5 m section from the middle of each plot using a small-plot harvester. Plot harvest in both years was carried out at 40% seed moisture content, on 6 July 1982 and 10 July 1983. The harvested material was placed in large burlap bags and allowed to air dry for approximately two weeks, while suspended on a wire line. Samples were placed is a forced air drier at 35° C for 12 hours prior to threshing with a belt thresher. Threshed seed was scalped and run through an air screen machine to remove chaff. Clean seed was weighed, and then divided using a seed divider to produce a random seed sample. This sample was used to determine 1000 seed weight by using an electronic seed counter and scale.

The actual number of seeds per unit area achieved at harvest was calculated by dividing the clean seed weight by the individual seed weight. Floret site utilization (FSU) was calculated as the ratio of actual seed number to potential seed number, expressed as percent:

$$\frac{\text{actual number of seed harvested}}{\text{potential number of seed at anthesis}} \times 100$$

Harvest index, defined as the ratio of economic yield to biological yield, expressed as percent, was calculated as:

$$\frac{\text{weight of clean seed at harvest}}{\begin{array}{c}\text{weight of above ground biomass cut and}\\ \text{bagged at final harvest}\end{array}} \times 100$$

In the analysis of variance (ANOVA) main effects were tested for a linear or non-linear relationship using contrasts. Orthogonal polynomial coefficients were used to solve the regression for the three rates (60, 90, and 120 kg N ha^{-1}), and in addition, compare the 0 rate vs. the N treatments at both growth stages. (The ANOVA table and contrast coefficients used are shown in Appendix Table 1.)

RESULTS

Tiller number. Rapid vegetative growth occurred following the application of N during vegetative development. In 1982 total tiller number at peak anthesis was significantly greater than where no early N was applied, primarily due to a greater number of vegetative tillers in the stand (Table I.4). Both total tiller number and vegetative tiller number showed a linear increase with increasing level of N. However, no difference was observed in the number of late-emerged or fully-emerged fertile tillers.

Similar data from the 1983 seed crop found a greater total number of tillers following N applied during vegetative development (Veg. N); this effect was curvilinear at the highest rate (Table I.5). Late-emerged tillers increased slightly over where no early N was applied. Similarly, the number of fully-emerged fertile tillers was slightly greater in comparison to no early N, and as with the total number of tillers, the rate effect was curvilinear.

Nitrogen applied after spikelet initiation (S.I. N) had less effect on tiller population at anthesis in both 1982 and 1983, than did Veg.N (Tables I.4 and I.5). Only slightly more vegetative tillers resulted in 1982 than where no N at spikelet initiation was applied. Also observed was an indication of an optimum response at 90 kg N ha^{-1} for maximum number of fully-emerged fertile tillers (Table I.4). However, no such effect was observed in 1983, although the total tiller number was significantly greater following N application after spikelet initiation (Table I.5). This result appears due to the significant interaction between Veg. N and S.I. N on vegetative tiller number in the stand at peak anthesis (Table I.6). Higher levels of Veg. N in combination with

Table I.4. Influence of N applied during vegetative stage of growth (above) and N applied after spikelet initiation (below) on tiller number at peak anthesis, 1982.

Time and Rate of Spring N	Tiller Number at Peak Anthesis			
	Total	Veg.	Late	Fertile
	------------(per m^{-2})------------			
Veg. N (kg ha^{-1})				
0	2787	401	568	1817
60	3034	553	615	1866
90	2983	512	595	1876
120	3362	753	594	2015
Veg. N Contrasts[1]				
Check vs. treatment	**	**	NS	NS
Linear	*	*	NS	NS
Quadratic	($P< 0.1$)	NS	NS	NS
S.I. N (kg ha^{-1})				
0	2943	456	618	1869
60	3023	564	600	1859
90	3126	544	570	2012
120	3074	655	583	1835
S.I. N Contrasts[1]				
Check vs. treatment	NS	($P< 0.1$)	NS	NS
Linear	NS	NS	NS	NS
Quadratic	NS	NS	NS	($P< 0.1$)

[1] Orthogonal contrasts significant at $P< 0.01$ (**), $P< 0.05$ (*), and the 0.1 probability level ($P< 0.1$).

Table I.5. Influence of N applied during vegetative stage of growth of (above) and N applied after spikelet initiation (below) on tiller population, 1983.

Time and Rate of Spring N	Tiller Number at Peak Anthesis			Spikes at Maturity
	Total	Late	Fertile	
	(per m^{-2})			
Veg. N (kg ha^{-1})				
0	1893	279	1402	1959
60	2000	358	1426	2114
90	2324	350	1692	2102
120	2218	366	1531	2102
Veg. N Contrasts				
Check vs. treatment	**	($P < 0.1$)	($P < 0.1$)	NS
Linear	*	NS	NS	NS
Quadratic	*	NS	*	NS
S.I. N (kg ha^{-1})				
0	1959	319	1425	2088
60	2182	337	1576	2041
90	2150	342	1558	2253
120	2142	354	1491	1894
S.I. N Contrasts				
Check vs. treatment	*	NS	NS	NS
Linear	NS	NS	NS	NS
Quadratic	NS	NS	NS	*

higher levels of S.I. N generally resulted in a greater number of vegetative tillers.

The number of spikes at maturity was not affected by N applied during vegetative growth in 1983, although an optimum response was observed when 90 kg N ha^{-1} was applied after spikelet initiation (Table I.5). However, in 1982 a significant interaction between Veg. N and S.I. N for number of spike at maturity resulted (Table I.7). These data suggest that at low rates of Veg. N (0-60 kg N ha^{-1}), increased levels of S.I. N will result in a greater number of spikes. However, when Veg. N at higher levels (90-120 kg N ha^{-1}) is followed by an increased rate of S.I. N, the number of spikes is reduced.

Spikelets per spike and florets per spikelet. In 1982 there was no effect from either Veg. N or S.I. N on the numbers of spikelets per spike (Table I.8). Floret number was only slightly higher in spikelets along the middle region of the spike when early N was applied, whereas N after spikelet initiation significantly increased the number of florets per spikelet throughout the length of the spike. In 1983 there was an increased number of florets per spikelet regardless of time of application (Table I.9). This effect was linear across the range of N rates studied. However, only N applied during vegetative growth increased the number of spikelets per spike.

Potential yield. The number of florets per unit area at peak anthesis (potential yield) was not strongly influenced by the time or rate of N application in 1982. Nitrogen applied during vegetative development showed a positive linear trend with increased rate, and a slightly greater potential yield resulted from N applied after spikelet initiation (Table I.10). The actual number of clean seed per unit area

Table I.6. Interaction of N applied during vegetative stage of growth and N applied after spikelet initiation on vegetative tiller number per m^{-2} at peak anthesis, 1983.

Veg. N (kg ha^{-1})	S.I. N (kg ha^{-1}) 0	60	90	120	mean
0	149	255	244	203	213
60	224	201	212	226	216
90	289	187	366	289	283
120	201	434	179	470	321
mean	216	269	250	297	

LSD .05 for intermeans = 185

Table I.7. Interaction of N applied during vegetative stage of growth and N applied after spikelet initiation on fertile tiller number (spikes) per m^{-2} at maturity, 1982.

Veg. N (kg ha^{-1})	S.I. N (kg ha^{-1}) 0	60	90	120	mean
0	2395	2391	2888	2668	2586
60	2619	2567	2761	2228	2544
90	3037	2872	2379	2345	2658
120	2578	2673	2686	2928	2716
mean	2657	2626	2678	2542	

LSD .05 for intermeans = 492

Table I.8. Influence of N applied during vegetative stage of growth (above) and N applied after spikelet initiation (below) on inflorescence yield components, 1982.

Time and Rate of Spring N	Spikelets per Spike	Florets per Spikelet			
		Bottom	Middle	Top	Mean
	-----------------------(No.)----------------				
Veg. N (kg ha^{-1})					
0	25.5	7.66	8.38	6.57	7.54
60	26.1	7.70	8.81	6.27	7.59
90	26.1	7.55	8.55	6.28	7.46
120	26.1	7.94	8.97	6.56	7.82
Veg. N Contrasts					
Check vs. treatment	NS	NS	($P < 0.1$)	NS	NS
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS
S.I. N (kg ha^{-1})					
0	26.1	6.94	7.76	5.99	6.89
60	26.0	7.88	8.86	6.51	7.75
90	25.9	7.79	8.80	6.60	7.73
120	25.8	8.24	9.30	6.58	8.04
S.I. N Contrasts					
Check vs. treatment	NS	**	**	**	**
Linear	NS	NS	($P < 0.1$)	NS	NS
Quadratic	NS	NS	NS	NS	NS

Table I.9. Influence of N applied during vegetative stage of growth (above) and N applied after spikelet initiation (below) on inflorescence yield components, 1983.

Time and Rate of Spring N	Spikelets per Spike	Florets per Spikelet			
		Bottom	Middle	Top	Mean
	------------------------(No.)-----------------				
Veg. N (kg ha^{-1})					
0	25.0	6.14	6.91	5.39	6.15
60	26.3	6.36	7.54	5.67	6.53
90	26.3	6.41	7.67	5.63	6.57
120	26.4	7.03	8.30	6.14	7.15
Veg. N Contrasts					
Check vs. treatment	**	($P< 0.1$)	**	*	**
Linear	NS	*	**	*	**
Quadratic	NS	NS	NS	NS	NS
S.I. N (kg ha^{-1})					
0	25.7	5.48	6.37	4.76	5.54
60	26.0	6.19	7.46	5.72	6.45
90	26.2	7.12	8.15	5.82	7.03
120	26.1	7.16	8.45	6.52	7.38
S.I. N Contrasts					
Check vs. treatment	NS	**	**	**	**
Linear	NS	**	**	*	**
Quadratic	NS	($P< 0.1$)	NS	NS	NS

recovered at harvest was significantly greater when either Veg. N or S.I. N was applied. However, only N applied after spikelet initiation resulted in a significant improvement in the number of seed per spike. Neither time or rate of N had a significant effect on FSU or 1000 seed weight.

In 1983 both the potential and actual number of seeds were increased by N applied during vegetative development. However, only the potential yield was increased by S.I. N; and this was optimum at 90 kg N ha^{-1} (Table I.11). Veg. N had no significant effect on the number of seeds per spike or FSU. Similarly, S.I. N had no effect on the number of seeds per spike, however, FSU was significantly decreased by late N application. The weight of 1000 seeds was significantly increased by N applied at either growth stage; the relationship was linear for Veg N and quadratic for S.I. N. Maximum 1000 seed weight was achieved by applying 90 kg N ha^{-1} after spikelet initiation.

Dry matter distribution at final harvest. In 1982, interactions were significant between N applied during the vegetative stage of growth and N applied after spikelet initiation for total dry weight, straw weight, and seed yield (Table I.12). Total dry weight and straw weight were generally lower where no Veg. N was applied, although intermean values were significant only for those plots receiving 0 + 0 kg N ha^{-1} (Veg. N + S.I. N) and 0 + 60 kg N ha^{-1}. Similarly, seed yield was not significantly affected except at very low rates of N, however, harvest index was improved where S.I. N was applied (Table I.13).

Time and rate of N effects on dry matter distribution in 1983 were very similar to those observed in 1982. Interactions were significant between N applied during vegetative stage of growth and N applied after

Table I.10. Influence of N applied during vegetative stage of growth (above) and N applied after spikelet initiation (below) on potential and actual seed yield, seeds per spike, floret site utilization (FSU), and 1000 seed weight, 1982.

Time and Rate of Spring N	Potential Seed Number	Actual Seed Number	Seeds per Spike	FSU	1000 Seed Weight
	(per m^{-2} x 10^3)		(No.)	(%)	(g)
Veg. N (kg ha^{-1})					
0	497	91.3	36.7	19.4	2.08
60	506	99.0	40.1	20.9	2.09
90	513	97.3	38.1	19.8	2.10
120	568	105.2	39.9	20.4	2.10
Veg. N Contrasts					
Check vs. treatment	NS	**	NS	NS	NS
Linear	($P < 0.1$)	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS
S.I. N (kg ha^{-1})					
0	481	91.5	34.9	19.7	2.07
60	528	97.9	38.6	19.3	2.11
90	541	101.7	39.1	20.2	2.08
120	534	101.8	42.3	21.2	2.11
S.I. N Contrasts					
Check vs. treatment	($P < 0.1$)	*	*	NS	NS
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS

Table I.11. Influence of N applied during vegetative stage of growth (above) and N applied after spikelet initiation (below) on potential and actual seed yield, seeds per spike, floret site utilization (FSU), and 1000 seed weight, 1983.

Time and Rate of Spring N	Potential Seed Number	Actual Seed Number	Seeds per Spike	FSU	1000 Seed Weight
	(per m^{-2} x 10^3)		(No.)	(%)	(g)
Veg. N (kg ha^{-1})					
0	299	36.3	19.3	12.7	1.92
60	363	39.7	19.5	11.6	1.93
90	365	41.1	21.3	12.7	1.98
120	395	41.1	20.5	10.9	2.01
Veg. N Contrasts					
Check vs. treatment	**	*	NS	NS	**
Linear	NS	NS	NS	NS	**
Quadratic	NS	NS	NS	NS	NS
S.I. N (kg ha^{-1})					
0	296	37.3	18.9	13.5	1.85
60	343	39.2	20.3	12.2	1.94
90	417	41.8	19.0	10.5	2.02
120	366	40.0	22.3	11.7	2.03
S.I. N Contrasts					
Check vs. treatment	**	NS	NS	*	**
Linear	NS	NS	NS	NS	**
Quadratic	**	NS	NS	NS	*

Table I.12. Interaction of N applied during vegetative stage of growth and N applied after spikelet initiation on dry matter distribution at final harvest, 1982.

Total dry weight (m t ha^{-1})

Veg. N (kg ha^{-1})	S.I. N (kg ha^{-1}) 0	60	90	120	mean
0	8.2	9.5	10.5	11.4	9.9
60	11.2	12.1	11.4	11.0	11.4
90	11.2	11.2	11.2	11.5	11.3
120	12.5	11.6	11.7	11.4	11.8
mean	10.8	11.1	11.2	11.3	

LSD .05 for intermeans = 1.4

Straw dry weight (m t ha^{-1})

Veg. N (kg ha^{-1})	S.I. N (kg ha^{-1}) 0	60	90	120	mean
0	6.8	7.6	8.4	9.2	8.0
60	9.2	9.9	9.3	9.1	9.4
90	9.3	9.2	9.1	9.4	9.2
120	10.4	9.4	9.5	9.2	9.6
mean	8.9	9.0	9.1	9.2	

LSD .05 for intermeans = 1.3

Seed yield (kg ha^{-1})

Veg. N (kg ha^{-1})	S.I. N (kg ha^{-1}) 0	60	90	120	mean
0	1429	1853	2049	2253	1896
60	2053	2124	2073	1961	2053
90	1930	1997	2118	2133	2045
120	2138	2255	2196	2210	2200
mean	1887	2058	2109	2139	

LSD .05 for intermeans = 323

Table I.13. Influence of N applied during vegetative stage of growth (above) and N applied after spikelet initiation (below) on harvest index, 1982.

Time and Rate of Spring N	Harvest Index
	(%)
Veg. N (kg ha^{-1})	
0	19.1
60	17.9
90	18.3
120	18.7
Veg. N Contrasts	
Check vs. treatment	NS
Linear	NS
Quadratic	NS
S.I. N (kg ha^{-1})	
0	17.5
60	18.8
90	18.9
120	18.9
S.I. N Contrasts	
Check vs. treatment	**
Linear	NS
Quadratic	NS

spikelet initiation for total dry weight and straw weight, with significant effects observed only at very low rates of N (Table I.14). However, seed yield data showed a significant increase where N was applied at the vegetative growth stage, and similarly, an increase where N was applied after spikelet initiation (Table I.15). These data indicate that split applications may benefit seed yield more than a single application. Harvest index was generally lower with higher total N rates, but improved somewhat where similar amounts were split applied (Table I.16).

Lodging percentages and severity. In 1983 lodging was a significant factor in the trials. Data collected at spike emergence found moderate lodging in plots receiving more than 150 kg N ha^{-1} (Table I.17), and by peak anthesis, all plots except for very low N rates were severely lodged (Table I.18). Unusually dry weather during the spring of 1982 reduced the severity of lodging, resulting in moderate and uniform lodging across all plots at maturity.

Table I.14. Interaction of N applied during vegetative stage of growth and N applied after spikelet initiation on dry matter distribution at final harvest, 1983.

Total dry weight (m t ha^{-1})

Veg. N (kg ha^{-1})	S.I. N (kg ha^{-1})				
	0	60	90	120	mean
0	3.8	4.7	5.3	6.8	5.1
60	5.0	5.5	7.8	6.7	6.2
90	6.0	6.7	7.3	5.0	6.2
120	6.8	6.1	6.3	6.2	6.3
mean	5.4	5.7	6.6	6.2	

LSD .05 for intermeans = 1.6

Straw dry weight (m t ha^{-1})

Veg. N (kg ha^{-1})	S.I. N (kg ha^{-1})				
	0	60	90	120	mean
0	3.3	4.0	4.6	5.9	4.4
60	4.4	4.7	6.9	5.9	5.5
90	5.2	5.9	6.4	4.2	5.4
120	6.0	5.3	5.4	5.4	5.5
mean	4.7	5.0	5.8	5.4	

LSD .05 for intermeans = 1.5

Table I.15. Influence of N applied during vegetative stage of growth (above) and N applied after spikelet initiation (below) on seed yield, 1983.

Time and Rate of Spring N	Seed Weight
	(kg ha^{-1})
Veg. N (kg ha^{-1})	
0	701
60	770
90	813
120	824
Veg. N Contrasts	
Check vs. treatment	**
Linear	NS
Quadratic	NS
S.I. N (kg ha^{-1})	
0	691
60	763
90	843
120	810
S.I. N Contrasts	
Check vs. treatment	**
Linear	NS
Quadratic	NS

Table I.16. Interaction of N applied during vegetative stage of growth and N applied after spikelet initiation on harvest index (%), 1983.

Veg. N (kg ha^{-1})	S.I. N (kg ha^{-1}) 0	60	90	120	mean
0	14.7	14.8	13.6	13.1	14.0
60	12.8	15.7	11.4	12.0	13.0
90	13.5	11.7	12.7	16.5	13.6
120	11.9	13.7	13.9	13.0	13.1
mean	13.2	14.0	12.9	13.7	

LSD .05 for intermeans = 3.1

Table I.17. Interaction of N applied during vegetative stage of growth and N applied after spikelet initiation on area of plot lodged (%) and severity of lodging (1-5) at spike emergence, 1983.

Area of plot lodged (%)

Veg. N (kg ha^{-1})	S.I. N (kg ha^{-1}) 0	60	90	120
0	0	0	0	2
60	0	8	40	62
90	0	43	65	78
120	13	62	82	80

LSD .05 for intermeans = 13

Severity of lodging (1-5)

Veg. N (kg ha^{-1})	S.I. N (kg ha^{-1}) 0	60	90	120
0	1	1	1	1
60	1	2	2	3
90	1	2	3	3
120	2	3	3	3

LSD .05 for intermeans = 0.4

Table I.18. Interaction of N applied during vegetative stage of growth and N applied after spikelet initiation on area of plot lodged (%) and severity of lodging (1-5) at peak anthesis, 1983.

Area of plot lodged (%)

Veg. N (kg ha^{-1})	S.I. N (kg ha^{-1})			
	0	60	90	120
0	3	28	48	62
60	27	65	70	72
90	55	68	70	77
120	73	78	80	73

LSD .05 for intermeans = 13

Severity of lodging (1-5)

Veg. N (kg ha^{-1})	S.I. N (kg ha^{-1})			
	0	60	90	120
0	1	2	3	4
60	2	4	4	4
90	3	4	4	4
120	4	4	4	4

LSD .05 for intermeans = 0.4

DISCUSSION

Seed yield of perennial ryegrass was quite insensitive to N rate applied as either early or late spring applications between 60-120 kg N ha^{-1}, although limited evidence suggested an optimum rate of 90 kg N ha^{-1} at either vegetative development or after spikelet initiation. However, intermean seed yield data in 1982, and significant increases in 1983 from both Veg. N and S.I. N indicate that split applications may be of greater benefit to seed yield than single applications. An unusually dry spring in 1982 resulted in a greater number of total tillers surviving between canopy closure, in early April, and anthesis. In addition, absence of any significant lodging resulted in extremely high yields. Data from 1983 represent more typical environmental conditions during the spring, however, unseasonably high rainfall in late June and early July resulted in lower than average seed yields. (Meteorological data are presented in Appendix Table 2.)

Early spring N applications, during the vegetative growth stage, increased the total tiller number at peak anthesis in both years of this study, a result of more vegetative tillers in the stand. These results were generally linear with treatment rate, although in the second year stand, total tiller number peaked at 90 kg N ha^{-1}. However, vegetative tiller number was not strongly influenced by N applied after spikelet initiation in either year.

The number of fertile tillers in the stand at peak anthesis was less significantly affected by the time or rate of spring N. However, there was slight evidence that 90 kg N ha^{-1} after spikelet initiation in 1982, and the same amount applied during vegetative growth in 1983, resulted in an optimum number of fertile tillers. Similarly, the greatest number of spikes at maturity in 1983 resulted from 90 kg N ha^{-1} after spikelet initiation. No significant difference was found in either year (data not presented) for the percentage of the total tillers at anthesis which were recovered in the stand as fertile tillers at maturity.

Individual components of each inflorescence were affected by N management. The application of N after spikelet initiation resulted in a significant increase in the number of florets per spikelet in both years. In 1983, this effect was linear within the range of treatment rates. Also, N applied during vegetative growth significantly increased the number of florets per spikelet, and increased the number of spikelets per spike in 1983.

Potential and actual seed number were slightly increased by spring N in 1982, regardless of time of application; however, the number of seeds per spike was greatest when N was applied after spikelet initiation. Floret site utilization and 1000 seed weight were not affected in 1982, as good conditions for seed pollination and seed filling were present. In 1983, the potential seed number was significantly increased regardless of time of application. The actual seed number was significantly increased only where N was applied during the vegetative growth stage, as FSU was reduced by N application after spikelet initiation. There was no significant difference in the number of seeds per spikelet; however, 1000 seed weight was significantly increased by spring N regardless of time of application.

Coefficients of linear correlation showed a significant, positive, relationship between the potential seed number and the number of spikes at maturity in both years. (Significant simple correlation coefficients for 1982 and 1983 are presented in Appendix Tables 3 and 4, respectively.) Although the number of spikes at maturity was not significantly associated with any category of tillers in the population at peak anthesis, the percentage of tillers which survived until maturity was, and had a significant, negative, relationship with the total number of tillers at anthesis. Thus, the competitive relationship among developing tillers may increase the mortality of potential seed bearing tillers before maturity. However, under drier spring conditions in 1982, the number of spikes at maturity was significantly and positively associated with the percentage of late-emerging tillers in the stand at peak anthesis. Thus, late-formed spring tillers can develop reproductive structures and contribute to final seed yield under certain environmental conditions.

Spikelets per spike were negatively associated with the percentage of fertile tillers at peak anthesis and, similarly, the number of florets per spikelet was negatively related with fertile tillers in 1983. The weight of 1000 seeds was not associated with other variables in 1982; however, in 1983, this component was positively associated with the number of florets in all spikelets.

The potential number of seeds was positively associated with the number of spikes at maturity, late-reproductive tillers at peak anthesis, spikelets per spike, and florets per spikelet. However, the association was slightly negative for the number of fertile tillers and total tillers at anthesis. The actual number of seeds harvested at maturity was positively associated with the total dry weight harvested, straw weight, seed weight, and harvest index. The number of seeds per spike was highly associated with the actual number of seeds and seed yield. However, there was a negative association with the number of spikes at maturity and the potential number of seeds. Thus yield components tend to compensate with one another, resulting in very little change in seed yield. FSU had a negative association with the number of spikes at maturity, seeds per spike, and the potential number of seeds at anthesis. FSU was positively associated with the total dry weight harvested, straw weight, seed weight, harvest index, and seed per spike.

Lodging data collected in 1983 showed a negative association with the fertile tiller percentage in the stand at anthesis, the percent tiller survival and FSU. There was a positive association between lodging and the total dry weights at harvest.

The major influence of Veg. N was to increase total number of tillers in the stand at anthesis, while that of S.I. N was to increase the number of seeds per spike. Ultimately, the number of spikes at maturity and the actual number of seeds per unit area harvested will determine seed yield. Conditions that improve the productivity of late-formed spring tillers will benefit seed yield.

SUMMARY

Late-formed tillers in heavily fertilized seed crops of perennial ryegrass can increase seed yield. However, as tiller densities increase, the components of seed yield on individual tillers decline, although, the overall potential number of seeds continues to increase. Unfortunately, the number of seeds per spike and FSU decline with a greater potential, and the resulting seed yield is not significantly changed. Improving the seed filling conditions between anthesis and maturity appears to provide the best opportunity for gains in seed yield. Reduced lodging lessens tiller mortality and harvest dry weight losses, and improves tiller survival, seeds per spike, and FSU.

Generally, an increase in seed yield can be expected with spring N rates between 60 and 120 kg N ha^{-1} regardless of the crop growth stage when applied. However, split spring N applications totaling 120 to 150 kg N ha^{-1} appeared to provide a better balance between compensating yield components, resulting in improved nitrogen efficiency while maintaining an economic seed yield.

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MANUSCRIPT II

The Effect of Chemical Dwarfing using the Plant Growth Retardant Paclobutrazol on Seed Yield and Yield Components of *Lolium perenne* L. cv. Pennfine

The Effect of Chemical Dwarfing using the Plant Growth Retardant Paclobutrazol on Seed Yield and Yield Components of *Lolium perenne* L. cv. Pennfine

INTRODUCTION

Late-formed tillers in heavily fertilized seed crops of perennial ryegrass have the potential to contribute to increased seed yield (Young, 1987). However, as tiller densities become greater, seed yield on individual tillers becomes smaller. And, although the potential number of seeds continue to increase, the number of seeds per spike and floret site utilization (FSU) decline, and the resulting seed yield is not significantly changed. Thus, perennial ryegrass realizes only a small percentage of the potential as harvested seed. Burbidge, Hebblethwaite and Ivins (1978) found the percentage of florets which set seed reached a maximum value of about 60% three weeks after peak anthesis, but decreased to about 20-30% by final harvest. This is consistent with results reported by Anslow (1963), who observed that only two-thirds of all florets set seed, and by Gangi (1984), who reported initial floret fertility of 61%, which by final harvest had decreased to 20-32%. Cross-pollinated grasses are subjected to environmental conditions which may further limit the capability of florets to develop seeds (Hill 1980).

When perennial ryegrass receives enough N to maximize seed yield, lodging often begins around the time of seed head emergence (Hebblethwaite, 1977; Young, 1987). Hebblethwaite, Burbidge and Wright (1978) have shown by comparing mechanically supported stands of perennial ryegrass with lodged ones, that lodging can decrease yields between 30% and 70%. Their data indicated that lodging was detrimental to the crop even during the latter stages of growth, affecting both pollination and seed development. If a stand is lodged at anthesis, pollen dispersal can be inhibited, resulting in a poor seed set (Anslow, 1963). The micro-environment in a lodged canopy facilitates fungal attack on the inflorescence, contributing to seed yield reduction (Griffiths, 1967). Lodging also is restricts light interception, reducing current photosynthate to the developing head, contributing to sterile florets (Spiertz and Ellen, 1972).

Cultural practices to control lodging, such as altering the amount and time of N application (Hebblethwaite, 1977), and grazing and defoliation (Green and Evans, 1956; Roberts, 1965) have been examined, but results have been variable. A promising alternative appears to be using growth retardant chemicals to decrease straw length and consequently reduce lodging. Several compounds have been used to chemically delay lodging in perennial ryegrass (Burbidge, Hebblethwaite and Ivins, 1978; Wright and Hebblethwaite, 1979; Hebblethwaite, Hampton, and McLaren, 1982; Hampton and Hebblethwaite, 1985; Hunter, 1985), and seed yield increases from nil to 100% have been reported depending upon the cultivar and the season.

The most recent work has concentrated on the use of paclobutrazol (PP333 = [(2RS,3RS)-1-(4-chlorophenyl)-4,4dimethyl-2-(1,2,4-triazol-1-yl)pentan-3-ol]), trade name, Parlay. Paclobutrazol inhibits sterol biosynthesis, reducing levels of endogenous gibberellins, resulting in long-term retardation and internode compression in grass species following root uptake (Shearing and Batch, 1982). Foliar uptake occurs, but has little effect, as paclobutrazol accumulates in the leaf and little reaches the meristematic area (Froggatt, Thomas and Batch, 1982).

Hampton and Hebblethwaite (1984) have shown the requirement for water before paclobutrazol is taken up by the root system and growth retardant properties are exhibited in perennial ryegrass.

Hebblethwaite, Hampton and McLaren (1982) reported that an application of paclobutrazol at the floret initiation growth stage resulted in 27% to 50% increases in seed yield of perennial ryegrass. Increased seed yield was attributed to more seeds per spikelet and seeds per unit area; fertile tiller number was not affected by stage of development. Straw weight was not significantly affected by paclobutrazol but harvest index was increased, which implies a more efficient partitioning of dry matter into seed yield.

Hampton and Hebblethwaite (1985) found that paclobutrazol applied to perennial ryegrass at the spikelet initiation stage of growth increased seed yield due to an increased production of fertile tillers in two years (1981 and 1982), and an increased number of seeds per spikelet in the second year. Seed yield increases were significantly greater at a rate of 2.0 kg a.i. ha^{-1} when compared to lower rates. Lodging was prevented completely by the 2.0 kg rate, delayed until after anthesis by the 1.0 kg rate, and began before anthesis with the 0.5 kg rate. In addition, paclobutrazol reduced stem internode length and strengthened the base of the stem. Their data showed that fertile tiller survival did not differ markedly between lodged and non-lodged plots, and that differences at final harvest resulted from increased tiller production following paclobutrazol application.

Chilcote, Youngberg and Albeke (1982) reported a seed yield increase of 49% to 109% on a six year old and first year crop of Pennfine perennial ryegrass, respectively, following paclobutrazol application during floret initiation stage of growth at 0.67 kg a.i. ha^{-1}. In their trials seed yield enhancement was primarily due to increased numbers on fertile tillers and more harvested seeds per inflorescence.

Hunter (1985) observed delayed lodging by restricting stem elongation in the basal internodes, where both internode length and weight were reduced. Paclobutrazol significantly reduced tiller mortality, which resulted in more fertile tillers at harvest in treated plots.

This research was designed to study the time and rate of paclobutrazol application in relation to two developmental growth stages: (1) after spikelet initiation, and (2) after floret initiation, under conditions of uniform nitrogen management. Objectives were to determine for Pennfine perennial ryegrass grown in the Willamette Valley of Oregon, USA:

(1) the effect of spring application of paclobutrazol at two rates on lodging, dry matter distribution, and final seed yield;

(2) the effect on yield components per tiller (spikelets per spike, florets per spikelets, and individual seed weight);

(3) the efficiency of seed production by describing the resulting effects on potential and actual seed yield.

MATERIALS AND METHODS

Experiments were conducted for two years on a first (1983) and second (1984) year seed crop of perennial ryegrass, using the variety Pennfine. The experimental site, located at the Oregon State University Hyslop Crop Science Field Laboratory, has previously been described (Young, 1987). After one year of fallow, 300 kg ha^{-1} ammonium phosphate-sulfate fertilizer (16-20-0-15) was incorporated during seedbed preparation. On 16 October 1981 the stand was established using a John Deere precision plate planter calibrated to seed 6.0 kg ha^{-1} in rows 30 cm apart. Finely ground activated carbon was mixed with water at a ratio of 60 g l^{-1}, and the resulting slurry was applied as a spray during planting in a band about 2.5 cm wide, over the row after covering, to protect seedlings from preemergence application of diuron (Lee, 1973). Immediately following seeding a broadcast spray of 2.1 kg a.i. ha^{-1} diuron was applied.

Due to the late planting date, an economic seed crop was not expected in the summer of 1982. However, standard cultural practices were employed during this establishment year. In late-January a tank mix of 2,4-D low volatile ester at 0.56 kg a.e. ha^{-1} plus dicamba at 0.28 kg a.e. ha^{-1} was broadcast sprayed, and in mid-April 200 kg ha^{-1} urea (46-0-0) was applied. In early-July, just before any seed matured, the stand was flail chopped to a height of 10 cm to remove any reproductive tillers and straw residue. Stubble residue was removed in late-August using a close-clipping technique described by Young, Youngberg and Chilcote (1984).

Cultural practices during the 1982-83 and 1983-84 crop years included atrazine at 1.35 kg a.i. ha^{-1} in mid-October and 200 kg ha^{-1}

ammonium phosphate-sulfate fertilizer (16-20-0-15) in late-October. In addition, a mid-February tank mix of 2,4-D low volatile ester at 0.56 kg a.e. ha^{-1} plus dicamba at 0.28 kg a.e. ha^{-1} was applied. Two applications of 1-[[2-(2,4dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl]methyl]-H1,2,4-triazole at 0.126 kg a.i. ha^{-1} (Tilt^R fungicide at 0.3 l ha^{-1}) were applied in 1983 and three applications in 1984, to all plots for the control of rust (Puccinia spp.). Straw residue was removed with a flail chopper immediately following seed harvest in 1983, and in mid-August the stubble was burned with a propane flamer (Chilcote and Youngberg, 1975) to simulate open field burning.

Spring N management used for this study was a broadcast split spring application of 60 kg N ha^{-1} during vegetative development, and another 60 kg N ha^{-1} after spikelet initiation growth stage to all plots. Calendar dates for vegetative N were 4 March 1983 and 5 March 1984. Similarly, spikelet initiation N was applied on 21 March 1983 and 26 March 1984. Ammonium nitrate was the source of all spring applied N in both years.

Paclobutrazol was applied in all possible combinations of two rates (0.50 and 0.75 kg a.i. ha^{-1}) at two spring dates based on morphological stage of development (spikelet initiation and floret initiation). The four factorial treatments were arranged in randomized complete blocks, with one untreated control outside the factorial. Plot size was 2.5 x 6.0 m, and treatments were replicated six times. Paclobutrazol treatments were applied using a Cooper-Pegler backpack sprayer and a hand-held 2 m boom. Approximately 415 l ha^{-1} spray volume was delivered from six 8002LP nozzles with an operating pressure of 1.2×10^5 Pa. Calendar dates for spikelet initiation applications were 23 March 1983 and 27 March 1984. Similarly, floret initiation treatments were applied on 8 April 1983 and 6 April 1984.

Details for growth stage determination, yield component measurement technique, lodging estimates, and harvesting procedure have been reported by Young (1987). In 1984 seed moisture content was monitored by stripping all spikelets from 20 spikes drawn at random from each treatment across 3 replications. Percent seed moisture was calculated on a wet weight basis following drying at 130^{o} C for 1 hour. No significant difference in seed moisture was found of 6 July or 10 July; all plots were harvested on 13 July 1984. Date of harvest in 1983 was 11 July. In addition, germination tests of seed harvested in 1983 from plots treated with 0.75 kg a.i. ha^{-1} at floret initiation (F.I.) were compared to untreated plots. Four lots of 50 seeds were randomly drawn from the 1000 seeds electronically counted for seed weight measurements from all six replications, and germinated on blotter paper wet with 0.2% KNO_3.

In the analysis of variance (ANOVA) the significance of main effects, rate of paclobutrazol and growth stage (time) of application, and their interaction were tested using single degree of freedom contrasts. In addition, a single degree of freedom contrast was used to test the significance of the untreated check plot over the factorial treatments. (The ANOVA table and contrast coefficients used are shown in Appendix Table 5.)

RESULTS

Tiller number. Total tiller number at peak anthesis was significantly increased in 1983 by paclobutrazol applied at spikelet initiation (S.I.), due to a greater number of fertile tillers in the stand (Table II.1). Vegetative tiller number was reduced by growth retardant application at either rate or growth stage, while the number of spikes at maturity was increased. Thus, paclobutrazol reduced the percentage of vegetative and late-reproductive tillers, while the percentage of fertile tillers increased. However, there was no significant difference for either rate or time of application, and the percentage of tillers which survived between peak anthesis and maturity was not different.

In 1984 only a slight decrease in the number of vegetative tillers occurred where paclobutrazol was applied, with no significant difference in the number of spikes at maturity (Table II.2). However, paclobutrazol increased the proportion fertile tillers, as in 1983.

Spikelets per spike and florets per spikelet. Application of paclobutrazol had little influence on the yield component data collected from individual inflorescences in 1983 (Table II.3). The only significant effect was an increase in the number of florets in spikelets positioned in the middle of the spike where paclobutrazol was applied during floret initiation (F.I.). However, in 1984 paclobutrazol applied at S.I. significantly increased the number of florets per spikelet throughout the inflorescence (Table II.4).

Potential yield. A greater number of spikes at maturity and a small gain in the number of florets per spikelet combined to significantly increase the potential seed number where paclobutrazol was

Table II.1. Influence of paclobutrazol at two growth stages and two rates on tiller population, 1983.

Stage and Rate of Paclobutrazol	Tiller Number at Peak Anthesis				Spikes at Maturity
	Veg.	Late	Fertile	Total	
	-----------------(per m^{-2})				---------------
Check	331	192	2031	2554	2049
Growth Stage[1]					
S.I.	141	183	2707	3031	2716
F.I.	184	142	2232	2557	2556
Rate of Paclobutrazol					
0.50 kg a.i. ha^{-1}	156	152	2426	2735	2714
0.75 kg a.i. ha^{-1}	169	172	2512	2853	2557
Contrasts[2]					
Stage	NS	(P< 0.1)	*	*	NS
Rate	NS	NS	NS	NS	NS
Stage x Rate	NS	NS	NS	NS	NS
Check vs. Fact.	*	NS	*	NS	*

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[1] S.I. = spikelet initiation; F.I. = floret initiation.

[2] Orthogonal contrasts significant at P< 0.01 (**), P< 0.05 (*), and the 0.1 probability level (P< 0.1).

Table II.2. Influence of paclobutrazol at two growth stages and two rates on tiller population, 1984.

Stage and Rate of Paclobutrazol	Tiller Number at Peak Anthesis				Spikes at Maturity
	Veg.	Late	Fertile	Total	
	-----------------(per m^{-2})				---------------
Check	524	1200	848	2572	2007
Growth Stage					
S.I.	352	1190	1074	2615	2259
F.I.	380	1255	947	2582	2023
Rate of Paclobutrazol					
0.50 kg a.i. ha^{-1}	457	1258	986	2701	2014
0.75 kg a.i. ha^{-1}	274	1187	1035	2496	2268
Contrasts					
Stage	NS	NS	NS	NS	NS
Rate	*	NS	NS	(P< 0.1)	NS
Stage x Rate	NS	NS	NS	NS	NS
Check vs. Fact.	(P< 0.1)	NS	NS	NS	NS

Table II.3. Influence of paclobutrazol at two growth stages and two rates on inflorescence components, 1983.

Stage and Rate of Paclobutrazol	Spikelets per Spike	Florets per Spikelet			
		Bottom	Middle	Top	Mean
	(No.)				
Check	25.1	5.96	7.14	5.24	6.11
Growth Stage					
S.I.	24.5	5.99	6.72	6.01	6.24
F.I.	25.6	6.18	7.59	5.77	6.52
Rate of Paclobutrazol					
0.50 kg a.i. ha^{-1}	24.6	6.04	6.93	5.73	6.23
0.75 kg a.i. ha^{-1}	25.5	6.13	7.39	6.05	6.52
Contrasts					
Stage	NS	NS	**	NS	NS
Rate	NS	NS	NS	NS	NS
Stage x Rate	NS	NS	NS	NS	NS
Check vs. Fact.	NS	NS	NS	$(P < 0.1)$	NS

Table II.4. Influence of paclobutrazol at two growth stages and two rates on inflorescence components, 1984.

Stage and Rate of Paclobutrazol	Spikelets per Spike	Florets per Spikelet			
		Bottom	Middle	Top	Mean
	(No.)				
Check	25.7	7.78	8.57	5.84	7.39
Growth Stage					
S.I.	25.6	8.19	8.59	6.87	7.88
F.I.	25.3	7.61	7.96	6.14	7.24
Rate of Paclobutrazol					
0.50 kg a.i. ha^{-1}	25.6	7.72	8.13	6.68	7.51
0.75 kg a.i. ha^{-1}	25.3	8.08	8.43	6.33	7.61
Contrasts					
Stage	NS	*	*	*	**
Rate	NS	NS	NS	NS	NS
Stage x Rate	NS	NS	NS	NS	NS
Check vs. Fact.	NS	NS	NS	$(P < 0.1)$	NS

applied in 1983 (Table II.5). The actual number of clean seed per unit area was similarly affected by paclobutrazol; the greatest increase occurred at the 0.75 kg a.i. ha^{-1} rate. Significance of the actual seed number was paralleled by a similar increase in the number of seed per spike, and floret site utilization (FSU) was improved by an average of 58% following the use of paclobutrazol. The weight of 1000 seeds, however, was found to decline slightly when a greater number of seeds were recovered, although this had no effect on subsequent germination.

The potential seed number in 1984 was not as strongly affected by paclobutrazol as 1983. Although application at S.I. did increase the number of florets per spikelet, there was no significant difference in the number of spikes at maturity; as a result, the potential yield of the paclobutrazol treated plots was not different from the check plot (Table II.6). However, a significant increase was observed between growth stages, with application at S.I. resulting in a greater potential than at F.I.. However, paclobutrazol did significantly increase the actual number of seed recovered at harvest. And in addition, the 0.75 kg a.i. ha^{-1} rate applied at S.I. had the greatest benefit (Table II.6). The number of seed per spike was significantly greater following the use of paclobutrazol, and FSU was again improved by an average of 58%. Also, as in 1983, the 1000 seed weight declined with paclobutrazol application. However, no significant difference in percent germination after 14 days was observed (data not shown).

Dry matter distribution at final harvest. Total dry weight at harvest was not significantly affected in either year by application of paclobutrazol (Tables II.7 and II.8). Straw weight was significantly reduced in 1983 (Table II.7), but in 1984 it was unchanged (Table II.8).

Table II.5. Influence of paclobutrazol at two growth stages and two rates on potential and actual seed yield, seeds per spike, floret site utilization (FSU), and 1000 seed weight, 1983.

Stage and Rate of Paclobutrazol	Potential Seed Number	Actual Seed Number	Seeds per Spike	FSU	1000 Seed Weight
	(per $m^{-2} \times 10^3$)		(No.)	(%)	(g)
Check	313	36.2	18.1	12	2.06
Growth Stage					
S.I.	413	79.9	29.7	19	1.91
F.I.	427	75.6	30.5	19	1.94
Rate of Paclobutrazol					
0.50 kg a.i. ha^{-1}	416	72.7	27.1	18	1.92
0.75 kg a.i. ha^{-1}	424	82.8	33.2	20	1.93
Contrasts					
Stage	NS	NS	NS	NS	*
Rate	NS	*	*	NS	NS
Stage x Rate	NS	NS	NS	NS	NS
Check vs. Fact.	**	**	**	**	**

Table II.6. Influence of paclobutrazol at two growth stages and two rates on potential and actual seed yield, seeds per spike, floret site utilization (FSU), and 1000 seed weight, 1984.

Stage and Rate of Paclobutrazol	Potential Seed Number	Actual Seed Number	Seeds per Spike	FSU	1000 Seed Weight
	(per $m^{-2} \times 10^3$)		(No.)	(%)	(g)
Check	386	52.3	27.1	15	1.73
Growth Stage					
S.I.	453	97.9	45.0	22	1.60
F.I.	372	88.3	45.0	25	1.61
Rate of Paclobutrazol					
0.50 kg a.i. ha^{-1}	388	87.0	45.2	24	1.62
0.75 kg a.i. ha^{-1}	437	99.2	44.8	24	1.59
Contrasts					
Stage	*	($P < 0.1$)	NS	NS	NS
Rate	NS	*	NS	NS	NS
Stage x Rate	NS	NS	NS	NS	NS
Check vs. Fact.	NS	**	**	**	**

Table II.7. Influence of paclobutrazol at two growth stages and two rates on dry matter distribution at final harvest and harvest index, 1983.

Stage and Rate of Paclobutrazol	Total Dry Weight	Straw Weight	Seed Weight	Harvest Index
	--(m t ha^{-1})--		(kg ha^{-1})	(%)
Check	6.7	5.9	748	11.1
Growth Stage				
S.I.	6.5	5.0	1529	23.6
F.I.	6.6	5.1	1466	22.5
Rate of Paclobutrazol				
0.50 kg a.i. ha^{-1}	6.5	5.1	1398	21.9
0.75 kg a.i. ha^{-1}	6.7	5.1	1597	24.2
Contrasts				
Stage	NS	NS	NS	NS
Rate	NS	NS	*	**
Stage x Rate	($P < 0.1$)	($P < 0.1$)	NS	NS
Check vs. Fact.	NS	**	**	**

Table II.8. Influence of paclobutrazol at two growth stages and two rates on dry matter distribution at final harvest and harvest index, 1984.

Stage and Rate of Paclobutrazol	Total Dry Weight	Straw Weight	Seed Weight	Harvest Index
	--(m t ha^{-1})--		(kg ha^{-1})	(%)
Check	5.9	5.0	903	15.5
Growth Stage				
S.I.	6.6	5.1	1569	23.8
F.I.	6.5	5.0	1415	22.1
Rate of Paclobutrazol				
0.50 kg a.i. ha^{-1}	6.6	5.2	1408	21.5
0.75 kg a.i. ha^{-1}	6.5	4.9	1577	24.3
Contrasts				
Stage	NS	NS	*	*
Rate	NS	NS	*	**
Stage x Rate	NS	NS	NS	NS
Check vs. Fact.	NS	NS	**	**

In both years a highly significant increase in seed yield resulted from the use of paclobutrazol, with the 0.75 kg a.i. ha^{-1} rate providing a superior effect. In addition, in 1984, application at S.I. resulted in significantly higher seed yield. Significant improvement in harvest index paralleled results observed for treatment effect on seed yield. On the average, paclobutrazol increased seed yield and harvest index by 100% and 107%, respectively, in 1983, and similarly, in 1984, by 65% and 48%, respectively.

Lodging percentages and severity. In 1983 lodging began in the control plots at about spike emergence (13 May); however, no lodging was observed in the paclobutrazol treated plots at that time, or on 27 May at about full heading (Table II.9). Heavy rainfall during June resulted in severe lodging conditions; however, all paclobutrazol treated plots had significantly less lodging through anthesis and at maturity. And at the 0.75 kg a.i. ha^{-1} rate lodging was less severe than at 0.50 kg a.i. ha^{-1}. Precipitation in the May-June, 1984, combination was the wettest such two-month period on record, which resulted in severe crop lodging. (Meteorological data are presented in Appendix Table 6.) Paclobutrazol again significantly reduced the area and severity of lodging (Table II.9). In addition, application at the S.I. growth stage was more effective in controlling lodging, and as in 1983, the 0.75 kg a.i. ha^{-1} rate was the more effective.

Table II.9. Influence of paclobutrazol at two growth stages and two rates on the area of plot lodged (%) and severity of lodging (1-5) at three dates, 1983.

Stage and Rate of Paclobutrazol	Lodging: 5-27-83		Lodging: 6-22-83		Lodging: 7-7-83	
	Area	Severity	Area	Severity	Area	Severity
	(%)	(1-5)	(%)	(1-5)	(%)	(1-5)
Check	88	4	100	5	100	5
Growth Stage						
S.I.	0	1	43	3	69	4
F.I.	0	1	39	3	67	4
Rate of Paclobutrazol						
0.50 kg a.i. ha^{-1}	0	1	63	3	88	4
0.75 kg a.i. ha^{-1}	0	1	18	2	48	4
Contrasts						
Stage	NS	NS	NS	NS	NS	NS
Rate	NS	NS	**	**	**	**
Stage x Rate	NS	NS	NS	NS	NS	NS
Check vs. Fact.	**	**	**	**	**	**

Table II.10. Influence of paclobutrazol at two growth stages and two rates on the area of plot lodged (%) and severity of lodging (1-5) at three dates, 1984.

Stage and Rate of Paclobutrazol	Lodging: 6-8-84		Lodging: 6-22-84		Lodging: 7-5-84	
	Area	Severity	Area	Severity	Area	Severity
	(%)	(1-5)	(%)	(1-5)	(%)	(1-5)
Check	78	4	82	5	89	5
Growth Stage						
S.I.	3	1	28	3	44	3
F.I.	14	2	54	4	64	4
Rate of Paclobutrazol						
0.50 kg a.i. ha^{-1}	13	2	53	4	67	4
0.75 kg a.i. ha^{-1}	3	1	29	3	42	3
Contrasts						
Stage	**	**	**	**	**	**
Rate	**	**	**	**	**	**
Stage x Rate	NS	NS	NS	NS	NS	**
Check vs. Fact.	**	**	**	**	**	**

DISCUSSION

Paclobutrazol application can significantly reduce lodging in seed crops of perennial ryegrass, and increase seed yield (Hebblethwaite, Hampton and McLaren, 1982; Hampton and Hebblethwaite, 1984). Wet weather conditions in both years during heading, anthesis and seed filling provided an opportunity to realize considerable benefit from chemical dwarfing. Increased seed yield in 1983 resulted from a greater number and percentage of fertile tillers in the stand at anthesis, and a concomitant reduction in the number and percentage of vegetative tillers, and a greater number of spikes at harvest. Similar trends were apparent in 1984; however, a much cooler than normal period between March-June may have delayed the development and emergence of many spring formed tillers. A slightly greater number of florets per spikelet resulted in 1984, but the potential number of seeds per unit area was not distinctly affected. Paclobutrazol had no effect on the number of spikelets per spike in either year.

Actual seed number recovered at final harvest was significantly greater in paclobutrazol treated plots due to an increased number of seeds per spike and spikes per unit area in 1983. Only seed number per spike was significantly increased in 1984. In both years, 1000 seed weight was reduced as a greater number of seeds were developing. Total dry weight was not affected in either year; nor was straw weight in 1983. However, in 1984 straw weight was significantly reduced by paclobutrazol. The efficiency of seed production was increased by paclobutrazol application as indicated by the significant increase in harvest index in both years. Improved efficiency and seed recovery appears to result from a delay in lodging and a reduction in the severity of lodging.

The presence of excessive numbers of vegetative tillers in untreated plots during the spring growing season and through peak anthesis reduced fertile tiller number at anthesis as indicated by the negative correlation coefficient between vegetative tillers and fertile tillers at peak anthesis. (Significant simple correlation coefficients for 1983 and 1984 are presented in Appendix Tables 7 and 8, respectively.) Paclobutrazol aided in maintaining yield potential developed at peak anthesis through delaying or eliminating lodging. The number of spikes at maturity was positively related with fertile tiller number at anthesis. In addition, seeds per spike and FSU were negatively associated with the vegetative tiller number, while both were positive in their relationship with fertile tiller number. Seed yield was similarly associated with the above components.

Seed yield was negatively related to both the area and severity of lodging in the stand from spike emergence through to maturity. This result is consistent with the deleterious effect of lodging on seed yield reported under United Kingdom conditions (Hebblethwaite, Burbidge and Wright, 1978; Hebblethwaite, Hampton and McLaren, 1982).

SUMMARY

Spring application of paclobutrazol delays the onset and severity of lodging, with very little effect on the reproductive portions of the plant. However, increased numbers of fertile tillers present in the stand result in a greater number of potential seed sites per unit area. Reduced lodging appears to enhance seed set, resulting in a greater number of seeds recovered at harvest and a higher FSU. Harvest index was also increased with paclobutrazol.

Earlier dates of application (S.I.) had a greater effect in reducing lodging in 1983, but no difference was observed between growth stages in 1984. Lodging severity, actual seed number recovered, seeds per spike, and seed yield were all significantly increased at the 0.75 kg a.i. ha^{-1} rate. Thus, under environmental conditions found in the Willamette Valley in western Oregon, and where cultural practices are consistent with those employed in this study, the chemical dwarfing agent, paclobutrazol, has consistently enhanced seed yield of Pennfine perennial ryegrass.

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MANUSCRIPT III

Relationships Between Increased Rate of Spring Nitrogen and Subsequent use of Paclobutrazol on Seed Yield and Yield Components of *Lolium perenne* L. cv. Pennfine

Relationships Between Increased Rate of Spring Nitrogen and Subsequent use of Paclobutrazol on Seed Yield and Yield Components of *Lolium perenne* L. cv. Pennfine

INTRODUCTION

Pennfine perennial ryegrass has responded to higher rates of nitrogen (N) applied during vegetative development by increased tiller density and more potential seed sites per unit area (Young, 1987a). However, this potential seed yield increase frequently does not materialize because the number of harvested seeds per tiller declines as tiller density increases. Lodging is a major factor limiting seed yield (Young, 1987b; Hampton and Hebblethwaite, 1985; Hampton, Clemence and Hebblethwaite, 1983; Hebblethwaite, Hampton and McLaren, 1982). Improved seed yield following paclobutrazol treatment to reduce lodging was due to a greater number of seeds per spike and a greater number of seed recovered at final harvest.

Other researchers have shown that N applications in excess of 120 kg ha^{-1} usually do not significantly increase seed yield because of increased lodging, production of secondary vegetative tillers and lower seed set (Hebblethwaite and Ivins, 1977; Nordestgaard, 1980). Positive effects on seed yield have been reported following application of growth retardant compounds which reduce or delay the onset and severity of lodging (Hebblethwaite, Wright and Noble, 1980; Hebblethwaite, Hampton and McLaren, 1982; Hampton and Hebblethwaite, 1985).

Albeke, Chilcote and Youngberg (1983) investigated the effect of paclobutrazol under different spring N levels in *Festuca rubra* and found increased potential yield at higher N rates, and increased seed yield at all N rates. Hampton, Clemence and Hebblethwaite (1983) investigated the influence of N rates and paclobutrazol in Lolium perenne and reported seed yield was increased by the same amount in paclobutrazol treated plots regardless of N levels when compared to untreated plots at the same N rate.

This research was designed to examine the effect of split spring N treatments, combined with an application of paclobutrazol at the floret iniation (F.I.) growth stage. Split spring N treatments were applied at increased levels during vegetative (Veg. N.) growth and were followed by a standard, uniform application of N after spikelet initiation (S.I.). Objectives were to determine for Pennfine perennial ryegrass grown in the Willamette Valley of Oregon, USA:

(1) if an interaction between increased level of vegetative N and paclobutrazol existed;

(2) if increased fertile tillers densities could be achieved and maintained until maturity;

(3) the efficiency of seed production by describing the resulting effects on potential and actual seed yield.

MATERIALS AND METHODS

Experiments were conducted for two years on a second (1984) and third (1985) year seed crop of perennial ryegrass, using the variety Pennfine. The experimental site, located at the Oregon State University Hyslop Crop Science Field Laboratory, has previously been described (Young, 1987a). Cultural practices employed during establishment and management during the first and second year seed crop has also been described (Young, 1987b). Straw residue was removed with a flail chopper immediately following seed harvest in 1984, and in mid-August the stubble was burned with a propane flamer (Chilcote and Youngberg, 1975) to simulate open field burning.

Cultural practices during 1984-85 crop year included atrazine at 1.35 kg a.i. ha^{-1} in mid-October and 200 kg ha^{-1} ammonium phosphate-sulfate fertilizer (16-20-0-15) in late-October. In addition, a mid-February tank mix application of 2,4-D low volatile ester at 0.56 kg a.e. ha^{-1} plus dicamba at 0.28 kg a.e. ha^{-1} was applied. Applications of 1-[[2-(2,4dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl]methyl]-H1,2,4-triazole at 0.126 kg a.i. ha^{-1} (Tilt^{R} fungicide at 0.3 l ha^{-1}) were applied in late-May and early-June to all plots for the control of rust (*Puccinia* spp.).

Spring N treatments during the vegetative growth stage (Veg N) were applied using a hand driven Gandy spreader calibrated at either 60, 120, or 180 kg N ha^{-1}. Calendar dates for Veg. N were 7 March 1984 and 8 March 1985. A broadcast application of an additional 60 kg N ha^{-1} was given to all plots on 26 March 1984 and 29 March 1985, after spikelet initiation. Thus, total spring N rates were 120, 180, and 240 kg ha^{-1}. Ammonium nitrate (34-0-0) was the source of all spring N in both years.

At the floret initiation growth stage paclobutrazol was applied to randomly selected plots at 0.75 kg a.i. ha^{-1} using a Cooper-Pegler backpack sprayer and a hand-held 2 m boom as previously described (Young, 1987b). Calendar dates for paclobutrazol application were 10 April 1984 and 13 April 1985. Thus, six factorial treatments were arranged in randomized complete blocks and replicated six times in both 1983-84 and 1984-85 crop years (Table III.1). Plot size was 2.5 x 6.0 m.

In distinct contrast to wetter than average April-May conditions experienced in 1984, dry conditions prevailed during this period in 1985. Only 57% and 51% of the expected precipation was recorded for April and May 1985, respectively. (Meteorological data are presented in Appendix Table 9.) Therefore, approximately 25 mm irrigation was used on 15 May 1985 to help insure adequate moisture.

Details for growth stage determination, yield component measurement technique, lodging estimates, and harvesting procedure have been reported by Young (1987a). In 1984 percent seed moisture content was determined as previously described (Young, 1987b); significant differences in seed moisture were found and harvest date for treatments was varied between 13-16 July. No significant difference in seed moisture was found in 1985 and all plots were harvested on 2 July 1985.

In the analysis of variance (ANOVA) the effect of Veg. N was tested for a linear or non-linear relationship using contrasts. Orthogonal polynomial coefficients were used to solve the regression for the three levels of N. In addition, a single degree of freedom contrast was used to test the significance between the paclobutrazol treated, and untreated plots. (The ANOVA table and contrast coefficients used are shown in Appendix Table 10).

RESULTS

Tiller number. The total number of tillers at peak anthesis had a significant linear relationship with increased rate of Veg. N in 1984 (Table III.2). This increase was the result of a significantly greater number of late-emerged reproductive tillers, as there was no change in the number of vegetative or fertile tillers due to increased rate of Veg. N The effect of paclobutrazol was to reduce significantly the number of vegetative tillers, and increase the number of fertile tillers; however, there was no effect on the total number of tillers at peak anthesis, and only a slight increase in the number of late-emerged tillers (Table III.2). The total number of spikes at maturity were significantly increased by both increased rate of Veg. N and paclobutrazol.

Tiller number at peak anthesis was not significantly affected by either Veg. N or paclobutrazol in 1985, however, the number of spikes at maturity showed a slight curvilinear response to early spring N (Table III.3). These data are not consistent with the effects observed in 1984, although cool, dry spring weather may have had a significant impact on treatment effects in 1985.

Spikelets per spike and florets per spikelet. Increased rate of Veg. N resulted in a significant linear increase in the number of florets per spikelet in 1984 (Table III.4). Spikelets positioned at the bottom of the inflorescence were most significantly affected, while number of florets in spikelets at the top of the spike were only slightly increased. However, the effect of paclobutrazol was found to significantly reduce the number of florets in lower spikelets, and slightly increased the florets per spikelet at the top of the

Table III.1. Factorial presentation of treatments for the increased rate of vegetative nitrogen x paclobutrazol study in 1984 and 1985.

	Rate of Vegetative Nitrogen (kg N ha^{-1})		
	60	120	180
Rate of Paclobutrazol (kg a.i. ha^{-1})	0.0	0.0	0.0
	0.75	0.75	0.75

Table III.2. Influence of increased rate of vegetative nitrogen and paclobutrazol application on tiller population, 1984.

Treatment	Tiller Number at Peak Anthesis				Spikes at Maturity
	Veg	Late	Fertile	Total	
	----------------(per m^{-2})----------------				
Nitrogen Rate (Veg. N)[1]					
60 kg ha^{-1}	409	1459	1034	2902	1933
120 kg ha^{-1}	313	1569	1107	2989	2226
180 kg ha^{-1}	365	1774	1132	3271	2359
N Rate Contrasts[3]					
Linear	NS	*	NS	*	*
Quadratic	NS	NS	NS	NS	NS
Paclobutrazol (F.I.)[2]					
0.0 kg a.i. ha^{-1}	487	1514	979	2980	1905
0.75 kg a.i. ha^{-1}	238	1687	1203	3128	2440
Paclobutrazol Contrast[3]					
Check vs. treatment	**	($P < 0.1$)	**	NS	**

[1] Veg. N = applied during vegetative growth stage.

[2] F.I. = applied at floret initiation growth stage.

[3] Orthogonal contrasts significant at $P < 0.01$ (**), $P < 0.05$ (*), and the 0.1 probability level ($P < 0.1$)

Table III.3. Influence of increased rate of vegetative nitrogen and paclobutrazol application on tiller population, 1985.

Treatment	Tiller Number at Peak Anthesis				Spikes at Maturity
	Veg	Late	Fertile	Total	
	(per m^{-2})				
Nitrogen Rate (Veg. N)					
60 kg ha^{-1}	857	286	948	2091	2474
120 kg ha^{-1}	933	397	1027	2357	2128
180 kg ha^{-1}	891	457	832	2180	2827
N Rate Contrasts					
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	(P< 0.1)
Paclobutrazol (F.I.)					
0.0 kg a.i. ha^{-1}	766	420	957	2143	2501
0.75 kg a.i. ha^{-1}	1021	341	914	2275	2452
Paclobutrazol Contrast					
Check vs. treatment	NS	NS	NS	NS	NS

Table III.4. Influence of increased rate of vegetative nitrogen and paclobutrazol application on inflorescence components, 1984.

Treatment	Spikelets per Spike	Florets per Spikelet			
		Bottom	Middle	Top	Mean
	(No.)				
Nitrogen Rate (Veg. N)					
60 kg ha^{-1}	25.2	7.9	8.6	6.0	7.5
120 kg ha^{-1}	25.5	8.3	9.1	6.3	7.9
180 kg ha^{-1}	25.7	8.9	9.5	6.8	8.4
N Rate Contrasts					
Linear	NS	**	*	(P< 0.1)	**
Quadratic	NS	NS	NS	NS	NS
Paclobutrazol (F.I.)					
0.0 kg a.i. ha^{-1}	25.6	8.7	9.2	6.1	8.0
0.75 kg a.i. ha^{-1}	25.3	8.1	8.9	6.7	7.9
Paclobutrazol Contrast					
Check vs. treatment	NS	*	NS	(P< 0.1)	NS

inflorescence. The number of spikelets per spike was not affected by either Veg. N or paclobutrazol. In 1985, however, no significant treatment effect was observed on floret number per spikelet (Table III.5). Although, a greater number of spikelets per spike resulted from 120 kg N ha^{-1} used without the growth retardant; no significant reduction of spikelet number was observed at the other N rates.

Potential yield. A greater number of spikes at maturity and more florets per spikelet combined to significantly increase the potential number of seeds for both Veg. N and paclobutrazol main effects in 1984 (Table III.6). However, the actual number of seed recovered at harvest was not increased by higher levels of Veg. N, and thus the number of seeds per spike and floret site utilization (FSU) were reduced. Conversely, paclobutrazol significantly increased the actual number of seed recovered at harvest, the number of seeds per spikelet, and FSU (Table III.6).

In 1985, the potential number of seeds was significantly increased with higher levels of Veg. N; however, paclobutrazol had no significant effect (Table III.7). Conversely, seeds per spike were significantly increased following application of paclobutrazol, while no effect of increased level of Veg. N was observed. In addition, several significant interactions between increased rate of vegetative nitrogen and paclobutrazol application were observed in 1985 (Table III.8). These data show that although paclobutrazol treatment resulted in a significant increase regardless of nitrogen rate, the most positive response was attained when growth retardant application was combined with 120 kg N ha^{-1} used during vegetative development. FSU was increased 151% (21.3% vs. 53.5%) for the above treatment.

Table III.5. Influence of increased rate of vegetative nitrogen and paclobutrazol application on inflorescence components, 1985.

Treatment	Spikelets per Spike	Florets per Spikelet			
		Bottom	Middle	Top	Mean
	---------------------	----------------	(No.)	----------------	----------------
Nitrogen Rate (Veg. N)					
60 kg ha^{-1}	19.9	6.5	7.7	5.8	6.7
120 kg ha^{-1}	21.3	6.3	7.7	5.8	6.6
180 kg ha^{-1}	20.8	7.1	8.4	6.3	7.3
N Rate Contrasts					
Linear	x[1]	NS	NS	NS	NS
Quadratic	x[1]	NS	NS	NS	NS
Paclobutrazol (F.I.)					
0.0 kg a.i. ha^{-1}	21.3	6.6	7.7	5.7	6.7
0.75 kg a.i. ha^{-1}	20.0	6.7	8.1	6.2	7.0
Paclobutrazol Contrast					
Check vs. treatment	x[1]	NS	NS	NS	NS

[1] N rate x paclobutrazol interaction significant at $P < 0.05$

Table III.6. Influence of increased rate of vegetative nitrogen and paclobutrazol application on potential and actual seed yield, seeds per spike, floret site utilization (FSU), and 1000 seed weight, 1984.

Treatment	Potential Seed Number	Actual Seed Number	Seeds per Spike	FSU	Seed Weight
	--(m^{-2} x 10^3)--		(No.)	(%)	(kg ha^{-1})
Nitrogen Rate (Veg. N)					
60 kg ha^{-1}	361	89.6	45.6	24.6	1481
120 kg ha^{-1}	441	91.0	40.5	20.2	1517
180 kg ha^{-1}	502	81.7	35.5	16.9	1409
N Rate Contrasts					
Linear	**	NS	*	**	NS
Quadratic	NS	NS	NS	NS	NS
Paclobutrazol (F.I.)					
0.0 kg a.i. ha^{-1}	387	57.1	31.4	15.8	1016
0.75 kg a.i. ha^{-1}	482	117.8	49.6	25.3	1922
Paclobutrazol Contrast					
Check vs. treatment	*	**	**	**	**

Table III.7. Influence of increased rate of vegetative nitrogen and paclobutrazol application on potential seed yield, seeds per spike, 1000 seed weight, total dry weight, and straw weight, 1985.

Treatment	Potential Seed Number	Seeds per Spike	1000 Seed Weight	Total Dry Weight	Straw Weight
	($m^{-2} \times 10^3$)	(No.)	(g)	--(m t ha^{-1})--	
Nitrogen Rate (Veg. N)					
60 kg ha^{-1}	322	40.1	1.79	8.2	6.7
120 kg ha^{-1}	301	49.2	1.80	8.9	7.1
180 kg ha^{-1}	419	40.3	1.81	9.3	7.5
N Rate Contrasts					
Linear	*	NS	NS	**	**
Quadratic	($P< 0.1$)	NS	NS	NS	NS
Paclobutrazol (F.I.)					
0.0 kg a.i. ha^{-1}	351	32.2	1.85	8.6	7.2
0.75 kg a.i. ha^{-1}	344	54.2	1.75	9.0	7.0
Paclobutrazol Contrast					
Check vs. treatment	NS	**	**	NS	NS

Table III.8. Interaction of increased rate of vegetative nitrogen and paclobutrazol application on actual seed number, seed yield, harvest index, and floret site utilization (FSU), 1985.

N Rate (kg ha^{-1}) x Paclobutrazol Intermeans	Actual Seed Number	Seed Weight	Harvest Index	FSU
	($m^{-2} \times 10^3$)	(kg ha^{-1})	(%)	(%)
N Rate / 0.0 kg a.i. ha^{-1}	72.4	1330	15.7	27.2
60 \ 0.75 kg a.i. ha^{-1}	104.5	1810	22.5	33.8
N Rate / 0.0 kg a.i. ha^{-1}	70.8	1304	15.7	21.3
120 \ 0.75 kg a.i. ha^{-1}	124.0	2167	22.9	53.5
N Rate / 0.0 kg a.i. ha^{-1}	86.0	1602	17.6	22.5
180 \ 0.75 kg a.i. ha^{-1}	115.8	2023	21.5	31.3
LSD .05 for intermeans	14.2	235	1.8	14.4

Dry matter distribution at final harvest. Total dry weight at harvest and straw weight were significantly increased in 1984 when paclobutrazol was applied to plots receiving either 120 or 180 kg N ha^{-1} during vegetative development (Table III.9). There was no difference observed where only 60 kg N ha^{-1} was applied. In 1985, a significant linear increase in both total dry weight and straw weight resulted from increased level of Veg. N; however, no significant difference due to paclobutrazol was observed (Table III.7).

Seed yield was significantly increased in 1984 following application of paclobutrazol; there was no effect due to increased level of Veg. N (Table III.6). In 1985 a significant interaction between increased rate of vegetative nitrogen and paclobutrazol application was observed; seed yield was significantly increased by growth retardant application at each level of Veg. N; however, the magnitude of this increase was greatest where 120 kg N ha^{-1} was applied (Table III.8). Also, the 1000 seed weight was significantly reduced in paclobutrazol treated plots in 1985 (Table III.7). And in 1984 1000 seed weight was also reduced, but only where 60 and 120 kg N ha^{-1} was applied; no significant reduction was observed where 180 kg N ha^{-1} was applied (Table III.9).

Lodging percentages and severity. May-June, 1984, the wettest such two-month period on record, produced severe lodging. Lodging did not significantly differ between Veg. N levels at spike emergence (14 May) or peak anthesis (7 June); however, application of paclobutrazol nearly eliminated lodging throughout this period (Table III.10). Lodging data at later dates, during seed filling (22 June) and near maturity (5 July), found a significant interaction between increased rate of

Table III.9. Interaction of increased rate of vegetative nitrogen and paclobutrazol application on total dry weight, straw weight, harvest index, and 1000 seed weight, 1984.

N Rate (kg ha^{-1}) x Paclobutrazol Intermeans		Total Dry Weight	Straw Weight	Harvest Index	1000 Seed Weight
		--(m t ha^{-1})--		(%)	(g)
N Rate 60	/ 0.0 kg a.i. ha^{-1}	7.5	6.5	13.7	1.80
	\ 0.75 kg a.i. ha^{-1}	7.2	5.3	27.1	1.59
N Rate 120	/ 0.0 kg a.i. ha^{-1}	6.9	5.9	14.9	1.78
	\ 0.75 kg a.i. ha^{-1}	8.5	6.5	24.2	1.62
N Rate 180	/ 0.0 kg a.i. ha^{-1}	5.5	4.5	18.2	1.76
	\ 0.75 kg a.i. ha^{-1}	7.9	6.1	24.0	1.70
LSD .05 for intermeans		1.5	1.3	3.4	0.08

Table III.10. Influence of increased rate of vegetative nitrogen and paclobutrazol application on the area of plot lodged (%) and severity of lodging (1-5) at two dates, 1984.

Treatment	Lodging: 5-14-84		Lodging: 6-7-84	
	Area	Severity	Area	Severity
	(%)	(1-5)	(%)	(1-5)
Nitrogen Rate (Veg. N)				
60 kg ha^{-1}	28	2	37	3
120 kg ha^{-1}	36	3	43	3
180 kg ha^{-1}	35	3	44	3
N Rate Contrasts				
Linear	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS
Paclobutrazol (F.I.)				
0.0 kg a.i. ha^{-1}	66	4	76	5
0.75 kg a.i. ha^{-1}	0	1	7	1
Paclobutrazol Contrast				
Check vs. treatment	**	**	**	**

vegetative nitrogen and paclobutrazol application (Table III.11). Although paclobutrazol significantly reduced both the area and severity of lodging at each level of Veg. N, lodging control was less at higher fertility levels.

In 1985 dry weather reduced the significance of early lodging; however, 56 mm of rain was recorded in the first 8 days of June (185% of average), and this was followed by 51 consecutive day without rain. Lodging during the seed filling period was significantly less in paclobutrazol treated plots; differences between Veg. N levels where not apparent (Table III.12).

Table III.11. Interaction of increased rate of vegetative nitrogen and paclobutrazol application on the area of plot lodged (%) and severity of lodging (1-5) at two dates, 1984.

N Rate (kg ha^{-1}) x Paclobutrazol Intermeans	Lodging: 6-22-84		Lodging: 7-5-84	
	Area	Severity	Area	Severity
	(%)	(1-5)	(%)	(1-5)
N Rate / 0.0 kg a.i. ha^{-1}	85	5	90	5
60 \ 0.75 kg a.i. ha^{-1}	28	3	33	3
N Rate / 0.0 kg a.i. ha^{-1}	87	5	90	5
120 \ 0.75 kg a.i. ha^{-1}	52	4	60	4
N Rate / 0.0 kg a.i. ha^{-1}	83	5	90	5
180 \ 0.75 kg a.i. ha^{-1}	55	4	63	4
LSD .05 for intermeans	12	0.4	11	0.4

Table III.12. Influence of increased rate of vegetative nitrogen and paclobutrazol application on the area of plot lodged (%) and severity of lodging (1-5) at two dates, 1985.

Treatment	Lodging: 6-5-85		Lodging: 6-21-85	
	Area	Severity	Area	Severity
	(%)	(1-5)	(%)	(1-5)
Nitrogen Rate (Veg. N)				
60 kg ha^{-1}	58	3	87	5
120 kg ha^{-1}	58	4	68	5
180 kg ha^{-1}	55	4	82	5
N Rate Contrasts				
Linear	NS	NS	NS	NS
Quadratic	NS	NS	*	NS
Paclobutrazol (F.I.)				
0.0 kg a.i. ha^{-1}	71	4	89	5
0.75 kg a.i. ha^{-1}	43	3	69	4
Paclobutrazol Contrast				
Check vs. treatment	**	**	**	**

DISCUSSION

The total tiller number at peak anthesis was lower for all treatments in 1985 than in 1984, although at maturity there was a greater number of spikes in 1985. Dry spring weather in 1985 probably reduced vegetative tiller development, resulting in a lower tiller density at peak anthesis. This effect subsequently delayed and lessened the severity of lodging, thereby reducing tiller mortality. These conditions created a situation where response to paclobutrazol application in 1985 had no significant effect on fertile tiller number at peak anthesis or on the number of spikes at maturity. The increased potential seed number in 1985 was a result of increased level of Veg. N, whereas in 1984 both N and paclobutrazol significantly increased yield potential. However, the actual number of seeds recovered at harvest was affected only by paclobutrazol in both years. Improved seed recovery was the result of a greater number of seeds per spike at maturity in paclobutrazol treated plots.

Extremely wet conditions during May-June, 1984, slightly delayed maturity in heavily fertilized plots that were subsequently treated with paclobutrazol. However, under the drier conditions of 1985 no significant difference in seed moisture content was found as plots approached maturity. Seed yield was not significantly improved by increased level of Veg. N in either year, although in 1984 a greater potential yield due to N was observed. This suggests that the 0.75 kg a.i. ha^{-1} rate of paclobutrazol may not be sufficient to reduce lodging to the extent necessary to insure maximum seed filling under growing conditions that stimulate vegetative growth and severe lodging. This may account for higher rates of paclobutrazol required for optimum seed production under United Kingdom conditions, which have a prolonged cool-moist spring growing season. In less severe lodging conditions during 1985, however, 0.75 kg a.i. ha^{-1} of paclobutrazol provided lodging control at each level of N; the maximum response was where paclobutrazol was used following 120 kg N ha^{-1} during the vegetative growth stage.

Significant linear correlation coefficients were found between the severity of lodging at maturity and fertile tiller number at peak anthesis, number of spikes at harvest, seed yield, harvest index, potential and actual number of seed, seeds per spike, and FSU in 1984. Under the drier conditions in 1985 the significance of these correlations was less significant. (Significant simple correlation coefficients for 1984 and 1985 are presented in Appendix Tables 11 and 12, respectively.)

SUMMARY

Increased yield potential following higher rates of Veg. N in 1984 was not recovered as higher seed yield, even where paclobutrazol was applied. In addition, FSU decreased due to N treatments. This may be due to significant lodging of treated plots prior to completion of the seed filling process. Application of paclobutrazol significantly increased seed yield, a result of improved seed recovery due to more seeds per spike. However, the increased yield potential resulting from higher N rates was not recovered by application of paclobutrazol.

Conversely, in 1985 a significant Veg. N x paclobutrazol interaction was reported, which found 120 kg N ha^{-1} yielding significantly more than the other N treatments if followed with a growth retardant application.

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CONCLUSIONS

The application of heavy rates of N increased the number of late-formed tiller, which increased the yield potential of the stand; however, the number of seeds per spike and FSU declined with greater potential. As a result seed yield of perennial ryegrass appears quite insensitive to either early or late spring N applications between 60-120 kg ha^{-1}.

Paclobutrazol applied alone under uniform N management can significantly reduce lodging and increase seed yield. Actual seed number recovered at final harvest was significantly greater in paclobutrazol treated plots due to an increased number of seeds per spike and spikes per unit area. The efficiency of seed production was increased by paclobutrazol application as indicated by the significant increase in harvest index. Improved efficiency and seed recovery appears to result from a delay in lodging and a reduction in the severity of lodging.

Increased yield potential resulting from higher levels of spring N applied during vegetative growth stage was not recovered by application of paclobutrazol. Where severe lodging conditions occur prior to the completion of seed filling, 0.75 kg a.i. ha^{-1} paclobutrazol may not be sufficient to reduce lodging, particularly at higher N levels.

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APPENDICES

Appendix Table 1. ANOVA table showing source of variation, degrees of freedom, and F ratios used to establish significance (above), and orthogonal contrasts used to calculate the partitioned sum of squares (below).

Source	df			F
Rep	5			
Treatment	15			
Veg. N		3		
Check vs. N treatment			1	1/75 df
Linear			1	1/75 df
Quadratic			1	1/75 df
S.I. N		3		
Check vs. N treatment			1	1/75 df
Linear			1	1/75 df
Quadratic			1	1/75 df
Veg. N x S.I. N		9		9/75 df
Error	75			
Total	95			

Orthogonal contrast coefficients used:

	0	60	90	120
Check vs. tmt.	-3	+1	+1	+1
Linear	0	-1	0	+1
Quadratic	0	+1	-2	+1

Appendix Table 2. Meteorological data for the 1981-82 and 1982-83 crop years at the Hyslop Crop Science Field Laboratory, Corvallis, Oregon.

	Daily Air Temperature Averages				Total Monthly Precipitation		
Month	1981-82		1982-83				
	Maximum	Minimum	Maximum	Minimum	1981-82	1982-83	1951-80
	(C°)	(C°)	(C°)	(C°)	(mm)	(mm)	(mm)
September	25.1	8.5	23.3	9.6	78	48	38
October	16.6	4.9	17.9	5.8	140	92	86
November	12.4	4.3	9.7	1.4	171	140	157
December	9.3	2.8	8.2	1.8	355	268	197
January	6.1	0.4	9.0	2.4	183	176	192
February	9.6	1.6	11.2	4.0	181	262	123
March	12.4	2.0	13.5	5.7	90	223	118
April	14.3	2.4	16.1	4.1	116	76	62
May	20.1	5.9	20.8	7.0	10	38	49
June	23.5	10.6	21.1	9.3	38	35	30
July	25.4	10.8	23.3	11.2	11	65	8
August	27.2	10.8	26.4	11.9	7	56	21
Average	16.8	5.4	16.7	6.2	-	-	-
Total	-	-	-	-	1381	1480	1081

Appendix Table 3. Significant simple linear correlation coefficients (r) for the time and rate of spring nitrogen study, 1982.

Characteristics	Peak Anthesis Tiller Number				Total Spikes at Maturity	Percent Peak Anthesis Tiller Classification			Percent Survival (Spikes/ Total at Anthesis)	Spikelets per Spike	Florets per Spikelet			
	Veg	Late	Fertile	Total		Veg	Late	Fertile			Bottom	Middle	Top	Mean
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.00	0.20		0.69		0.94		-0.65	-0.40				-0.18	
2		1.00	-0.23	0.32			0.84	-0.68		0.36				
3			1.00	0.66		-0.17	-0.61	0.57	-0.56				-0.25	0.18
4				1.00		0.47	-0.22	-0.23	-0.69				-0.31	
5					1.00			-0.19	0.64					
6						1.00		-0.72	-0.23					
7							1.00	-0.60	0.24	0.40				
8								1.00		-0.24				
9									1.00				0.29	
10										1.00	0.28	0.31	0.18	0.28
11											1.00	0.90	0.78	0.96
12												1.00	0.72	0.94
13													1.00	0.89
14														1.00
15														
16														
17														
18														
19														
20														
21														
22														
23														

The 0.01, 0.05, and 0.10 significance levels (n = 96) are 0.26, 0.20, and 0.17, respectively.

Appendix Table 3. (continued)

Characteristics	Total Dry Weight	Straw Weight	Seed Weight	Harvest Index	1000 Seed Weight	Potential Seed Number	Actual Seed Number	Seeds per Spike	Floret Site Utiliza.
	15	16	17	18	19	20	21	22	23
1			0.19				0.23		
2						0.20			
3						-0.18			
4									
5						0.73		-0.72	-0.60
6			0.20				0.24		
7						0.25			
8						-0.20	-0.20		
9						0.55		-0.48	-0.47
10						0.50			-0.40
11						0.58			-0.41
12			0.23			0.60			-0.37
13						0.59			-0.45
14						0.63			-0.44
15	1.00	0.98	0.74				0.71	0.49	0.41
16		1.00	0.60	-0.29			0.58	0.41	0.35
17			1.00	0.58			0.94	0.64	0.52
18				1.00			0.54	0.33	0.26
19					1.00		-0.30		-0.22
20						1.00		-0.48	-0.74
21							1.00	0.66	0.57
22								1.00	0.83
23									1.00

The 0.01, 0.05, and 0.10 significance levels (n = 96) are 0.26, 0.20, and 0.17, respectively.

Appendix Table 4. Significant linear correlation coefficients (r) for the Time and rate of spring nitrogen study, 1983

Characteristics	Peak Anthesis Tiller Number				Total Spikes at Maturity	Percent Peak Anthesis Tiller Classification			Percent Survival (Spikes/ Total at Anthesis)	Spikelets per Spike	Florets per Spikelet			
	Veg	Late	Fertile	Total		Veg	Late	Fertile			Bottom	Middle	Top	Mean
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.00	0.18	-0.19	0.30		0.95		-0.66	-0.30	0.28	0.29	0.30		0.26
2		1.00	-0.20	0.36			0.94	-0.73	-0.31	0.45	0.39	0.35		0.35
3			1.00	0.76		-0.41	-0.45	0.59	-0.43		-0.31		0.25	
4				1.00					-0.67	0.21		0.23	0.30	0.19
5					1.00				0.65					
6						1.00		-0.68		0.22	0.29	0.25		0.23
7							1.00	-0.78		0.39	0.39	0.28		0.28
8								1.00	0.18	-0.42	-0.47	-0.36		-0.35
9									1.00			-0.21	-0.27	-0.20
10										1.00	0.33	0.35		0.31
11											1.00	0.84	0.38	0.39
12												1.00	0.63	0.96
13													1.00	0.72
14														1.00
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														

The 0.01, 0.05, and 0.10 significance levels (n = 96) are 0.26, 0.20, and 0.17, respectively.

Appendix Table 4. (continued)

Characteristics	Total Dry Weight	Straw Weight	Seed Weight	Harvest Index	1000 Seed Weight	Potential Seed Number	Actual Seed Number	Seeds per Spike	Floret Site Utiliza.	Lodging: 5-12-83		Lodging: 5-27-83	
										Area	Severity	Area	Severity
	15	16	17	18	19	20	21	22	23	24	25	26	27
1					0.18					0.23	0.27		
2						0.26				0.22			
3												0.26	0.20
4					0.20	0.19				0.30	0.28	0.32	0.28
5						0.73		-0.69	-0.63				
6											0.20		
7						0.19							
8						-0.19		-0.18		-0.18			
9					-0.20	0.36		-0.47	-0.32	-0.18	-0.18	-0.22	-0.20
10						0.43			-0.26	0.36	0.31	0.21	
11	0.23	0.21	0.30		0.41	0.55	0.23	0.20	-0.33	0.48	0.44	0.37	0.39
12	0.29	0.27	0.38		0.62	0.57	0.28	0.24	-0.32	0.65	0.63	0.63	0.61
13	0.19		0.30		0.53	0.30	0.20	0.21	-0.19	0.52	0.50	0.45	0.48
14	0.27	0.25	0.38		0.59	0.56	0.27	0.25	-0.33	0.63	0.60	0.55	0.56
15	1.00	1.00	0.81	-0.62	0.45	0.17	0.78	0.51	0.33	0.23	0.26	0.44	0.57
16		1.00	0.77	-0.66	0.44		0.74	0.49	0.32	0.22	0.26	0.43	0.56
17			1.00		0.45	0.21	0.98	0.65	0.40	0.31	0.30	0.46	0.55
18				1.00	-0.19								-0.23
19					1.00	0.30	0.26	0.24		0.61	0.57	0.69	0.70
20						1.00		-0.39	-0.72	0.48	0.42	0.35	0.37
21							1.00	0.65	0.46	0.19	0.19	0.36	0.45
22								1.00	0.79			0.24	0.25
23									1.00	-0.28	-0.24		
24										1.00	0.91	0.61	0.54
25											1.00	0.62	0.54
26												1.00	0.84
27													1.00

The 0.01, 0.05, and 0.10 significance levels (n = 96) are 0.26, 0.20, and 0.17, respectively.

Appendix Table 5. ANOVA table showing source of variation, degrees of freedom, and F ratios used to establish significance (above), and orthogonal contrasts used to calculate the partitioned sum of squares (below).

Source	df		F
Rep	5		
Treatment	4		
Stage		1	1/20 df
Rate		1	1/20 df
Stage x Rate		1	1/20 df
Check vs. Factorial		1	1/20 df
Error	20		
Total	29		

Orthogonal contrast coefficients used:

		Stage 1		Stage 2	
	Check	Rate 1	Rate 2	Rate 1	Rate 2
Stage	0	-1	-1	1	1
Rate	0	-1	1	-1	1
Stage x Rate	0	1	-1	-1	1
Ck vs. Fact.	-4	1	1	1	1

Appendix Table 6. Meteorological data for the 1982-83 and 1983-84 crop years at the Hyslop Crop Science Field Laboratory, Corvallis, Oregon.

Month	Daily Air Temperature Averages				Total Monthly Precipitation		
	1981-82		1982-83				
	Maximum	Minimum	Maximum	Minimum	1982-83	1983-84	1951-80
	(C^{o})	(C^{o})	(C^{o})	(C^{o})	(mm)	(mm)	(mm)
September	23.3	9.6	22.8	8.8	48	13	38
October	17.9	5.8	17.4	4.7	92	27	86
November	9.7	1.4	11.9	5.5	140	252	157
December	8.2	1.8	4.8	-0.5	268	187	197
January	9.0	2.4	9.3	1.7	176	83	192
February	11.2	4.0	11.2	2.1	262	176	123
March	13.5	5.7	14.4	4.6	223	97	118
April	16.1	4.1	14.0	3.8	76	87	62
May	20.8	7.0	17.6	5.9	38	93	49
June	21.1	9.3	20.9	8.1	35	110	30
July	23.3	11.2	27.3	10.6	65	5	8
August	26.4	11.9	27.4	9.6	56	0	21
Average	16.7	6.2	16.6	5.4	-	-	-
Total	-	-	-	-	1480	1130	1081

Appendix Table 7. Significant linear correlation coefficients (r) for the paclobutrazol growth stage and rate study, 1983.

Characteristics	Peak Anthesis Tiller Number				Total Spikes at Maturity	Percent Peak Anthesis Tiller Classification			Percent Survival (Spikes/ Total at Anthesis)	Spikelets per Spike	Florets per Spikelet			
	Veg	Late	Fertile	Total		Veg	Late	Fertile			Bottom	Middle	Top	Mean
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.00		-0.47			0.96	0.29	-0.93					0.28	
2		1.00					0.85	-0.27						
3			1.00	0.94	0.31	-0.63	-0.34	0.65	-0.54	0.31		-0.33		
4				1.00		-0.35		0.35	-0.63	0.30		-0.35		
5					1.00	-0.28		0.29	0.57					
6						1.00		-0.97						
7							1.00	-0.52		-0.29				
8								1.00						
9									1.00	-0.30				
10										1.00		0.27		
11											1.00	0.66	0.30	0.80
12												1.00	0.38	0.85
13													1.00	0.73
14														1.00
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
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27														
28														
29														
30														
31														

The 0.01, 0.05, and 0.10 significance levels (n = 30) are 0.46, 0.36, and 0.27, respectively.

Appendix Table 7. (continued)

Characteristics	Total Dry Weight	Straw Weight	Seed Weight	Harvest Index	1000 Seed Weight	Potential Seed Number	Actual Seed Number	Seeds per Spike	Floret Site Utiliza.	Lodging: 5-10-83 Area	Lodging: 5-10-83 Severity	Lodging: 5-27-83 Area	Lodging: 5-27-83 Severity	Lodging: 6-22-83 Area	Lodging: 6-22-83 Severity	Lodging: 7-7-83 Area	Lodging: 7-7-83 Severity
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1			-0.38	-0.29	0.46		-0.39	-0.34	-0.32	0.48	0.46	0.45	0.46	0.31	0.34		0.44
2																	
3			0.46	0.38	-0.43	0.31	0.47	0.32	0.28	-0.38	-0.37	-0.36	-0.37		-0.33		-0.37
4			0.37	0.29	-0.30		0.38						-0.22				
5		-0.32	0.49	0.61	-0.53	0.73	0.50			-0.63	-0.61	-0.61	-0.61		-0.27		-0.35
6			-0.40	-0.30	0.43		-0.41	-0.33	-0.31	0.48	0.44	0.43	0.44		0.32		0.44
7		0.30		-0.41	0.37					0.42	0.44	0.44	0.44	0.30	0.30	0.35	0.29
8			0.42	0.37	-0.48		0.43	0.36	0.32	-0.54	-0.51	-0.50	-0.51	-0.31	-0.36		-0.47
9						0.38				-0.32	-0.30	-0.30	-0.30				
10						0.37											
11	-0.29	-0.32				0.59			-0.38								
12						0.38										-0.27	
13			0.28	0.29		0.43	0.28	0.27		-0.37	-0.33	-0.33	0.33	-0.40	-0.45	-0.38	-0.42
14						0.58								-0.35	-0.34	-0.36	
15	1.00	0.94	0.41				0.38	0.49	0.49								
16		1.00		-0.56	0.44	-0.34				0.30	0.33	0.33	0.33			0.31	
17			1.00	0.76	-0.69	0.44	1.00	0.81	0.77	-0.82	-0.82	-0.82	-0.82	-0.67	-0.80	-0.47	-0.70
18				1.00	-0.83	0.58	0.78	0.52	0.47	-0.88	-0.89	-0.89	-0.89	-0.72	-0.79	-0.60	-0.75
19					1.00	-0.45	-0.73	-0.54	-0.51	0.87	0.90	0.90	0.90	0.57	0.70	0.33	0.69
20						1.00	0.45			-0.56	-0.55	-0.55	-0.55	-0.39	-0.41	-0.43	-0.30
21							1.00	0.81	0.77	-0.84	-0.84	-0.84	-0.84	-0.67	-0.81	-0.47	-0.71
22								1.00	0.91	-0.60	-0.61	-0.61	-0.61	-0.65	-0.76	-0.38	-0.63
23									1.00	-0.55	-0.56	-0.56	-0.56	-0.49	-0.63		-0.60
24										1.00	0.99	0.98	0.99	0.70	0.79	0.46	0.78
25											1.00	1.00	1.00	0.71	0.80	0.47	0.79
26												1.00	1.00	0.70	0.80	0.47	0.79
27													1.00	0.71	0.80	0.47	0.79
28														1.00	0.87	0.82	0.82
29															1.00	0.68	0.86
30																1.00	0.60
31																	1.00

The 0.01, 0.05, and 0.10 significance levels (n = 30) are 0.46, 0.36, and 0.27, respectively.

Appendix Table 8. Significant linear correlation coefficients (r) for the paclobutrazol growth stage and rate study, 1984.

Characteristics	Peak Anthesis Tiller Number				Total Spikes at Maturity	Percent Peak Anthesis Tiller Classification			Percent Survival (Spikes/ Total at Anthesis)	Spikelets per Spike	Florets per Spikelet			
	Veg	Late	Fertile	Total		Veg	Late	Fertile			Bottom	Middle	Top	Mean
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.00			0.44		0.95	-0.48		-0.32					
2		1.00	-0.30	0.41		-0.38	0.82	-0.62						
3			1.00	0.56	0.31		-0.66	0.87	-0.42					
4				1.00					0.81		0.34			0.27
5					1.00			0.27			0.38	0.31		0.31
6						1.00	-0.50							
7							1.00	-0.73						
8								1.00						
9									1.00					
10										1.00	-0.29		-0.36	-0.33
11											1.00	0.83	0.62	0.93
12												1.00	0.51	0.88
13													1.00	0.82
14														1.00
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														

The 0.01, 0.05, and 0.10 significance levels (n = 30) are 0.46, 0.36, and 0.27, respectively.

Appendix Table 8. (continued)

Characteristics	Total Dry Weight	Straw Weight	Seed Weight	Harvest Index	1000 Seed Weight	Potential Seed Number	Actual Seed Number	Seeds per Spike	Floret Site Utiliza.	Lodging: 6-8-84		Lodging: 6-22-84		Lodging: 7-5-84	
										Area	Severity	Area	Severity	Area	Severity
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	-0.34		-0.45	-0.29	0.47		-0.49	-0.38	-0.35	0.34	0.33	0.29	0.45	0.36	0.53
2															
3						0.33						-0.27			
4									-0.30						
5			0.30	0.32		0.95	0.30	-0.49	-0.54				-0.27	-0.30	-0.28
6	-0.35		-0.43		0.49		-0.47	-0.37	-0.31	0.37	0.36	0.28	0.44	0.32	0.54
7															
8			0.38	0.36			0.38			-0.30	-0.28	-0.40	-0.41	-0.44	-0.34
9			0.35	0.36		0.72	0.34	-0.34	-0.35				-0.33	-0.36	-0.31
10															
11						0.60			-0.37				-0.29	-0.32	-0.38
12						0.54			-0.38						
13			0.35	0.31		0.32	0.35			-0.36	-0.41	-0.28	-0.38	-0.31	-0.33
14						0.55			-0.28		-0.29	-0.27	-0.31	-0.34	-0.36
15	1.00	0.95	0.64				0.61	0.45	0.40						
16		1.00	0.37	-0.31			0.34	0.28							
17			1.00	0.77	-0.58	0.29	0.99	0.65	0.56	-0.81	-0.79	-0.68	-0.80	-0.76	-0.69
18				1.00	-0.57	0.31	0.78	0.46	0.39	-0.88	-0.89	-0.86	-0.84	-0.79	-0.77
19					1.00		-0.69	-0.50	-0.38	0.67	0.68	0.53	0.58	0.50	0.62
20						1.00	0.31	-0.42	-0.56				-0.32	-0.33	-0.36
21							1.00	0.66	0.56	-0.83	-0.81	-0.69	-0.81	-0.76	-0.72
22								1.00	0.95	-0.60	-0.60	-0.45	-0.49	-0.43	-0.43
23									1.00	-0.51	-0.48	-0.35	-0.37	-0.32	-0.29
24										1.00	0.97	0.81	0.85	0.75	0.76
25											1.00	0.87	0.90	0.81	0.82
26												1.00	0.88	0.92	0.79
27													1.00	0.85	0.89
28														1.00	0.79
29															1.00

The 0.01, 0.05, and 0.10 significance levels (n = 30) are 0.46, 0.36, and 0.27, respectively.

Appendix Table 9. Meteorological data for the 1983-84 and 1984-85 crop years at the Hyslop Crop Science Field Laboratory, Corvallis, Oregon.

Month	Daily Air Temperature Averages				Total Monthly Precipitation		
	1983-84		1984-85				
	Maximum	Minimum	Maximum	Minimum	1983-84	1984-85	1951-80
	(C°)	(C°)	(C°)	(C°)	(mm)	(mm)	(mm)
September	22.8	8.8	23.7	8.6	13	19	38
October	17.4	4.7	15.0	5.4	27	118	86
November	11.9	5.5	10.7	3.9	252	344	157
December	4.8	-0.5	6.6	-0.1	187	102	197
January	9.3	1.7	5.8	-2.2	83	6	192
February	11.2	2.1	9.2	-0.1	176	93	123
March	14.4	4.6	11.7	1.1	97	125	118
April	14.0	3.8	16.8	5.5	87	27	62
May	17.6	5.9	19.6	6.0	93	24	49
June	20.9	8.1	24.1	8.6	110	56	30
July	27.3	10.6	30.6	11.3	5	14	8
August	27.4	9.6	27.2	10.0	0	12	21
Average	16.6	5.4	16.7	4.8	-	-	-
Total	-	-	-	-	1130	940	1081

Appendix Table 10. ANOVA table showing source of variation, degrees of freedom, and F ratios used to establish significance (above), and orthogonal contrasts used to calculate the partitioned sum of squares (below).

Source	df			F
Rep	5			
Treatment	5			
Veg. N		2		
Linear			1	1/25 df
Quadratic			1	1/25 df
Paclobutrazol		1		1/25 df
Veg. N x Paclobutrazol		2		2/25 df
Error	25			
Total	35			

Orthogonal contrast coefficients used:

Veg. N contrasts	60	120	180
Linear	-1	0	+1
Quadratic	+1	-2	+1

Paclobutrazol Contrast	Check	Treated
Check vs. treatment	-1	+1

Appendix Table 11. Significant linear correlation coefficients (r) for the Veg. N x paclobutrazol study, 1984.

Characteristics	Peak Anthesis Tiller Number				Total Spikes at Maturity	Percent Peak Anthesis Tiller Classification			Percent Survival (Spikes/ Total at Anthesis)	Spikelets per Spike	Florets per Spikelet			
	Veg	Late	Fertile	Total		Veg	Late	Fertile			Bottom	Middle	Top	Mean
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.00		-0.54		-0.31	0.97		-0.58	-0.34				-0.34	
2		1.00		0.76	0.58		0.83	-0.52						
3			1.00	0.39		-0.61	-0.49	0.86				0.29	0.30	0.35
4				1.00	0.36		0.29							
5					1.00	-0.37	0.50		0.84					
6						1.00		-0.55					-0.39	
7							1.00	-0.71	0.32		-0.31			
8								1.00			0.31			0.34
9									1.00					
10										1.00				
11											1.00	0.85	0.41	0.89
12												1.00	0.40	0.89
13													1.00	0.74
14														1.00
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														

The 0.01, 0.05, and 0.10 significance levels (n = 36) are 0.42, 0.33, and 0.28, respectively.

Appendix Table 11. (continued)

Characteristics	Total Dry Weight	Straw Weight	Seed Weight	Harvest Index	1000 Seed Weight	Potential Seed Number	Actual Seed Number	Seeds per Spike	Floret Site Utiliza.	Lodging: 5-14-84 Area	Lodging: 5-14-84 Severity	Lodging: 6-7-84 Area	Lodging: 6-7-84 Severity	Lodging: 6-22-84 Area	Lodging: 6-22-84 Severity	Lodging: 7-5-84 Area	Lodging: 7-5-84 Severity
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1			-0.63	-0.65	0.33	-0.38	-0.61	-0.45	-0.35	0.65	0.64	0.66	0.66	0.51	0.63	0.56	0.57
2						0.47											
3				0.42						-0.43	-0.41	-0.31	-0.43		-0.29		-0.32
4						0.35											
5	0.38		0.56	0.35		0.86	0.53			-0.48	-0.41	-0.48	-0.46	-0.41	-0.40	-0.34	-0.41
6			-0.63	-0.66	0.32	-0.46	-0.61	-0.42	-0.31	0.68	0.64	0.66	0.66		0.62	0.53	0.55
7						0.35											
8				0.39				0.35		-0.37	-0.36	-0.29	-0.41		-0.29	-0.31	-0.32
9	0.40	0.28	0.55	0.32		0.70	0.52			-0.40	-0.37	-0.44	-0.41	-0.45	-0.38	-0.41	-0.40
10																	
11	-0.58	-0.54	-0.41		0.28		-0.43	-0.33	-0.55	0.30		0.31			0.33	0.31	
12	-0.46	-0.46							-0.41								
13				0.43				0.32				-0.30	-0.30				
14	-0.42	-0.45							-0.33								
15	1.00	0.96	0.62				0.59	0.42	0.51	-0.34	-0.32	-0.40	-0.30				
16		1.00	0.37	-0.33			0.34		0.34								
17			1.00	0.73	-0.57	0.45	0.99	0.75	0.74	-0.86	-0.86	-0.90	-0.84	-0.78	-0.81	-0.78	-0.76
18				1.00	-0.55	0.42	0.74	0.61	0.50	-0.78	-0.80	-0.78	-0.76	-0.78	-0.79	-0.74	-0.80
19					1.00		-0.67	-0.59	-0.63	0.67	0.68	0.67	0.70	0.69	0.70	0.64	0.64
20						1.00	0.41			-0.42	-0.35	-0.44	-0.41	-0.31			-0.32
21							1.00	0.78	0.78	-0.88	-0.88	-0.92	-0.86	-0.81	-0.84	-0.81	-0.78
22								1.00	0.94	-0.67	-0.68	-0.69	-0.64	-0.63	-0.68	-0.68	-0.59
23									1.00	-0.62	-0.63	-0.64	-0.58	-0.63	-0.70	-0.70	-0.57
24										1.00	0.93	0.92	0.92	0.82	0.83	0.78	0.81
25											1.00	0.93	0.94	0.84	0.86	0.80	0.83
26												1.00	0.93	0.85	0.88	0.83	0.86
27													1.00	0.85	0.87	0.83	0.85
28														1.00	0.91	0.95	0.92
29															1.00	0.93	0.92
30																1.00	0.89
31																	1.00

The 0.01, 0.05, and 0.10 significance levels (n = 36) are 0.42, 0.33, and 0.28, respectively.

Appendix Table 12. Significant linear correlation coefficients (r) for the Veg. N x paclobutrazol study, 1985.

Characteristics	Peak Anthesis Tiller Number				Total Spikes at Maturity	Percent Peak Anthesis Tiller Classification			Percent Survival (Spikes/ Total at Anthesis)	Spikelets per Spike	Florets per Spikelet			
	Veg	Late	Fertile	Total		Veg	Late	Fertile			Bottom	Middle	Top	Mean
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.00	0.36	-0.29	0.73		0.76	0.92	-0.66	-0.39	0.37				
2		1.00	-0.47	0.50			-0.59	-0.66	-0.32	0.58			0.35	
3			1.00			-0.61		0.82	-0.32					
4				1.00					-0.70	0.44				
5					1.00				0.72					
6						1.00		-0.77						
7							1.00	-0.69		0.52			0.36	0.30
8								1.00		-0.41				
9									1.00	-0.31				
10										1.00				
11											1.00	0.93	0.44	0.89
12												1.00	0.55	0.93
13													1.00	0.79
14														1.00
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														

The 0.01, 0.05, and 0.10 significance levels (n = 36) are 0.42, 0.33, and 0.28, respectively.

Appendix Table 12. (continued)

Characteristics	Total Dry Weight	Straw Weight	Seed Weight	Harvest Index	1000 Seed Weight	Potential Seed Number	Actual Seed Number	Seeds per Spike	Floret Site Utiliza.	Lodging: 6-5-85		Lodging: 6-21-35	
										Area	Severity	Area	Severity
	15	16	17	18	19	20	21	22	23	24	25	26	27
1			0.29	0.37	-0.50		0.34						
2						0.30							
3						-0.35							0.30
4					-0.28			0.31					
5						0.75		-0.72	-0.65			0.43	
6		-0.32	0.31	0.48	-0.51		0.36			-0.29	-0.46		-0.43
7						0.29							
8			-0.29	-0.36	0.36		-0.31				0.33		0.31
9						0.43		-0.57	-0.46			0.33	
10						0.33							
11						0.39							
12						0.47							
13						0.30							
14						0.44							
15	1.00		0.60				0.54	0.47	0.41				
16		1.00			0.30								
17			1.00	0.88	-0.63		0.99	0.63	0.60	-0.70	-0.73	-0.40	-0.59
18				1.00	-0.76		0.91	0.50	0.50	-0.73	-0.78	-0.34	-0.67
19					1.00		-0.73	-0.40	-0.40	0.66	0.66		0.50
20						1.00		-0.59	-0.75			0.30	
21							1.00	0.62	0.60	-0.73	-0.76	-0.40	-0.60
22								1.00	0.92	-0.40	-0.54	-0.61	
23									1.00	-0.35	-0.53	-0.60	
24										1.00	0.77	0.33	0.65
25											1.00	0.45	0.75
26												1.00	
27													1.00

The 0.01, 0.05, and 0.10 significance levels (n = 36) are 0.42, 0.33, and 0.28, respectively.