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Dr. David O. Chilcote

Rapid tiller and root production can improve seedling survival and benefit stand establishment of perennial ryegrass (Lolium perenne L.) in commercial seed fields. Environmental conditions after establishment and inherent morphological factors combine to reduce the commercially harvested yield below the theoretical potential yield.

These studies were conducted to determine if the growth retardant paclobutrazol and KCl could favor maximum seed yields of the cultivar Ovation under field conditions. In addition, effects of paclobutrazol and P on seedling development were examined in a growth chamber.

Paclobutrazol increased seed yields in both first- and second-year stands in each of three climatically different years. Yield increases were primarily due to increased numbers of spikes per unit area during the wet year of 1984 and to increaseed numbers of seeds per spike in the dry years of 1985 and 1986. Seeds per unit area and harvest indices increased and thousand seed weights (TSW) decreased in all

three years. KCl applications were intended to offset the anticipated paclobutrazol-induced TSW reductions. Positive fertilizer effects were due to Cl rather than K. Chloride fertilizer salts tended to increase seed yields, seeds per unit area, and TSW in 1984 and significantly increased yields, seeds per unit area and TSW in 1985. Severe drought masked possible Cl effects in 1986. The effects of Cl were thought to be due to its influence on N form taken up by the plant.

Paclobutrazol reduced shoot and root weights but did not affect the shoot:root ratios of 90-day old growth chamber grown seedlings. Plant growth in height was reduced within two days of application, which suggested the dependence of seedlings on continual gibberellin production. Phosphorus increased the shoot weights of 90-day old seedlings, but did not affect root weights. Significant interactions were observed on the numbers of leaves and tillers per plant within 9 and 16 days of treatment applications, respectively. Paclobutrazol increased numbers of leaves and tillers per plant, but only at the high P rate. The reduced root growth caused by paclobutrazol and the immobile nature of P in the soil may account for the interaction effects.

Paclobutrazol and Nutrient Treatment Effects on Ovation Perennial Ryegrass

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J. Kevin Turner

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Redacted for privacy

Head of Department of Crop Science

Redacted for privacy

Dean of Graduate School

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INTRODUCTION

The goal of commercial seed production is to maximize the potential yield and to harvest yields as close to the potential as possible. Potential yield estimates made for perennial ryegrass assume that every fertile tiller produced will survive to harvest and every floret will set and develop a seed of average weight. Actual harvested yield, however, falls far short of the theoretical yield potential. Inherent morphological factors and environmental conditions can continue to limit the degree to which potential yield is achieved.

Through crop management, the farmer hopes to maximize yields by creating situations in which the plant can more fully utilize its environment. Plant nutrition and soil fertility management have long been practiced with this objective in mind. Recently, chemical growth regulators have become available which can alter plant morphology and improve harvested yields under a range of environmental conditions.

Successful stand establishment following seeding is an obvious prerequisite for the production of high yields of perennial ryegrass seed. The differences between attaining a good turfgrass stand and complete stand failure, however, can be very small and may depend on the rate of seedling growth. Several environmental factors and management techniques have been shown to influence the rate of turfgrass shoot and root growth, including light intensity, temperature, moisture level and nutrient status.

In recent years the use of plant growth regulators has increased in the management of grasses grown for both turf and seed. The use of growth regulators will require that soil fertility management be re-examined in response to chemically altered plant growth. These studies were undertaken to examine the effects of the plant growth regulator paclobutrazol and KCl on the seed yield, seed yield components, and growth habit of perennial ryegrass under western Oregon conditions. Positive responses to KCl led to further investigations to determine if the observed effects were due to K or Cl. Additional growth chamber studies were conducted to determine the influence of paclobutrazol and P treatments on the shoot and root growth of Ovation perennial ryegrass seedlings.

LITERATURE REVIEW

Several researchers have submitted formulas for calculating the potential or theoretical maximum seed yields of perennial ryegrass (10, 21, 29, 49). The components most frequently used to compute the potential yield are the number of fertile tillers per unit area, the number of spikelets per head, the number of florets per spikelet, and the average realized seed weight. In other words, potential yield estimates assume that every fertile tiller produced would survive to harvest and every floret would set and develop a seed of average weight (10).

The potential yield estimates for perennial ryegrass have generated figures that are greatly in excess of actual field-harvested yields. Ryle (76) estimated the potential seed yield of the cultivar S.24 to be 4,900 pounds per acre compared to an actual average of 570 pounds per acre. Hebblethwaite, Burbidge and Wright (43) estimated potential yield of perennial ryegrass to be over seven tons per hectare with actual yields averaging about 10% of this total potential.

Hebblethwaite, Wright, and Noble (49) defined yield potential as the number of florets per unit ground area of the crop at anthesis. They stated that the utilization of the yield potential is influenced by events and circumstances at and after anthesis. Conditions affecting pollination, fertilization and subsequent seed growth combine to determine seed number and seed size. Elgersma (21) referred to yield potential utilization as measuring the efficiency of the reproductive system and defined it as the percentage of flowers which produce seeds and the size to which the seeds develop.

Calculations used to describe actual seed yield employ a set of parameters which is quite similar to that used to calculate potential yield. The major difference, however, is that actual seed yield components generally include some measure of seed set percentage (28, 29, 50, 84) such that actual yield depends on the number of heads per unit area, the number of seeds per head, and the weight of a single seed. Seed set is a term which describes the early growth of the embryo and endosperm; "set" being determined by cell division following fertilization (50, 21).

Actual harvested yields underestimate the amount of seed produced because the amount of viable seed lost as shatter and the loss of light seed during threshing and conditioning are not accounted for. Still, the amount of seed produced by the plant falls far short of the calculated maximum potential.

Griffiths, Roberts, and Lewis (29) gave two broad reasons to explain the difference between the actual and potential yield of grasses. They cited the wide variety of adverse environmental stresses to which crops are subjected throughout their life cycle as one reason and the compensatory mechanisms whereby an improvement in one yield component often unfavorably affects another as the second reason. More specifically, Hebblethwaite, Wright, and Noble (49) said the shortfall was due to a loss of fertile tillers before and after ear emergence, and to poor utilization of potential seed sites. They pointed out that in perennial ryegrass, only 60% of the fertile tillers survive to harvest and less than 1 out of 6 florets develop into seeds which are harvested. They felt competition for light within the crop canopy contributed to tiller death and that lodging was a major factor responsible for poor floret site utilization.

Spiertz and Ellen (84) observed tiller death of up to 60% of the total population. Their data showed that tiller mortality increased with increasing tiller density, a situation in which competition for light in the canopy was intensified. They also found that supplemental light increased the number of seeds harvested per fertile tiller. Therefore, competition for light reduced both the number of fertile tillers and floret site utilization. Langer and Lambert (55) suggested that in a dense stand competition between tillers for light, nutrients, and water could prevent many tillers from contributing to seed yield.

Poor utilization of potential seed sites may be due to the consequences of uneven pollination, seed fertilization, development, and ripening. Anslow (2) pointed out that anthers emerged in perennial ryegrass over a 9 to 10 day period, depending on when the tiller originated. Andersen and Andersen (1) further demonstrated that anthesis occurred for a period of 10 days within a single spikelet and that this resulted in a range of seed developmental stages when subsequent dissections were made. Meijer (64) suggested that uneven development of ears and uneven ripening within ears contributed to a light seed fraction. These light, poorly filled seeds could be lost in threshing and seed conditioning processes.

Ryle (77) said the number of fertile tillers per unit area and the number of florets per head both are influenced by the date of tiller origin. The earlier a tiller is formed, the more likely it is to produce a head. That a tiller formed early has a greater chance to produce an inflorescence is due to the inductive requirement of exposure primarily to cold conditions (15). Heads arising from early formed tillers were shown to develop a greater number of spikelets and more florets per spikelet. Other workers have similarly reported that the seed yield from the heads of early formed tillers is greater than that of later formed tillers (2, 25, 61, 84).

Ryle (76) noted that the date of tiller origin influenced the numbers of unexpanded leaf primordium accumulated from early tiller bud growth to the beginning of reproductive development. During tiller leaf growth, leaf primordia were seen to be initiated faster than they expanded. Hence, there was a gradual increase in the length of the shoot apex and the number of primordia borne on it. Since spikelets develop in the axils of the leaf primordia (53), Ryle found that shoots arising in the early spring developed only about half as many potential seed sites as those originating in autumn and early winter. Ryle (77) also noted that floret number per spikelet was greater for early formed tillers and that this could be further increased at higher N rates. On the other hand, increases in temperature and day length tended to decrease florets per spikelet and spikelets per head.

Anslow (3) speculated that the lower fertility of florets on the last heads to emerge might have resulted from differences in the microclimate within the crop. These heads were shorter and occurred under conditions of reduced light intensity and greater humidity than the earlier, taller heads. This situation may have led to fewer florets opening and, therefore, to reduced fertilization.

Seed yield and fertile tiller number per area are not always closely related in studies involving perennial ryegrass. Hebblethwaite and Hampton (44) found that once fertile tillers reached a density of approximately 2,000 per square meter, further increases in density up to around 4,000 per square meter had little effect on either seed numbers or yield. Seed numbers accounted for most of the variation in yield, ranging from 60% to 98% of the yield variance. Hampton and Hebblethwaite (32) reported that over a period of years seed yield in perennial ryegrass is best explained by a variation in the number of seeds per unit area. In lodged crops, seed numbers were only poorly related to fertile tiller numbers. In non-lodged crops, fertile tiller numbers became a more important determining factor. Spiertz and Ellen (84) found seed yield and fertile tiller numbers to be closely correlated but speculated that the great differences in seed yield from year to year were due to variation in the numbers of seeds per head.

Several workers have asserted that variation in seed size is only a minor component in seed yield (61, 63, 84). Seed size tends to be relatively constant over a range of conditions; however, this may be the result of threshing and seed conditioning separations. In a review of 10 perennial ryegrass seed yield experiments, Hampton and Hebblethwaite (32) reported that seed yield depended primarily on the number of seeds per unit area and that, while seed size varied somewhat, it was not significantly related to seed number or yield.

Anslow (3), on the other hand, reported that seed harvested from early formed heads was 67% heavier than that in late heads. He thought this might be due to the unfavorable position the later, shorter heads occupy in the inter-inflorescence competition for light. This disadvantage would persist and intensify after the crop became lodged. The ability of the late, small heads to photosynthesize would thereby have been reduced and seed size would be less than possible in full daylight. Meijer (63), in agreement with Anslow, has shown that in less dense stands of Kentucky bluegrass and red fescue, the seed size was larger. In this situation, Meijer suggests, there is less shading and more assimilates available for seed filling. Meijer, however, concluded that seed weight was less important than numbers of panicles per area in these two species.

Day and Intalap (17) have shown that spring wheat stressed for moisture at the flowering and dough stages suffered grain yield reduction due to decreased seed weight. In this situation, the plants had fewer days from flowering to maturity and, consequently, had less time for carbohydrate accumulation in developing seeds.

The system of early and late formed tillers within a plant is an inter-related one in which intra-plant competition exists. Nyahosa, Marshall, and Sagar (68) traced the flow of labeled carbon between tillers and rhizomes in Kentucky bluegrass. Once established, primary tillers and rhizomes become independent of the parent shoot for carbohydrates. If, however, all but one of the tillers were defoliated, the defoliated primary tillers and rhizome tillers were once again supplied with carbohydrates from the remaining shoot.

A defoliated tiller obviously has a greatly reduced ability to produce its own photosynthates. Lodging similarly reduces a low-lying tiller's access to the light energy necessary for photosynthesis. Clemence and Hebblethwaite (14) demonstrated that subtending perennial ryegrass tillers increased in sink strength from 14 days after anthesis to just prior to harvest. These vegetative tillers subtending fertile tillers competed with the growing seed for the labeled photosynthates.

Ryle (79) presented data which showed that the proportion of labeled carbon moving to the subtending tillers and to the roots decreased as the ears developed. Tillers still received 10-20% of the carbon assimilated by the leaves at the seedhead emergence stage. Low-lying vegetative tillers, therefore, remained a competing sink for assimilates. The dependence of the subtending tillers on the primary reproductive tiller for assimilates would increase as light availability deep in the sward decreased.

Hampton et al (31) showed that preventing perennial ryegrass from lodging with paclobutrazol reduced the amount of labelled carbon exported from the flag leaf to subtending vegetative tillers and increased the proportion of labelled assimilates exported to the ear and stem. Similar results were observed in plants where lodging was prevented mechanically.

Hebblethwaite and Ivins (47) suggested that subtending tillers are likely to compete for assimilates until they become independent (at the three mature leaf stage) and for water, light, and minerals right up until harvest. Hebblethwaite (40) showed that increased tillering could occur after fertilization in response to excess water and suggested that this increase in vegetative tillers could result in increased competition for assimilates with floret sites.

Ong, Marshall, and Sagar (70) demonstrated that much of the carbon assimilated by, or translocated to, the small subtending tillers makes no contribution to the seed crop. They observed that in a perennial ryegrass stand, tillers which died were mainly the small vegetative tillers along with some small flowering tillers. Using labeled carbon, they showed that tiller death was largely due to lack of adequate carbon support from the larger tilers and that this process began during the period of stem elongation.

Tiller production and survival is strongly influenced by light intensity (4, 11, 56, 69, 84, 91). Tillering can be reduced by low light levels or by defoliation, both of which relate to photosynthate supply. At times, defoliation can improve light levels and may enhance tillering (94). Auda, Blaser, and Brown (4) found tillering in orchard-grass to be associated with light intensity. As light intensity increased from 25% of normal to normal sunlight, tillering increased. Laude (65) reported on work done with barley which showed that tillering and the general growth rate increased with increases in light intensity.

Chastain and Grabe (11) demonstrated that the establishment of red fescue by interplanting with winter wheat or winter barley companion crops resulted in decreased red fescue tiller numbers and dry matter production and increased tiller height. At peak cereal leaf area the photosynthetic photon flux density incident on the red fescue was reduced by as much as 90%. The inhibition of red fescue growth was attributed mainly to decreased light intensity rather than to competition for soil moisture or other factors.

Ong (69) has shown that light intensity is the main factor influencing tiller or leaf death. He pointed out that the smallest perennial ryegrass tillers were the most vulnerable when light intensity was reduced. Shading promoted tiller death and limited the production of new tillers. Ryle (78) observed that shading perennial ryegrass resulted in slower apical growth and delayed or inhibited inflorescence development. Supplemental light treatments after head emergence increased tillering, but these tillers all remained vegetative. All high light intensity treatments, whether given before or after the onset of inflorescence development, increased seed production.

Spiertz and Ellen (84) exposed field plots of perennial ryegrass to shading and supplemental light treatments. Increased light intensity stimulated tillering in both autumn and spring. The high spring light treatments increased the number of fertile tillers produced and also increased the fertility of all the reproductive tillers, defined as the relation between the number of florets and the number of viable seeds produced. They felt that these increases, which were in response to high light intensity, were due to a greater availability of assimilates for the rapidly growing embryos.

As mentioned earlier, seed set is the factor which distinguishes actual seed yield from potential seed yield. It is also the factor most frequently cited as responsible for the great yield fluctuations from year to year and from field to field.

In a study conducted by Westgate and Boyer (90), maize plants were stressed by withholding water for a few days at anthesis. The stress treatments reduced leaf water potential to -1.2 MPa, at which point photosynthesis was inhibited. Two days after pollination, plants were rewatered so subsequent seed development occurred at high leaf water potentials. Inspection of the ears 10 days after pollination showed that pollen tube growth and egg sac fertilization had occurred, but that embryo development had aborted after just one or two cell divisions. Since the water stress treatments had inhibited photosynthesis, it appears that current photosynthates are essential for seed set to occur. It is also implied that there is a limited capacity to mobilize existing reserves to the developing reproductive structures or a limited supply of reserves exist at this time in the life cycle. Consequently, any stress which reduces the supply of current photosynthates may contribute to reduced seed set.

Westgate and Boyer (89), again working with maize, demonstrated that seed abortion due to reduced current photosynthate supply could occur through the early grain fill stage. By imposing water stress treatments at early grain fill and maintaining them to maturity, yield reductions occurred which were due to decreased seed size and seed number per ear. It is thus seen that reductions in photosynthesis at seed set or early in seed filling may result in increased seed abortion.

Lodging in perennial ryegrass frequently occurs at or just before the onset of anthesis. Lodging may be advantageous in preventing seed losses due to shattering if it occurs after seed formation (29). Nevertheless, early lodging has been cited as a causal factor in the shortfall of actual yields from potential yield levels (10, 28, 29, 61). Wright and Hebblethwaite (92) showed that potential yield at anthesis, in fact, does not differ between lodged and unlodged crops, even though many studies have demonstrated actual seed yield reductions due to lodging.

Large increases in harvested seed result if lodging is prevented or reduced (61). Seed set reductions due to lodging have been identified as a major factor responsible for decreased yields (29, 43, 49). Lowered seed set in lodged crops has been attributed to several causes including reduced pollen release and dispersal (28, 40, 42, 74), restricted light interception (42), and a limited supply of assimilates

(10, 38, 49) Hebblethwaite, Burbidge, and Wright (43) looked at yield reductions due to lodging in terms of the yield components of perennial ryegrass. They found natural lodging occurred at about the time the first ears emerged from the flag leaf sheath, resulting in yield losses of 30-70%, which were due to a decrease in the number of seeds per unit area. Hand shaking the lodged crop to aid pollination did not increase yields. When the crop was mechanically supported with wires, large yield increases of up to 60% over lodged controls were reported.

Hampton and Hebblethwaite (38) showed that in a lodged crop 60% of the florets initially set seed, but the percentage of florets contributing to yield rapidly fell to about 20% at harvest. It appears, then, that conditions in the crop canopy allowed for good anthesis, pollination, and fertilization, but that many developing seeds were subsequently aborted. The authors suggest that the supply of assimilates may be more important in ultimate seed set than the factors influencing fertilization. Lodging occurring at or before anthesis increases self-shading restrictions in photosynthetic capacity and may consequently reduce seed set.

Fungicide treatments have been shown to increase perennial ryegrass seed yields by increasing the number of seeds per spikelet even when incidence of leaf pathogens in control plots was low (34). It was thought that in untreated plots, earlier leaf senescence resulted in a reduced capacity to assimilate carbon and increased competition for photosynthates at a time when seed set was being determined.

Michael and Beringer (67) reviewed the involvement of phytohormones in the establishment and utilization of yield components in the gramineae. The number of seedheads per plant depend in part on the factors which influence apical dominance, including the balance between auxins and cytokinins. Jewiss (53) pointed out that auxin acts to reduce tillering and, hence, seed head production in the grasses. He showed that TIBA, an antiauxin, promoted the growth of axillary buds of wheat which were repressed during the inflorescence development stage.

Auxin is one of the factors inducing apical dominance in grasses by acting in the control of tillering. Gibberellin has been shown to reduce tillering in wheat (52) and barley (54). Tillering is also influenced by cytokinins which favor the growth of buds and tillers. Any factor favoring root growth and development, such as mineral nutrition, availability of N, increased light intensity, or moisture availability tends to increase the production of cytokinins and their export to the shoots (67).

Conditions which raise the carbohydrate level of the plant can reduce apical dominance. On the other hand, apical dominance is increased when plants are grown at low light intensity. Jewiss (53) indicated that raising the carbohydrate content may increase the quantity of auxin required to suppress bud development. It may also increase the carbohydrate supply translocated to the roots, which would increase cytokinin production. In this case, the cytokinin to auxin ratio would increase which would encourage lateral bud development.

Cytokinins may aid in seed retention once seed is set. Single seed weight is determined in part by the number and size of the endosperm cells. Cytokinins stimulate cell division and are in high concentrations in the developing seed during this stage. Cytokinins, auxins, and gibberellins have been shown to stimulate sink strength and to retard senescence while abscisic acid accelerates senescence (67).

Several different synthetic chemicals, which act to inhibit the production or activity of the naturally occurring phytohormones, have been used to modify general plant growth and development. Among the first of these plant growth regulators was maleic hydrazide (MH), which has been shown to reduce plant growth (57, 81). Hebblethwaite and Burbidge (42) found that MH decreased plant height and lodging in perennial ryegrass but also decreased all yield components. MH reduces cell division and stem elongation but also suppresses seed head formation in turf grasses. Other growth regulators which also limit foliar growth but inhibit seedhead formation include mefluidide and chlorflurecol (82).

Chlorocholine chloride (CCC) applications have been shown to increase seed yields in perennial ryegrass without reducing stem length or tillering (30, 42). Yield increases were thought to be due to a redistribution of dry matter resulting in a higher harvest index (42), increased fertile tiller survival, and increased seeds per spikelet (30).

Ancymidol (92) and flurprimidol (36, 45) have both been shown to reduce stem length and lodging and to increase seed yields in perennial ryegrass. Ancymidol reduced thousand seed weight but increased harvest index and number of seeds per unit area. Fertile tiller numbers were increased in one out of two years. Seed yield increases from flurprimidol were due to increased fertile tiller numbers and numbers of seeds per spikelet. Thousand seed weight was unchanged and harvest index was increased following flurprimidol treatments. In a mixed Kentucky bluegrass-red fescue turf, plants treated with flurprimidol possessed significantly more tillers and leaves than mowed controls, but shoot/root ratios did not differ (19).

In perennial ryegrass, plant growth regulators have most often been used in an attempt to decrease lodging and offset the yield losses associated with this growth habit. Success with such chemicals as MH, mefluidide, and chlorflurecol was limited because they inhibited seed head development. CCC applications did not decrease lodging but did result in some increases in seed yield. However, this effect has been considered too inconsistent and not great enough to justify further usage. Ancymidol has resulted in good yield increases and lodging reductions, but material cost outweighs the yield advantages. Flurprimidol has been demonstrated to effectively increase seed yields and decrease lodging in perennial ryegrass, but relatively high application rates are required. A new material, paclobutrazol, has been shown to have a comparable effect on perennial ryegrass seed yield and plant growth but at half the active ingredient rate of that required for flurprimidol.

Paclobutrazol (PP333 = [(2RS+3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)pentan-3-ol]), trade name "Parlay," is a broad-spectrum growth retardant which has activity on a wide range of graminaceous crops. It produces dose related vegetative growth reductions by inhibiting gibberellin biosynthesis resulting in reductions in cell division and extension (58). Gibberellin biosynthesis is inhibited by blocking the mono-oxygenases that oxidize ent-kaurene via ent-kaurenol and ent-kaurenal to ent-kaurenoic acid (71).

Richardson and Quinlan (73) observed only acropetal translocation of carbon labeled paclobutrazol applied to various parts of apple rootstock shoots. They detected no basipetal translocation and concluded that paclobutrazol moves in the xylem transpiration stream.

Shearing and Batch (82) have noted that the primary route of uptake of paclobutrazol in grasses is through the roots. Consequently, uptake and activity are influenced by soil moisture. A larger response occurs when rainfall is high than during dry conditions. Greater perennial ryegrass seed yield increases have been observed following applications made in wet years than in dry years in Oregon (51). Hampton and Hebblethwaite (35) reported that growth retardant effects on perennial ryegrass and significant seed yield increases were found only when applications occurred in wet conditions. Hebblethwaite, Hampton, and McLaren (46) also reported a lower level of response during a very dry season persisting from the floret initiation date of paclobutrazol application until seedhead emergence. They believed the dry conditions limited uptake of the material.

Several studies have been conducted in which seed yields have been increased in response to paclobutrazol applications. Many of these experiments have involved the application of paclobutrazol at the time of seed head formation and early stem elongation and were aimed at reducing or delaying lodging. With perennial ryegrass, which is susceptible to early and severe lodging, plants treated with paclobutrazol have remained more nearly upright for a longer period of development than non-treated plants (30, 35, 36, 37, 41, 51, 64, 93). Applications early in the inflorescence initiation stage (double-ridge stage) have resulted in increased lodging control; however, this may have been as a result of wetter conditions early compared to the later application dates (41). Stem length of perennial ryegrass is reduced by paclobutrazol (37, 51). Applications at spikelet initiation stage have been shown to reduce stem extension and lodging by decreasing the length of all internodes (37).

Langer and Lambert (55) have pointed out that seed production in perennial grasses depends on many interrelated factors which are controlled by variations in the environment. They reviewed information which shows that changes in one yield component are often accompanied by changes in the opposite direction of another. Paclobutrazol has been shown to inhibit a key physiological process in plants, gibberellin biosynthesis. As a result, lodging is delayed and decreased and, hence, the plant's environment changes. This changes the degree of inter and intra-plant competition for factors such as nutrients, light, water, and carbon assimilates and also changes the levels of the individual yield components.

There is good general agreement that paclobutrazol treatments early in the development of the initiating inflorescence can result in yield increases in perennial ryegrass. Yield increases have been attributed to increases in the number of fertile tillers at harvest (30, 35, 36, 37, 41, 51, 93), seeds per spikelet (30, 36, 38, 41), seeds per area (41, 46), and seeds per spike (51, 93).

Increases in fertile tiller numbers have been shown to be due to either an increase in fertile tiller production (30, 37) or an increase in survival (51). Increases in fertile tiller production may be due to a paclobutrazol caused reduction in apical dominance (30) resulting from an increase in carbon assimilation. Hunter (51) felt that more efficient light interception occurred in the erect, paclobutrazol treated plants and that in this environment a larger number of fertile tillers could be maintained. Hebblethwaite, Wright, and Noble (49) felt that changing the light availability within the crop canopy could affect both tiller death and tiller production.

Similarly, total tiller numbers, including both vegetative and fertile tillers, have been increased following paclobutrazol treatments (30, 33, 51). Both increased production of vegetative tillers (36) and decreased tiller mortality (51) have been associated with this general increase. Hunter (51) showed that Paclobutrazol applications on vegetative annual ryegrass increased tillering by 100% and decreased leaf area by 30% and tiller height by 90%. Weights of shoots and roots and root lengths were unaffected.

Hampton and Hebblethwaite (38) showed that seeds per spikelet are increased by paclobutrazol. They suggested that this was because the number of seeds aborted during seed development was reduced. Hunter (51) cited improved pollination in an erect crop, improved seed filling, and decreased embryo abortion as additional possible causes. Hampton (30) added consideration of alterations in the relationship between competing assimilate sinks as another possibility.

Meijer (64) suggested that seeds which were aborted late in the filling stage might give rise to an increased proportion of light seeds. If fertile tiller production is increased in paclobutrazol treated plants, then seeds of these late heads may be only poorly filled. Late aborted seeds and seeds of late formed heads may both be lost in the seed conditioning process. Meijer presented data that indicated the better light environment in treated plants led to an increase in fertile florets per area, an increased seed number, an increase in florets per area, but a decrease in percent of florets resulting in cleaned seed. Since the light seed fraction described by Meijer is presumably removed during harvest and conditioning, most of the paclobutrazol data suggests no differences in thousand seed weight (36, 38, 41, 51, 62) or only a slight decrease (30, 33, 51). Young (93) observed a perennial ryegrass seed size reduction with paclobutrazol in two years but no affect on germination percentage. Although seed filling conditions were improved with paclobutrazol, Young attributed the seed weight reduction to the greater numbers of developing seeds. Seed maturity has been delayed in treated plots (37, 38). Premature harvest could further contribute to the light seed fraction, lowered thousand seed weights, or both.

Germination and vigor have both been related to seed weight (18, 50). Maguire (60) has presented data in which a speed of germination index has been used to demonstrate that reduced seed size can result in reduced seedling vigor. Hebblethwaite, Hampton, and McLaren (46) ran standard germination tests (ISTA rules) that showed paclobutrazol had no significant effects on germination. However, little attention has been given to possible effects on seed vigor.

Paclobutrazol has been shown to alter dry matter partitioning in perennial ryegrass. Dry matter distribution has been altered in favor of the seed such that harvest index values have risen in treated plants (41, 46, 93). Harvest index is the ratio of the yield of grain to the total yield of plant material. It increases with light intensity, decreases with water stress and is influenced by nitrogen nutrient status (20). Hunter (51) reported that in the paclobutrazol treated plots, the amount of dry matter partitioned into the stem per unit of length was increased, but overall length was decreased.

Alterations in the shoot to root ratio have resulted from paclobutrazol applications. Hampton and Hebblethwaite (37) reported a reduction in stem dry matter, but root dry matter was increased at all rooting depths. In Kentucky bluegrass turf, on the other hand, paclobutrazol caused a significant decline in photosynthate partitioning to the roots at four weeks after application (39). Hampton and Hebblethwaite (35) found that under dry conditions, water deficits in perennial ryegrass built up more quickly when paclobutrazol was applied, especially in the 65-115 cm root zone. The authors thought this implied some effect on root growth.

Perennial ryegrass can deplete soil moisture to depths of three feet and below (26). First year stands have been shown to extract water from the 35 to 65 cm zone by mid April and from the 60-105 cm zone by early May. Older stands were shown to extract water from all zones by mid April (48). Various authors have reported rooting penetration of perennial ryegrass to depths of 99 to 145 centimeters depending on plant age and environment (87).

In rapidly growing plants, the carbohydrate supply is the limiting factor in root growth (9). Increasing the photoperiod or light intensity generally increases the growth of the whole plant, the root system being affected to a greater extent that the shoot. Similarly, shading or defoliation reduces perennial ryegrass root growth more than shoot growth (87). Root growth is, therefore, diminished when photosynthesis and the resulting supply of carbohydrates are reduced in response to factors such as defoliation, low light intensity, or lodging.

Through crop management, the farmer hopes to maximize yields by helping the plant more fully utilize its environment. Plant nutrition and soil fertility management have long been practiced with these goals in mind.

Jewiss (53) observed that high rates of N lead to a decrease in apical dominance and an increase in tillering. At still higher rates, however, plant density can result in self-shading, a decrease in carbohydrates and an increase in apical dominance. Hebblethwaite and Ivins (47) showed that beyond a certain level, increasing N did not further increase perennial ryegrass yields because of increased lodging and increased vegetative tiller production. Nitrogen deficiency, on the other hand, can decrease shoot/root ratios due to decreased shoot growth (9) and is characterized by poor tillering in cereals (65).

Nitrogen form can influence a plant's response to N nutrition. In seedling perennial ryegrass, maximum yields were obtained when cultures were supplied with low levels of NH_4 in combination with adequate NO_3 levels (72). Similar dry matter increases were observed in one month old wheat plants (8, 16). Addition of NH_4 depressed the uptake of NO_3, but total nitrogen uptake was increased (72). Increased NH_4 uptake has also been shown to decrease total inorganic cation content (8, 16, 72), lower NO_3 reductase activity (8), increase concentrations of P, S, and Cl in plant tissues (16), and increase plant succulence and shoot/root ratios (16).

In perennial ryegrass, NH_4 uptake is enhanced when Cl is the accompanying anion (59). Chloride salts have been shown to stimulate mineralization and inhibit nitrification in acid soils (27). Plants growing in such situations tend to increase their NH_4 uptake. Nitrate uptake might be directly inhibited by the presence of Cl in the nutrient medium. The most common anion antagonism is between NO_3 and Cl (65).

Wheat and barley yield increases in response to Cl fertilization have been reported in Oregon, North Dakota, and South Dakota. In Oregon, Cl has come under increased attention due to its role in combating take-all root rot Gaeumannomyces graminis (Sacc.) in winter wheat (12, 13, 85). High rates of Cl (428 kg Cl/ha) increased both fresh weight and grain yields of take-all infected winter wheat, and root infection was most effectively suppressed by the NH_4-N form. Christensen and Brett (12) suggest that on moderately acid soils, Cl salts appear to increase NH_4 uptake by decreasing nitrification, perhaps by reducing nitrifiers directly. They demonstrated that take-all is suppressed at low pH and stated that rhizosphere pH is reduced when NH_4 uptake exceeds NO_3 uptake.

Christensen et al (13) provided evidence that the osmotic potential in wheat is readily affected by fertilization with Cl salts. Winter wheat fresh weights, grain yields, and kernel weights were increased with spring Cl salt fertilizer application. These effects were possibly due to reduced stripe rust (Puccinia sp.) and take-all infections resulting from the Cl effects on water potential and turgor pressure. The authors speculate that the take-all pathogen may be indirectly affected by the decreased chemical potential of the water in the roots through a change in the quantity or nature of root exudates which could favor antagonistic soil microbes.

Roseburg et al (75) demonstrated that Cl inhibited nitrification under laboratory conditions. This effect was greatest at low soil pH (4.5-5.5) and was greatly reduced at pH above 6.0. They further pointed out that the "microbial transformation of NH_4 to NO_2 was more sensitive to inhibition by Cl than was the conversion of NO_2 to NO_3."

Scheyer et al (80) studied the effects of Cl on stripe rust and grain yield in winter wheat. Disease suppression was thought to be related to Cl effects on the osmotic and turgor potentials in wheat leaves, Cl effects on leaf habit (erectness) or Cl effects on the relative proportion and concentration of NH_4 and NO_3 in moderately acid soils. Increases in kernel weight and grain yield were also noted but were greater than could reasonably be accounted for by the degree of disease suppression.

Timm et al (86) reported a Cl induced disease repression and yield and quality increases in malting barley grown in North Dakota. Foliar and root diseases were suppressed, and NO_3 concentration in plant foliage tended to be reduced at the highest rate of KCl. Prior to the study, soils were determined to have ample native supplies of exchangeable K.

Timm et al (86) suggested that Cl could reduce plant NO_3 concentration by direct interference with NO_3 uptake and, under some circumstances, by inhibiting nitrification. Moraghan (66), however, showed that NO_3 uptake in sugar beets did not influence the plant's ability to absorb Cl.

Fixen et al (23) showed that barley and spring wheat grain yields in South Dakota increased in response to Cl treatments. Although grain yields increased in these studies, total dry matter yields did not; and, consequently, harvest indices were higher with Cl treatments. This suggests that Cl might be influencing carbohydrate translocation within the plant. Fixen (22) cites evidence that the severity of at least 15 different foliar and root diseases on 10 different crops have been significantly reduced with the addition of Cl. However, yield responses due to Cl have also been associated with improved plant water status in situations where disease suppression wasn't a factor (24).

Potassium, like Cl, is taken up very rapidly by plants. Both elements are particularly effective in osmotic adjustment and can be accumulated in high concentrations. Potassium may also be involved in stomatal regulation as it is known to accumulate in the guard cells of open stomata. Phloem loading and translocation processes are influenced by K nutrition (65).

Potassium was shown by Beringer and Schacherer (6) to influence the number of endosperm cells in barley grains. They reported a higher cell number at high K treatments 15 to 17 days after anthesis which was positively correlated with single grain weight at maturity. The authors assumed that high K nutrition affected photosynthesis and the supply of assimilates to the developing grain, which further contributed to increased single-grain weights.

Phosphorus provides the plant with a means of holding and transferring energy for metabolic processes (88). New turfgrass plantings can be slow to establish if the seedbed is low in P (83). Barry and Miller (5) observed increased growth rates in maize seedlings at greater than normally recommended levels of P. Plants suffering from P deficiency exhibit reduced shoot/root ratios and decreased tillering. Low soil P availability has been shown to limit adventitious root formation and tillering in spring wheat (7). Container grown perennial ryegrass plants have been reported to increase shoot and root weights following superphosphate applications to seedlings (76). In this study, the percentage of the plant's weight in the roots decreased; and, consequently, the shoot/root ratio increased.

Many factors operate to influence and determine the developmental growth and seed production performance of perennial ryegrass. Increases in harvested seed yields can occur when potential yield is increased and seed set percentage is either maintained or increased. Though not generally expected, increasing one or more yield components while avoiding yield compensation adjustments in the others, would also result in increased harvested yield. Through the judicious use of mineral nutrient fertilizers and plant growth regulators, it is hoped to manipulate yield components such that seed yields will be maximized.

I. Paclobutrazol and Chloride Treatment Effects on Ovation Perennial Ryegrass (*Lolium perenne* L.) Grown for Seed

ABSTRACT

Environmental conditions and inherent morphological factors can combine to reduce commercial seed yields of perennial ryegrass (*Lolium perenne* L.). This study examined effects of the growth retardant paclobutrazol (PP333 = ((2RS+3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)pentan-3-ol)) and Cl fertilizer treatments on seed yields. The effects of paclobutrazol and Cl fertilizer salts on seed yield, yield components, and growth habit of `Ovation' perennial ryegrass were studied during three climatically different years at Gervais, Oregon. Paclobutrazol significantly increased seed yields in all years. Yield increases from paclobutrazol were primarily due to an increase in the number of spikes per unit area during the wet year of 1984 and to increases in seeds per spike in the dry years of 1985 and 1986. Seeds per unit area and harvest indices increased and thousand seed weights (TSW) decreased in all three years. Paclobutrazol reduced the severity of lodging which provided better conditions for canopy photosynthesis and theoretically improved the allocation of photosynthates to the developing seeds. Potassium fertilizer (KCl) applications were intended to offset the anticipated paclobutrazol induced TSW reductions by enhancing carbohydrate translocation to the developing seeds. The 1985 data demonstrated that positive fertilizer effects

were due to Cl rather than K. Chloride fertilizer salts tended to increase seed yields, seeds per unit area, and TSW in 1984 and significantly increased yields, seeds per unit area and TSW in 1985. Severe drought masked the possible Cl effects in 1986. The effects of Cl were thought to be due to its influence on N form taken up by the plant. Chemical growth regulation and nutrient management altered plant morphology and growth habit resulting in increased yields under a wide range of environmental conditions.

INTRODUCTION

Potential yield estimates made for perennial ryegrass assume that every fertile tiller produced will survive to harvest and every floret will set and develop a seed of average weight (6). These estimates generate figures which are far greater than the actual harvested yields. Inherent morphological factors and environmental conditions can combine to limit the degree to which potential yield is achieved. The goal of commercial seed production is to maximize the potential yield and to harvest yields as close as possible to the potential.

Utilization of yield potential is influenced by events and circumstances at and after anthesis which combine to determine seed number and seed size (23). Lodging and competition for light within the crop canopy may contribute to poor floret site utilization and to tiller death (23, 25, 40). Uneven ripening due to a range in the dates of tiller origin and anthesis dates within the heads may result in a further loss of yield potential (1, 2, 31, 38).

Seed yield fluctuations in perennial ryegrass are best explained by the variation in the number of seeds per unit area (15). Fertile tiller numbers have a greater impact on seed number and yield when lodging is reduced (15). Shading promotes tiller death (32) while increased light intensity promotes fertile tiller production and enhances floret site utilization (40).

Reductions in photosynthesis at seed set or early in seed filling may result in increased seed abortion and, consequently, decreased seed size, decreased seed number per ear, and yield reductions. Water stress imposed at levels which inhibited photosynthesis either at anthesis or at early grain fill led to increased seed abortion and reduced yields in corn (41, 42). Lodged crops of perennial ryegrass have a restricted photosynthetic capacity and may suffer reduced seed set and yield.

The growth retardant paclobutrazol has been used in perennial ryegrass to decrease lodging and offset the yield losses associated with this problem. It produces dose related vegetative growth reductions by inhibiting gibberellin biosynthesis resulting in reductions in cell division and extension (26) and thereby reducing stem length. Perennial ryegrass seed yield increases resulting from paclobutrazol applications have been attributed to increases in the number of fertile tillers at harvest (14, 23, 24, 44), seeds per spikelet (14, 18), seeds per area (19), and seeds per spike (24, 44).

Hebblethwaite, et al (23) felt that changing the light availability within the crop canopy could affect both tiller death and tiller production. Seeds per spikelet increases from paclobutrazol could be due to several causes including improved pollination conditions (24) or decreased seed abortion during seed development (18). Seed size reductions have been reported in response to paclobutrazol (14, 16, 24, 44) in some cases but no affect was noted on germination percentage (44).

Potassium nutrition is known to enhance carbohydrate translocation processes. Beringer and Schacherer (4) showed that high K treatments increased the number of endosperm cells in barley grains which was positively correlated with single-grain weight at maturity. They assumed that K nutrition also affected photosynthesis and the supply of assimilates to the developing grain, which further contributes to increased single-grain weights.

Nitrogen form has been shown to influence the growth of perennial ryegrass and wheat seedlings (5, 9, 36). Ammonium uptake is enhanced when Cl is the accompanying anion (27). On moderately acid soils, Cl salts appear to increase NH_4 uptake by decreasing nitrification (7, 37). Scheyer et al (39) showed increased grain yields and kernel weights in winter wheat in response to Cl. Although Cl has been shown to significantly reduce the severity of at least 15 different foliar and root diseases on 10 different crops (11), yield responses have sometimes been observed in the absence of disease suppression (12, 39).

Several environmental and morphological factors combine to determine the extent to which potential yield is realized. Chemical growth regulation and nutrient management may alter plant morphology and improve the harvested yield levels under a range of environmental conditions.

This study was undertaken to examine the effects of paclobutrazol and Cl fertilizers on the seed yield, seed yield components, and growth habit of perennial ryegrass in western Oregon. First- and second-year stands were used in these investigations. Changes in soil water levels were examined since this could impact results. The study was conducted during three years which differed greatly in precipitation and temperature.

MATERIALS AND METHODS

Experiments were conducted on Ovation perennial ryegrass seed fields which were each located on Woodburn silt loam soils (fine-silty, mixed, mesic Aquultic Argixeroll) near Gervais, Oregon. Soils in this series are moderately well drained and moderately fine textured with slopes of 0 to 3 percent. Rooting is expected to a depth of 81 cm with few roots in the 81 to 99 cm depth and no roots below this point. The available water capacity is 28 to 33 cm and permeability is moderately slow (43).

A total of three field sites were used. A field planted 3 October 1983 was used to examine treatment effects on first- and second-year stands in 1984 and 1985, respectively. Similarly, a field planted 26 September 1984 provided first- and second-year stands in 1985 and 1986, respectively, and a field planted 15 October 1985 provided the first-year stand in 1986 (Appendix Table I.1). Planting was done with a modified grain drill using the carbon band technique, a 30 cm row width and a post-plant spray of 2.7 kg a.i. ha^{-1} diuron. After the first year's harvest, fall weed control was aided by baling and removing the straw and propane flame sanitizing the fields twice. Additional weed and disease control practices followed OSU recommendations (Appendix Table I.2). First-year fields received 170 kg N ha^{-1} from NH_4 and $(NH_2)_2CO$ sources. Second-year fields received 160 kg N ha^{-1} from NH_4 and NH_4NO_3 sources (Appendix Table I.3).

Soil samples were taken from the experimental sites in early spring in 1985 and 1986. OSU Soil Testing Laboratory values indicated pH ranged from 5.6 to 5.8 and P and K levels ranged from high to very high (Appendix Table I.4)..

Factorial experiments were conducted to determine the effects of different supplemental fertilizer treatments in combination with three different paclobutrazol rates on growth and development and on selected seed yield components. Paclobutrazol was applied at 0.0, 0.56, or 0.84 kg ha^{-1} at the floret initiation stage of development in all fields. Similar rates and dates of application have previously been effectively used in western Oregon (24, 44). Apical development stage was determined by frequent microscopic dissections. Paclobutrazol was applied in suspension with 43 1 water ha^{-1} with a bicycle type plot sprayer. Approximately 1.6 cm of rainfall was recorded in the 24 hours following application in 1984. Rainfall following applications on the 1985 first-year stand and on the 1986 second-year stand totaled less than 0.5 cm and no rain was recorded on the 1985 second-year and 1986 first-year stands. Therefore, plots received 0.4 and 0.5 cm of overhead irrigation in 1985 and 1986 respectively.

Supplemental fertilizer treatments in 1984 were 0, 187, and 560 kg KCl ha^{-1} in all possible combinations with the three paclobutrazol treatments. A randomized complete block design was used with four blocks of nine experimental units.

Treatments in 1985 and 1986 included all possible combinations of a check, 560 kg KCl ha^{-1}, 660 kg K_2SO_4 ha^{-1}, and 415 kg $CaCl_2$ ha^{-1} with the 3 paclobutrazol treatments. The fertilizer treatments were selected to determine if effects observed in 1984 were due to K or Cl. The experimental design was a randomized complete block with 4 blocks of 12 experimental units. Plot size was 2.1 m by 6.1 m in all years.

KCl and K_2SO_4 were applied with a calibrated, hand-driven Gandy spreader. $CaCl_2$ was applied with a hand shaker. Treatment application dates are given in Table I.1. Analysis of variance was used to test the effects of supplemental fertilizers, paclobutrazol and the interaction of these factors. Fisher's protected least significant difference values were used for most mean separations with the exception that selected fertilizer effects were compared by utilizing orthogonal contrasts.

Initial heading dates and anthesis dates were recorded and plots were considered to be at peak anthesis when the majority of spikes had exserted anthers. Lodging severity was visually assessed at intervals on a scale of 1 to 5 where 1 was upright and 5 was flat.

Plots were harvested at a seed moisture content of approximately 33 percent with a reciprocating blade mower. A single cut 91 cm wide (three rows) by 6.1 m long was harvested at ground level. The cut material was stuffed into large burlap bags and hung on outdoor drying lines until seed moisture was 10% or less. All plots at a given site were harvested on the same day between 0600 h and 0900 h to minimize seed shatter. Plots were evaluated for shatter after harvest on a 1 to 5 scale where 1 is the least and 5 is the most shattered seed (Appendix Tables I.5 and I.6). Harvest dates are given in Table I.1.

Plots harvested in 1984 and 1986 were threshed with a large custom made belt thresher at Oregon State University. Plots harvested in 1985 were threshed with a modified bean thresher (Seedburo, 618 West Jackson, Chicago, Illinois). Total harvested biomass weight was recorded for each plot prior to threshing.

Seed was conditioned on an air-screen machine (Ferrell-Ross Clipper #27; Saginaw, Michigan). Screens used were a number 7 round-hole screen on top and a 6 x 42 wire mesh screen on the bottom. Seed purity of the conditioned seed was determined using a General Seed Blower. Thousand seed weights were determined for pure seed using an electronic seed counter (Agricultural Specialty Co., Inc., Beltsville, Maryland). Germination percentages were determined according to AOSA rules and a speed of germination index was calculated (28).

One quadrat sample, consisting of a 15 cm length of row, was taken from each plot immediately prior to harvest in 1984 and 1985. Two quadrat samples were similarly taken from each plot in 1986 with the lightest of the two subsequently discarded. Total numbers of spikes were recorded for each quadrat prior to being threshed on a small custom built belt thresher. The threshed material was then conditioned on a table top model Clipper air screen machine. Top screen used was a 1 x 12 oblong hole and the bottom screen was a 6 x 38 wire mesh.

Gypsum blocks and a soil moisture tester (Delmhorst Model KS-1 Tester, Delmhorst Instrument Co., Towaco, New Jersey) were used in 1986 to examine the effect of paclobutrazol on soil moisture usage. Blocks were placed at soil depths of 25, 51, and 76 cm in fertilizer check plots which received paclobutrazol at rates of either 0.84 kg a.i. ha^{-1} or nil.

Table I.1. Dates of experimental treatments and stage of development of five fields of Ovation perennial ryegrass.

	Year and Stand Age				
	1984 1st yr	1985 1st yr	1985 2nd yr	1986 1st yr	1986 2nd yr
Fertilizers	6 March	6 March	6 March	4 March	3 March
Paclobutrazol	1 May	24 April	15 April	23 April	15 April
Head Emergence	26 May	22 May	17 May	21 May	15 May
First Anthesis	7 June	4 June	27 May	1 June	28 May
Max. Anthesis	16 June	14 June	3 June	13 June	6 June
Harvest	19 July	11 July	5 July	15 July	9 July

RESULTS AND DISCUSSION

The three years during which this field study was conducted differed climatically. The period from March through June in 1984 was one of the coolest and wettest on record (33), and this encouraged late-season tillering and early and severe lodging. Both 1985 and 1986 were much drier and warmer than normal over the same period (34, 35). Of the two dry years, 1986 was drier and warmer than 1985. The first week of June in 1985 provided 5.6 cm of rain, while only 0.8 cm was accumulated in June, 1986. Consequently, the June drought was an overriding factor in 1986 and tended to mask the supplemental fertilizer treatment effects.

Paclobutrazol Effects

Paclobutrazol increased seed yield in all years and decreased above-ground plant dry weight in 1984 and 1986 (Table I.2). This was the basis for the greater harvest indices observed. The 0.56 kg rate was as effective as the 0.84 kg rate and was economically superior. The observed effects on harvest index indicate a greater allocation of photosynthates to the seeds and the tillers contributing to seed yield. These responses are in agreement with results reported by Young (44). First-year seed yields tended to be higher than second-year yields. Second-year fields have been shown to develop deeper root systems earlier than first-year fields (22). They consequently may deplete soil moisture throughout the root zone earlier in the season and encounter greater late-season moisture stress. Yield increases in 1985 and 1986 were greater on a percentage basis

Table I.2. Paclobutrazol effects on the seed yield, dry weight, and harvest index in first- and second-year stands of Ovation perennial ryegrass in 1984, 1985, and 1986.

Year	Stand Age	Paclobutrazol kg a.i. ha^{-1} 0.0	0.56	0.84	SE[1.]
		--- Seed Yield (kg ha^{-1}) ---			
1984	first yr	1917 b*	2143 a	2164 a	47.6
1985	first yr	1633 c	1857 b	2050 a	41.2
1985	second yr	1277 b	1631 a	1646 a	22.4
1986	first yr	1627 b	2156 a	2119 a	36.0
1986	second yr	1098 b	1482 a	1416 a	34.5
		--- Dry Wt (kg ha^{-1}) ---			
1984	first yr	13 890 a	11 750 b	10 390 c	270
1985	first yr	10 760 a	10 710 a	10 830 a	171
1985	second yr	9 980 a	9 750 a	9 550 a	131
1986	first yr	11 440 a	10 650 b	10 480 b	244
1986	second yr	11 260 a	8 950 b	8 330 b	308
		--- Harvest Index (%) ---			
1984	first yr	13.7 c	18.2 b	20.7 a	0.24
1985	first yr	15.6 c	17.4 b	18.9 a	0.29
1985	second yr	12.8 b	16.8 a	17.2 a	0.16
1986	first yr	14.2 b	20.4 a	20.3 a	0.40
1986	second yr	9.8 b	16.6 a	17.2 a	0.35

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

1. 24df in 1984 and 33df in 1985 and 1986.

than those recorded in 1984. Conditions favored high yields in the control plots in 1984; and, consequently, the potential for a yield enhancement may have been somewhat reduced.

It has been suggested that lodging may reduce seed yields as a result of poor pollination (20) and seed set conditions (6). Paclobutrazol reduced the severity of lodging at anthesis (Table I.3) and delayed its onset (Appendix Table I.7) in all three years. Lodging was generally most severe in 1984 and least severe in 1986. The heavy rainfall recorded during the first week of June in 1985 was responsible for the high degree of lodging at maximum anthesis in the first year 1985 field.

Paclobutrazol reduced plant height from 10 to 30 percent and dry weight per spike in all three years (Appendix Tables I.8 and I.21) Height reductions persisted throughout the season. Reduced plant height may have contributed to the treated plants' resistance to lodging. Similar paclobutrazol effects on lodging, plant height, and spike dry weight, have been reported elsewhere (17, 24).

In dry years, lodging may help to conserve soil moisture by preventing excessive transpiration and thereby enhance late-season seed filling. Gypsum soil moisture blocks were placed in the 1986 second year fertilizer check plots which were treated with paclobutrazol at rates of 0.0 or 0.84 kg a.i. ha^{-1}. The blocks indicated that the non-treated plants used more moisture early in the season possible because of greater top growth and greater root development (Table I.4). By June 13, however, the non-treated plants had become tightly lodged. This canopy configuration likely enabled the plants to reduce transpiration losses, possibly as a consequence

Table I.3. Paclobutrazol effects on the relative severity of lodging at maximum anthesis in first- and second-year stands of Ovation perennial ryegrass in 1984, 1985, and 1986.

Date	Year	Stand Age	Paclobutrazol (kg a.i. ha^{-1}) 0.0	0.56	0.84	SE[1]
			- (1-5: 1 is upright, 5 is flat) -			
16 June	1984	first yr	4.2 a*	2.5 b	1.4 c	0.29
14 June	1985	first yr	4.4 a	3.1 b	1.9 c	0.13
3 June	1985	second yr	3.1 a	1.3 b	1.1 b	0.09
13 June	1986	first yr	3.4 a	1.2 b	1.1 b	0.12
6 June	1986	second yr	3.4 a	1.0 b	1.0 b	0.11

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

1. 24df in 1984 and 33df in 1985 and 1986.

Table I.4. Paclobutrazol effects on the mean available soil moisture measured from 25 to 76 cm soil depth in a second-year stand of Ovation perennial ryegrass in 1986.

	Paclobutrazol (kg a.i. ha^{-1})		
	0.0	0.84	SE (15df)
(0-10: 0.6 = wilting point, 9.8 = field capacity)			
16 May	9.5 a*	9.5 a	0.05
30 May	6.9 a	7.6 b	0.19
9 June	4.4 a	4.9 a	0.34
13 June	3.7 a	3.7 a	0.18
19 June	3.6 a	3.2 a	0.15
23 June	3.3 a	2.5 a	0.28
26 June	3.2 a	1.8 b	0.34
2 July	2.3 a	1.2 a	0.41

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

of restrictions imposed by self-shading. Plants which received the 0.84 kg a.i. ha^{-1} paclobutrazol treatment resisted lodging throughout the season which led to greater soil moisture depletion. Late-season lodging during the very dry conditions of 1986 may have been beneficial in terms of moisture conservation.

Seed yield components include the number of spikes per unit area, seeds per spike, and seed weight. Paclobutrazol increased the number of spikes per unit area present at harvest in 1984 (Table I.5) and in one of the two 1985 fields. Lodging was most severe in 1984; and improved light conditions in the 1984 paclobutrazol treated plots may have allowed the survival of some small, late-formed tillers. The June rain may have stimulated late tiller survival in the second year 1985 field. Development and survival of late-formed heads in 1986 and to some extent in 1985 may have been limited by moisture availability and, therefore, yield enhancement was related to increases in the number of seeds.

Seeds per spike and seed weight per spike were decreased by paclobutrazol in 1984 but tended to be increased in 1985 and 1986 (Table I.5). The 1984 decrease may have been caused by the apparent increase in survival of smaller, late-formed tillers. These tillers have been shown to contribute not only smaller seeds, but fewer seeds than tillers originating earlier in the year (2, 29, 40). The increase in seeds per spike and seed weight per spike in 1985 and 1986 may have been caused by enhanced seed set and seed fill conditions in an upright canopy. The

drought conditions in 1985 and especially in 1986 may have limited the development or survival of late-formed tillers.

Paclobutrazol increased seed number per area and decreased thousand seed weight (TSW) in all years (Table I.6). This is in agreement with previous research on the effects of paclobutrazol on seed number per area (19, 21). However, most previous paclobutrazol data suggests no differences in TSW (17, 18, 19, 24, 30) or only a slight decrease (14, 16, 24). Conditions for seed set and seed fill were improved in the upright canopy found in the paclobutrazol treated plots as opposed to the lodged check plots. Lodging may have restricted seed set and seed fill by limiting current photosynthesis as a result of self-shading. Improved light penetration in upright plots may have allowed late-formed heads to survive and contribute to seed yield. Previous research indicates that seed from late-formed heads is smaller (3). During dry years, the lack of moisture late in the seed filling stage would be accentuated in an upright canopy and could contribute to reduced TSW. There were no effects of paclobutrazol on seed germination or seedling vigor resulting from the decreased TSW (Appendix Tables I.9 and I.10).

Plots were evaluated for seed shatter after harvest each year. Though the paclobutrazol treated plots were rated to have shattered less, the differences were considered to be negligible (Appendix Table I.5).

Seed yields, seeds per unit area, and harvest index increased in all years and fields. Seed yield increases during wet years have been attributed to the beneficial influence of reduced lodging on seed set (6) and spikes per unit area (15, 32, 40). Spikes per unit area increased most in the wet year of 1984. Seeds per spike increased in 1985 and 1986 but not in 1984. In all years, however, paclobutrazol

Table I.5. Paclobutrazol effects on the number of spikes per 15 cm of row, number of seeds per spike, and seed weight per spike in first- and second-year stands of Ovation perennial ryegrass in 1984, 1985, and 1986.

		Paclobutrazol kg a.i. ha^{-1}			
Year	Stand Age	0.0	0.56	0.84	SE[1]
		- - - Spikes per 15 cm of row (No.) - - -			
1984	first yr	136 b*	175 a	166 ab	10.7
1985	first yr	143 a	150 a	149 a	6.9
1985	second yr	143 b	176 a	154 ab	8.2
1986	first yr	141 a	146 a	139 a	7.0
1986	second yr	123 a	129 a	123 a	4.4
		- - - Seeds per spike (No.) - - -			
1984	first yr	45 a	36 b	40 ab	2.0
1985	first yr	33 a	34 a	37 a	1.9
1985	second yr	29 b	38 a	34 ab	1.8
1986	first yr	53 b	58 b	66 a	2.2
1986	second yr	42 b	52 a	52 a	2.5
		- - - Seed Wt. per Spike (mg) - - -			
1984	first yr	69.8 a	47.7 b	49.9 b	3.65
1985	first yr	49.6 a	51.4 a	52.0 a	3.40
1985	second yr	41.9 b	52.0 a	48.0 ab	2.14
1986	first yr	97.1 b	102.4 ab	112.6 a	4.32
1986	second yr	68.8 b	87.7 a	81.9 a	4.16

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

1. 24df in 1984 and 33df in 1985 and 1986.

Table I.6. Paclobutrazol effects on the number of seeds per 929 cm^2 and thousand seed weight of first- and second-year stands of Ovation perennial ryegrass in 1984, 1985, and 1986.

Year	Stand Age	Paclobutrazol (kg a.i. ha^{-1}) 0.0	0.56	0.84	SE[1.]
		- - - Seeds per 929 cm^2 (no.) - - -			
1984	first yr	10 000 b*	12 280 a	12 720 a	288
1985	first yr	9 250 c	10 930 b	12 060 a	224
1985	second yr	7 750 b	10 000 a	10 170 a	141
1986	first yr	8 380 b	11 520 a	11 320 a	215
1986	second yr	6 220 b	8 500 a	8 160 a	198
		- - - Thousand Seed Wt (g) - - -			
1984	first yr	1.761 a	1.594 b	1.555 c	0.009
1985	first yr	1.621 a	1.554 b	1.558 b	0.008
1985	second yr	1.515 a	1.499 ab	1.489 b	0.006
1986	first yr	1.763 a	1.693 b	1.687 b	0.008
1986	second yr	1.577 a	1.561 ab	1.548 b	0.007

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

1. 24 df in 1984 and 33 df in 1985 and 1986.

applications resulted in a greater allocation of photosynthates to the developing seeds as illustrated by the recorded harvest indices.

Chloride Effects

KCl was initially used in these studies because it was hoped that K would stimulate translocation of carbohydrates to the developing seeds and thereby increase TSW and seed yield. KCl increased TSW and dry weight, tended to increase seed number per area and seed yield, but decreased the harvest index in 1984 (Table I.7). The question of Cl effects was raised in this study, and thus experiments in 1985 and 1986 dealt with both nutrients.

The 1985 and 1986 data showed that the effect on TSW was due to Cl, and the presence or absence of K appeared to have no effect (Table I.8). Although the fertilizer treatments affected TSW, there were no effects on germination percentage or on seed vigor (Appendix Tables I.11 and I.12). Seed number per area was increased by Cl in 1985 but not in 1986 (Table I.9). Increases in yield and dry weight were recorded in 1985 and were also shown to be in response to Cl applications as opposed to a K effect (Table I.10 and I.11). No positive yield or dry weight responses were observed in 1986 from the fertilizer treatments, perhaps due to overriding drought effects. Harvest index was not affected by fertilizer treatments in 1985 and 1986 (Appendix Table I.13).

Supplemental Cl fertilizer treatments did not affect the number of spikes per area, number of seeds per spike, or the seed weight per spike (Appendix Tables I.14, I.15, I.16, and I.17). Total dry weight per spike tended to increase in response to KCl in 1984 and in response to Cl containing fertilizers in 1985 fields and the first-year 1986 field (Appendix Tables I.14 and I.18). No differences in the amount of seed shattered were observed following harvest in response to fertilizer treatments (Appendix Table I.6).

The pH levels in the present study ranged from 5.6 to 5.8. Chloride has been shown to inhibit nitrification under such pH conditions (7, 37) and thereby enhance NH_4 and total N uptake (36). This has previously been shown to increase grain yield in wheat and barley (12, 39), increase kernel weights in winter wheat (39), and increase dry matter in wheat and perennial ryegrass (5, 9, 36). Results in this study on ryegrass support these findings. Donald and Hamblin (10) have pointed out that dry matter in cereals commonly increases in response to increased N. However, cereal crops suffering from water stress have been shown to have lower dry matter yields (10). This supports the observation that drought effects in 1986 may have over-ridden the effects of Cl on N form and uptake. Other previously cited Cl effects on plant osmotic potential (8, 13) and disease suppression (7) may also be contributing to the positive Cl responses observed in this study.

Table I.7. KCl effects on the dry weight, seed yield, harvest index, seeds per unit area, and thousand seed weight of a 1984 first-year stand of Ovation perennial ryegrass.

	KCl (kg ha^{-1})			
	0	187	560	SE (24df)
Dry weight (kg ha^{-1})	11 356 a*	12 070 ab	12 608 b	270.2
Seed yield (kg ha^{-1})	1987 a	2115 a	2121 a	47.6
Harvest index (%)	17.9 a	17.8 a	16.9 b	0.24
Seeds per 929 cm^2	11 360 a	11 770 a	11 870 a	288
Thousand seed wt. (g)	1.610 a	1.654 b	1.647 b	0.009

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

Table I.8. Fertilizer effects on the thousand seed weights of first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Fertilizer		Year and Stand Age			
		1985 1st	1985 2nd	1986 1st	1986 2nd
	($kg\ ha^{-1}$)	- - - (g) - - -			
Check	0	1.578	1.489	1.686	1.554
KCl	560	1.588	1.512	1.736	1.573
K_2SO_4	660	1.558	1.488	1.699	1.558
$CaCl_2$	415	1.586	1.514	1.738	1.562
LSD .05		0.027	0.020	0.028	0.025
Contrasts[1.]					
Cl vs. No Cl		(P<0.1)	**	**	NS
K vs. No K		NS	NS	NS	NS
K x Cl		NS	NS	NS	NS
Check vs. Some		NS	*	**	NS

1. Orthagonal contrasts significant at P <0.01 (**), P <0.05 (*), and P <0.1 where so indicated.

Table I.9. Fertilizer effects on the number of seeds per 929 cm^2 in first-and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Fertilizer		Year and Stand Age 1985 1st	1985 2nd	1986 1st	1986 2nd
	(kg ha^{-1})	- - - (No.)- - -			
Check	0	10 210	9 035	10 520	7 900
KCl	560	10 800	9 620	10 360	7 440
K_2SO_4	660	10 850	9 110	10 720	7 360
$CaCl_2$	415	11 130	9 450	10 020	7 805
LSD .05		750	470	720	660
Contrasts					
Cl vs. No Cl		(P<0.1)	*	NS	NS
K vs. No K		NS	NS	NS	*
K x Cl		(P<0.1)	NS	NS	NS
Check vs. Some		*	NS	NS	NS

Table I.10. Fertilizer effects on the seed yields of first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Fertilizer		Year and Stand Age			
		1985 1st	1985 2nd	1986 1st	1986 2nd
	($kg\ ha^{-1}$)	--- ($kg\ ha^{-1}$) ---			
Check	0	1756	1463	1957	1380
KCl	560	1864	1579	1977	1300
K_2SO_4	660	1841	1475	2014	1284
$CaCl_2$	415	1924	1553	1924	1363
LSD .05		138	75	120	115
Contrasts[1.]					
Cl vs. No Cl		*	**	NS	NS
K vs. No K		NS	NS	NS	*
K x Cl		NS	NS	NS	NS
Check vs. Some		*	*	NS	NS

Table I.11. Fertilizer effects on dry weight production of first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Fertilizer		Year and Stand Age 1985 1st	1985 2nd	1986 1st	1986 2nd
	$(kg\ ha^{-1})$	- - - $(kg \times 10^3\ ha^{-1})$ - - -			
Check		0	10.45	9.42	10.97
9.46					
KCl	560	11.18	10.16	10.96	9.51
K_2SO_4	660	10.53	9.48	10.62	9.45
$CaCl_2$	415	10.95	9.99	10.87	8.64
LSD .05		0.198	0.151	0.281	0.356
Contrasts					
Cl vs. No Cl		**	**	NS	NS
K vs. No K		NS	NS	NS	NS
K x Cl		NS	NS	NS	NS
Check vs. Some		NS	*	NS	NS

SUMMARY

No significant interactions between paclobutrazol and fertilizer treatments were observed for any examined characteristic. Paclobutrazol altered plant morphology, increased seed yields, and altered the seed yield components measured in this study. Many of these paclobutrazol responses were due in part to lodging reductions and to improved allocation of photosynthates to the developing seeds. Fertile tiller numbers were increased in 1984 and in one of the two 1985 fields, and seeds per spike were increased in 1985 and 1986. Harvest index and seeds per unit area were increased in all years and fields over a range of environmental conditions. Yield, dry weight, seeds per unit area, and TSW increases observed on KCl treated plots in 1984 were shown to be due to Cl in 1985 and 1986. No positive responses to K were recorded. The greatest observed responses from Cl came in the two wettest years, 1984 and 1985. Chloride-containing fertilizers have previously been shown to alter the form of N taken up by the plant, and this is thought to account for the responses observed in this study. Possible responses due to the influence of Cl on the plant's osmotic potential or disease resistance probably were of minor importance. Disease appeared to be well controlled by applications of a broad spectrum fungicide.

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II. Paclobutrazol and Phosphorus Treatment Effects on the Growth of Ovation Perennial Ryegrass (Lolium perenne L.) Seedlings

ABSTRACT

Rapid tiller and root production can improve the establishment and survival of perennial ryegrass (Lolium perenne L.) seedlings in commercial field and turf situations. This study examined the effects of the growth regulator paclobutrazol (PP333 = ((2RS+3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl) pentan-3-ol) and P treatments and their interactions on shoot and root growth of 'Ovation' perennial ryegrass seedlings. Treatments were imposed on 46-day old ryegrass seedlings in a growth chamber, and plants were observed for an additional 44 days. Paclobutrazol limited shoot and root weight increases but did not affect shoot:root ratios. Plant growth in height was reduced within two days of application. The rapid response to paclobutrazol suggests that young seedlings may depend on continual gibberellin production. Phosphorus increased the shoot weights of 90-day old seedlings, but root weights were unchanged. Significant interaction effects were observed on the numbers of leaves and tillers per plant within 9 and 16 days of treatment, respectively. Leaves and tillers per plant were increased by paclobutrazol but only in the presence of high P. The reduced root growth caused by paclobutrazol and the immobile nature of P in the soil may account for the interaction effects. Effective use of growth regulators to enhance seedling establishment will depend on an integrated strategy involving nutrient manipulation.

INTRODUCTION

Rapid tiller and root development can enhance seedling survival and benefit stand establishment in commercial field and turf situations. Several environmental factors and management techniques have been shown to influence the rate of turfgrass shoot and root growth. Factors such as light intensity, moisture level, and nutrient status have been studied for effects on the growth and development of turfgrass species. In recent years, the use of plant growth regulators has increased in the management of grasses grown for both seed and turf. The use of growth regulators will require that nutrient applications be modified in response to chemically altered plant growth.

Rapid tillering following seeding can hasten stand establishment. Tillering can be slowed by low light levels or by defoliation, both of which reduce the photosynthate supply (27). Work with barley (16), wheat (26), orchardgrass (1), fine fescue (4) and perennial ryegrass (20, 23) shows that increased light intensity leads to increased tillering. Soil moisture restrictions can reduce tillering in perennial ryegrass (6) and decrease shoot:root ratios (24).

New turfgrass plantings can be slow to establish if the seedbed is deficient in phosphorus (22). Phosphorus is a very immobile element in the soil. Even when soil tests indicate adequate P levels, the limited root system of a young seedling may be unable to supply enough P to support a rapidly growing shoot. P deficiency symptoms are most evident during establishment and include reduced growth, dark to reddish coloration, and narrow leaf blades (25). Seedling vigor, tillering, and root development are enhanced with supplemental P (3, 22).

Troughton (24) reported an increase in shoot and root weights and in the shoot:root ratio in superphosphate treated, container grown perennial ryegrass seedlings. Barry and Miller (2) observed increased growth rates in maize seedlings given greater than recommended levels of P.

Nitrogen has been shown to stimulate tillering in perennial ryegrass (11, 14) probably due to the effect of N on cytokinin synthesis (17). Cytokinins are produced in and transported from the growing root apices. All factors, therefore, favoring the growth and branching of roots such as adequate supplies of carbohydrates, nitrogen, and other nutrients may lead to the production of cytokinins and an increase in tiller bud initiation and growth (14, 18).

Gibberellin has been shown to reduce tillering (13, 14, 15). Gibberellin biosynthesis inhibitors, such as paclobutrazol and flurprimidol have increased tillering in several species including annual ryegrass (12), perennial ryegrass (7, 8), and Kentucky bluegrass (5). Hanson and Branham (10) showed a significant reduction in the percentage of photosynthates partitioned to the roots of Kentucky bluegrass 4 weeks after treatment with paclobutrazol. Hunter (12), however, observed no significant effects on the shoot weights, root weights, or the shoot:root ratio of annual ryegrass seedlings 4 weeks after paclobutrazol application. Dernoeden (5) similarly observed no significant effects on the shoot:root ratios in a Kentucky bluegrass-red fescue turf after 4 years of flurprimidol treatments. Hampton and Hebblethwaite (9) found paclobutrazol reduced stem dry matter but increased root dry matter at all rooting depths in perennial ryegrass seed fields.

Effective management of turfgrasses whether grown for turf or seed requires that optimum conditions for both shoot and root growth be provided. Rapid establishment can enhance the chances for survival in turf situations or seed field stands. The objective of this study was to determine the influence of paclobutrazol and P treatments on the shoot and root growth of Ovation perennial ryegrass seedlings. The identification of any interaction effects is important so that fertility management guidelines can be modified when paclobutrazol is used to affect seedling development.

MATERIALS AND METHODS

Ovation perennial ryegrass seeds were planted on May 23, 1986 (day 0) in a plastic tray filled with washed silica sand and were placed in a controlled environment chamber set for 17/7˚ C day/night temperature with a 12-hour photoperiod. The photosynthetic photon flux density (PPFD) was approximately 200 micromoles per square meter per second (umol m^{-2} s^{-1}) provided by VHO cool white fluorescent lights. The plants were watered three times per week with 0.2% KNO_3 until June 15 (day 23) and were then given a complete nutrient solution (19) three times per week until June 27 (day 35). Half the N occurred as NH_4 and the other half as NO_3 in this nutrient solution. On June 27, the seedlings were transplanted into 5-cm plastic pots filled with a 3:1 sand:soil potting mix. Results of the Oregon State University soils lab test (lab report no. 067-004 (4987)) gave a pH of 5.9, and values of P and K which are in the adequate range for a sandy soil (Appendix Table II.1). Seedlings were at the 2 to 4 leaf stage when transplanted. On July 8 (day 46), chamber conditions were set to promote vegetative growth at 24/13˚ C day/night temperature with a 16-hour photoperiod of approximately 280 umol m^{-2} s^{-1} provided by a combination of VHO cool white fluorescent lights and 40-watt incandescent bulbs.

From June 27 to August 21 (day 90), plants were watered with distilled water four times per week. The treatments listed in Table II.1 were applied on July 8. Fertilizer was applied with a calibrated drop-type lawn spreader. The 22-3-3 fertilizer used is derived from $(NH_4)_2SO_4$, $NH_4H_2PO_4$, $(NH_2)_2CO$, methylene ureas, KCl and $FeSO_4$. The 17-23-6 fertilizer used is derived from $NH_4H_2PO_4$, $(NH_2)_2CO$, methylene ureas, and KCl. Paclobutrazol was applied with a pipette using dilute solutions of a 50% WP formulation. All plants were reduced to a maximum height of 3 cm by clipping with scissors immediately prior to fertilizer treatments.

The study was conducted as a randomized complete block design in a factorial arrangement with three rates of paclobutrazol in all combinations with two rates of phosphorus. Plants were periodically observed for treatment effects on leaf and tiller numbers and maximum plant height. Shoot and root dry weights were recorded on the final observation date.

Table II.1. Experimental treatments applied to 46-day old Ovation perennial ryegrass seedlings.

Treatment No.	Paclobutrazol (kg a.i. ha^{-1})	Fertilizer Analysis	N (kg ha^{-1})	P (kg ha^{-1})
1	0.000	22-3-3	45	6
2	0.000	17-23-6	45	61
3	0.035	22-3-3	45	6
4	0.035	17-23-6	45	61
5	0.070	22-3-3	45	6
6	0.070	17-23-6	45	61

RESULTS AND DISCUSSION

Whole plant shoot weight and total biomass were significantly reduced by paclobutrazol. The magnitude of these reductions was rate dependent (Table II.2). Shoot and root weights on a per tiller basis were similarly reduced (Table II.3). Because shoot and root weights were both reduced by paclobutrazol, shoot:root ratios were not affected. Reduced shoot growth may have resulted in limited carbohydrate production and consequently restricted root growth. The net effect was limited total plant growth when paclobutrazol was applied to seedlings.

Reductions in plant height due to paclobutrazol were observed within 2 days of treatment (Table II.4) to 46-day old seedlings and persisted throughout the duration of the study. Differences in leaves per plant and tillers per seedling were observed within 9 and 16 days after application, respectively. These results appeared much more quickly than previously reported. Shearing and Batch (21) felt that chemical growth retardation in amenity grasses required 10 to 20 days before effects were evident. The rapid response observed in the present study may indicate that young seedlings have a requirement for continual gibberellin production due to a lack of any reserves or storage gibberellin forms.

Phosphorus increased the shoot weight of 90-day old seedlings, but root weight was unchanged (Table II.5). As a result of the increased shoot weight, total biomass and shoot:root ratios increased as well. These results are similar to those reported by Troughton (24).

Table II.2. Paclobutrazol effects on the shoot weight, root weight, total biomass, and shoot:root ratio of 90-day old Ovation perennial ryegrass seedlings.

	Paclobutrazol (kg a.i. ha^{-1})			
	0.0	0.035	0.070	SE (28df)
Shoot Wt. (mg)	478 a*	399 b	317 c	14.2
Root Wt. (mg)	317 a	292 a	214 b	16.6
Total Biomass (mg)	795 a	692 b	531 c	28.0
Shoot:Root	1.79 a	1.61 a	1.86 a	0.105

* Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

Table II.3. Paclobutrazol effects on the shoot weight per tiller and root weight per tiller of 90-day old Ovation perennial ryegrass seedlings.

	Paclobutrazol (kg a.i. ha^{-1})			
	0.0	0.035	0.070	SE (28df)
Shoot Wt. per tiller (mg)	27.5 a*	20.4 b	14.1 c	1.22
Root Wt. per tiller (mg)	18.0 a	15.4 a	9.6 b	1.28

* Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

Table II.4. Paclobutrazol effects on the growth of 48- to 90-day old Ovation perennial ryegrass seedlings. Applications made on 46-day old seedlings.

Paclobutrazol	Seedling Age (days)					
	48	55	62	69	76	90
(kg a.i. ha^{-1})						
			Plant Height (cm)			
0	10.5 a	14.7 a	19.5 a	23.9 a	25.4 a	23.6 a
0.035	7.0 b	10.0 b	12.3 b	15.3 b	16.7 b	16.4 b
0.070	5.7 c	9.2 b	9.3 c	10.4 c	11.4 c	12.1 c
SE (28 df)	0.32	0.21	0.47	0.50	0.78	0.66
			Leaves per Plant (No.)			
0	5.8 a	--	--	34.9 a	38.1 a	53.4 a
0.035	5.5 a	--	--	39.5 b	52.3 b	58.6 a
0.070	5.9 a	--	--	44.4 c	58.5 b	74.5 b
SE (28 df)	0.17	--	--	1.59	2.71	4.13
			Tillers per Seedling (No.)			
0	2.2 a*	3.75 a	--	13.0 a	15.1 a	20.7 a
0.035	2.0 a	4.11 a	--	14.9 b	20.1 b	20.7 a
0.070	2.1 a	4.36 a	--	16.2 b	19.9 b	26.0 b
SE (28 df)	0.10	0.21	--	0.67	1.01	1.50

* Means within columns followed by a common letter are not significantly different at the 0.05 probability level.

Although soil test results indicated adequate P nutrition, shoot growth was stimulated by supplemental P.

Tillering was stimulated in 90-day old seedlings by P (Table II.6). The increase in tillering resulted in decreased root weights per tiller and unchanged shoot weights per tiller (Appendix Table II.2).

Significant interactions between P and paclobutrazol were observed on the shoot growth of 55- and 62-day old seedlings (9 and 16 days after treatment applications, respectively). Leaves per plant were increased by paclobutrazol in 55- and 62-day old seedlings but only at the high P rates (Table II.7). Similarly, tillers per seedling of 62-day old seedlings were increased more by paclobutrazol at the high P level (Table II.8). Paclobutrazol reduced root weight of seedling ryegrass in this study. Since P is very immobile in the soil, reduced root growth may have limited P uptake. Consequently, leaf and tiller production increases due to paclobutrazol were only possible when supplemental P was applied.

As plants grew past the 62-day old stage, no further interaction effects were observed. The seedlings were growing in 5 cm pots and may have had sufficient root development by this time that access to P was no longer restricted.

Table II.5. Phosphorus effects on the shoot weight, root weight, total biomass, and shoot:root ratio of 90-day old Ovation perennial ryegrass seedlings.

	Phosphorus (kg ha^{-1})		
	6	60	SE (42df)
Shoot Wt. (mg)	362 a*	433 b	11.6
Root Wt. (mg)	277 a	272 a	13.8
Total Biomass (mg)	639 a	705 b	22.9
Shoot:Root	1.52 a	2.00 b	0.090

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

Table II.6. Phosphorus effects on the growth of 48- to 90-day old Ovation perennial ryegrass seedlings.

Phosphorus		Seedling Age (days)					
		48	55	62	69	76	90
($kg\ ha^{-1}$)							
				Plant Height (cm)			
6		7.6 a	11.2 a	13.6 a	16.3 a	17.4 a	16.8
a							
60		7.8 a	11.4 a	13.8 a	16.8 a	18.3 a	17.9
a							
	SE (42df)	0.26	0.31	0.39	0.41	0.64	0.54
				Leaves per Plant (No.)			
6		5.8 a	--	--	38.1 a	47.4 a	57.2
a							
60		5.7 a	--	--	41.1 a	51.9 a	67.1
b							
	SE (42df)	0.13	--	--	1.30	2.22	3.37
				Tillers per Seedling (No.)			
6		2.1 a*	3.81 a	--	14.2 a	17.8 a	20.1
a							
60		2.1 a	4.33 b	--	15.2 a	19.0 a	24.9
b							
	SE (42df)	0.09	0.17	--	0.54	0.83	1.23

* Means within columns followed by a common letter are not significantly different at the 0.05 probability level.

Table II.7. Phosphorus and paclobutrazol effects on leaves per plant of 55- and 62-day old Ovation perennial ryegrass seedlings.

Paclobutrazol ($kg\ a.i.\ ha^{-1}$)	55-day old seedlings		62-day old seedlings	
	Phosphorus ($kg\ ha^{-1}$)			
	6	60	6	60
0.0	150	136	312	275
0.035	138	163	298	353
0.070	154	175	348	380

Table II.8. Phosphorus and paclobutrazol effects on tillers per seedling of 62-day old Ovation perennial ryegrass seedlings.

Paclobutrazol ($kg\ a.i.\ ha^{-1}$)	Phosphorus ($kg\ ha^{-1}$)	
	6	60
0.	117	102
0.035	110	132
0.070	132	142

SUMMARY

Cultural management practices can influence leaf and tiller production and root development. Paclobutrazol increased the number of leaves and tillers produced but reduced the root and shoot dry weight growth of perennial ryegrass seedlings. Effects on perennial ryegrass seedlings were observed within two days after paclobutrazol was applied to 46-day old plants. Phosphorus increased shoot growth and shoot:root ratios. Increased seedling leaf and tiller production due to paclobutrazol depended on increased P levels under some conditions because of the reduced root growth associated with the growth regulator. An integrated management strategy involving paclobutrazol may require supplemental P applications to maximize seedling establishment rates.

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CONCLUSIONS

Paclobutrazol altered plant morphology, increased seed yields, and altered the seed yield components measured in field studies in western Oregon. Many of these paclobutrazol effects were due in part to lodging reductions and to improved allocation of photosynthates to the developing seeds. Fertile tiller numbers were increased in the wet year of 1984 and in one of the two 1985 fields and seeds per spike were increased in the dry years of 1985 and 1986. However, harvest index and seeds per unit area were increased in all fields over the entire range of environmental conditions. Seed yield, dry weight, seeds per unit area, and TSW increases observed on KCl treated plants in 1984 were shown to be due to Cl in 1985. No positive responses to K were observed. Chloride responses may be due to the influence of Cl on the form of N taken up by the plant.

Paclobutrazol increased the numbers of leaves and tillers produced but reduced root and shoot dry weight increases growth chamber-grown perennial ryegrass seedlings. Effects on plant height were noted within 2 days after paclobutrazol was applied to 46-day old seedlings. Paclobutrazol-induced increases in the numbers of leaves and tillers in 55- and 62-day old plants were observed only in the presence of supplemental P. Since P is very immobile in the soil, the reduced root growth caused by paclobutrazol may have limited P uptake.

The commercial use of paclobutrazol to increase seed yields or hasten stand establishment will require a re-examination of soil fertility management practices.

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APPENDIX

Appendix Table I.1. Experimental details: Previous crop and sowing dates of five Ovation perennial ryegrass fields.

Year	Stand Age	Previous Crop	Sowing Date
1984	first yr	Winter wheat	3 Oct 1983
1985	first yr	Winter wheat	26 Sep 1984
1985	second yr	Ovation	3 Oct 1983
1986	first yr	Winter wheat	5 Oct 1985
1986	second yr	Ovation	26 Sep 1984

Appendix Table I.2. Experimental details: Pesticide applications made on five Ovation perennial ryegrass fields.

		Herbicide			Fungicide*
Year	Stand Age	Date	Material	Rate ($kg\ ha^{-1}$)	Date
1984	first yr	4 Oct 1983	diuron	2.7 a.i.	26 May 1984
		1 Jan 1984	dinitro	0.56 a.i.	
		21 Jan 1984	ethofumesate	1.12 a.i.	10 June
1984					
		10 Mar 1984	MCPA and	0.56 a.e.	24 June
1984					
			dicamba	0.28 a.e.	
1985	first yr	27 Sep 1984	diuron	2.7 a.i.	
		15 Jan 1985	bromoxynil	0.56 a.i.	22 May 1985
		5 Mar 1985	MCPA and	0.56 a.e.	13 June
1985					
			dicamba	0.28 a.e.	
1985	second yr	18 Oct 1984	atrazine	1.35 a.i.	17 May 1985
		3 Mar 1985	MCPA and	0.56 a.e.	8 June
1985					
			dicamba	0.28 a.e.	
1986	first yr	5 Oct 1985	diuron	2.7 a.i.	21 May 1986
		12 Jan 1986	dinitro	0.56 a.i.	12 June
1986					
		10 Mar 1986	MCPA and	0.56 a.e.	
			dicamba	0.28 a.e.	
1986	second yr	1 Nov 1985	atrazine	1.35 a.i.	15 May 1986
		10 Mar 1986	MCPA and	0.56 a.e.	6 June
1986					
			dicamba	0.28 a.e.	

* All fungicide applications were Tilt[R] at 0.3 $l\ ha^{-1}$.

Appendix Table I.3. Experimental details: Fertilizer applications made on five Ovation perennial ryegrass fields.

		Fertilizer		
Year	Stand Age	Date	Material	Rate (kg ha^{-1})
1984	first yr	3 Oct 1983	16-16-16 (N-P-K)	175
		8 Mar 1984	Ammonium sulfate	267
		16 Ap 1984	Urea	183
1985	first yr	26 Sep 1984	16-16-16 (N-P-K)	175
		28 Feb 1985	Ammonium sulfate	257
		16 Ap 1985	Urea	200
1985	second yr	22 Oct 1984	10-20-20 (N-P-K)	252
		7 Mar 1985	Amm. nitrate sulfate	205
		15 Ap 1985	Amm. nitrate sulfate	247
1986	first yr	5 Oct 1985	16-16-16 (N-P-K)	175
		8 Mar 1986	Ammonium sulfate	238
		16 Ap 1986	Urea	183
1986	second yr	20 Oct 1985	10-20-20 (N-P-K)	252
		8 Mar 1986	Amm. nitrate sulfate	205
		16 Ap 1986	Amm. nitrate sulfate	247

Appendix Table I.4. OSU Soil Testing Laboratory values from experimental sites for a 0 to 15 cm sample depth.

Year	Stand Age	Sample Date	pH	P	K
				---(ppm)---	
1985	first yr	19 Feb 1985	5.7	124	234
1985	second yr	19 Feb 1985	5.8	52	163
1986	first yr	10 Mar 1986	5.8	94	218
1986	second yr	10 Mar 1986	5.6	94	210

Appendix Table I.5. Paclobutrazol effects on the relative amount of shattered seed after harvest in first- and second-year stands of Ovation perennial ryegrass in 1984, 1985, and 1986.

Year	Stand Age	0.0	0.56	0.84	SE[1.]
		(1-5: 1 is least, 5 is most)			
1984	first yr	2.7 a	1.8 b	1.3 b	0.21
1985	first yr	1.5 b	1.9 a	2.2 a	0.34
1985	second yr	2.4 a	1.6 b	1.3 b	0.43
1986	first yr	2.1 a	1.7 a	1.9 a	0.36
1986	second yr	2.8 a	1.6 b	1.5 b	0.42

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

1. 24df in 1984 and 33df in 1985 and 1986.

Appendix Table I.6. Fertilizer effect on the relative amount of shattered seed after harvest in first- and second-year stands of Ovation perennial ryegrass in 1984, 1985, and 1986.

Year	Stand Age	Check	KCl (560)	K_2SO_4 (660)	$CaCl_2$ (415)	SE (33df)
		Fertilizer (kg ha^{-1})				
		--- (1-5: 1 is least, 5 is most) ---				
1985	first yr		1.8	1.8	1.9	
2.00.12						
1985	second yr	1.8	1.8	1.8	1.8	0.17
1986	first yr	2.0	1.8	1.7	2.0	0.14
1986	second yr	1.8	2.0	1.9	2.0	0.17

Year	Stand Age	Check	KCl (187)	KCl (560)	SE (24df)
1984	first yr	1.8	2.0	2.0	0.21

Appendix Table I.7. Paclobutrazol effects on the timing and relative severity of lodging in first- and second-year stands of Ovation perennial ryegrass in 1984, 1985, and 1986.

Date	Year	Stand Age	Paclobutrazol (kg a.i. ha^{-1}) 0.0	0.56	0.84	SE[1.]
		(1 to 5: 1 is flat, 5 is upright)				
11 June	1984	first yr	2.4 a*	1.0 b	1.0 b	0.09
16 June	1984	first yr	4.2 a	2.5 b	1.4 c	0.29
25 June	1984	first yr	4.6 a	2.9 b	1.7 c	0.21
18 July	1984	first yr	4.8 a	2.8 b	1.8 c	0.17
3 June	1985	first yr	3.3 a	1.5 b	1.1 b	0.15
		second yr	3.1 a	1.3 b	1.1 b	0.09
14 June	1985	first yr	4.4 a	3.1 b	1.9 c	0.13
		second yr	4.1 a	2.5 b	1.3 c	0.13
24 June	1985	first yr	4.8 a	3.4 b	2.4 c	0.15
		second yr	4.5 a	2.8 b	1.9 c	0.12
5 July	1985	first yr	4.9 a	3.8 b	2.9 c	0.10
		second yr	4.9 a	3.1 b	1.7 c	0.15
23 May	1986	first yr	1.2 a	1.0 a	1.0 a	0.01
		second yr	1.7 a	1.0 b	1.0 b	0.16
6 June	1986	first yr	3.4 a	1.0 b	1.0 b	0.10
		second yr	3.4 a	1.0 b	1.0 b	0.11
13 June	1986	first yr	3.4 a	1.2 b	1.1 b	0.12
		second yr	3.4 a	1.0 b	1.0 b	0.11
2 July	1986	first yr	4.5 a	2.1 b	1.8 b	0.20
		second yr	4.8 a	1.2 b	1.0 b	0.10

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

1. 24 df in 1984 and 33df in 1985 and 1986.

Appendix Table I.8. Paclobutrazol effects on plant height of first- and second-year stands of Ovation perennial ryegrass in 1984, 1985, and 1986.

Date	Year	Stand Age	Paclobutrazol (kg a.i. ha^{-1}) 0.0	0.56	0.84	SE[1]
			- - - - - - - (cm)	- - - - - -		
11 June	1984	first yr	84 a*	75 b	69 c	1.0
22 May	1985	first yr	60 a	50 b	47 c	0.8
		second yr	60 a	48 b	45 b	1.5
14 June	1985	first yr	89 a	82 b	81 b	0.8
		second yr	87 a	78 b	76 b	1.9
24 June	1985	first yr	90 a	81 b	79 b	1.1
		second yr	86 a	77 b	75 b	1.7
9 July	1985	first yr	88 a	79 b	78 b	0.7
16 May	1986	first yr	45 a	37 b	37 b	0.8
		second yr	54 a	34 b	32 b	1.1
23 May	1986	first yr	60 a	40 b	41 b	1.2
		second yr	64 a	37 b	33 c	1.1
30 May	1986	first yr	77 a	53 b	51 b	1.2
		second yr	84 a	52 b	46 c	1.4
6 June	1986	first yr	82 a	60 b	57 b	1.2
		second yr	87 a	60 b	53 c	1.4
13 June	1986	first yr	89 a	68 b	65 b	1.1
		second yr	88 a	67 b	58 c	1.2
2 July	1986	first yr	91 a	75 b	72 b	1.6
		second yr	90 a	69 b	62 c	1.5

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

1. 24 df in 1984 and 33df in 1985 and 1986.

Appendix Table I.9. Paclobutrazol effects on the seed germination percentage from first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Year	Stand Age	Paclobutrazol kg a.i. ha^{-1}			
		0.0	0.56	0.84	SE[1]
		- - - -	%	- - - -	
1984	first yr	96.2	96.3	95.8	0.67
1985	first yr	96.9	97.1	97.4	0.53
1985	second yr	96.1	96.4	95.9	0.59
1986	first yr	97.1	96.8	97.4	0.51
1986	second yr	96.6	97.7	96.6	0.50

1. 24 df in 1984 and 33df in 1985 and 1986.

Appendix Table I.10. Paclobutrazol effects on the rate of seed germination[1] from first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Year	Stand Age	Paclobutrazol kg a.i. ha^{-1} 0.0	0.56	0.84	SE[2.]
1984	first yr	16.84	16.56	16.67	0.160
1985	first yr	16.96	16.92	16.89	0.114
1985	second yr	14.78	15.10	14.63	0.163
1986	first yr	15.95	15.73	15.76	0.141
1986	second yr	15.80	15.86	15.63	0.144

1. Calculated as:

$$\frac{\text{number of normal seedlings}}{\text{days to first count}} + \ldots + \frac{\text{number of normal seedlings}}{\text{days to final count}}$$

on a per 100 seeds basis in a standard germination test. Maguire, J.D. 1962. Crop Sci. 2:176-177.

2. 24 df in 1984 and 33 df in 1985 and 1986.

Appendix Table I.11. Fertilizer effects on the seed germination percentage from first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Fertilizer	Year and Stand Age			
	1985 1st	1985 2nd	1986 1st	1986 2nd
(kg ha^{-1})	- - - - - - - -	(%)	- - - - - - - -	
Check	97.4	96.3	96.8	97.5
KCL	97.3	96.7	97.7	97.6
K_2SO_4	97.7	95.6	96.1	96.1
$CaCl_2$	96.1	96.0	97.8	96.8
LSD .05	1.8	2.0	1.7	1.7
Contrasts				
Cl vs No Cl	(P<0.1)	NS	*	NS
K vs No K	NS	NS	NS	NS
K x Cl	*	NS	NS	*
Check vs Some	*	NS	NS	NS

Appendix Table I.12. Fertilizer effects on the rate of seed germination from first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Fertilizer		Year and Stand Age			
		1985 1st	1985 2nd	1986 1st	1986 2nd
	($kg\ ha^{-1}$)	- - - -	- - - - (%)	- - - -	- - - -
Check	0	17.11	14.86	15.55	15.97
KCL	560	17.03	14.73	16.00	16.00
K_2SO_4	660	16.82	14.83	15.65	15.58
$CaCl_2$	415	16.73	14.92	16.06	15.50
	LSD .05	0.38	0.54	0.47	0.48
Contrasts					
Cl vs No Cl		NS	NS	*	NS
K vs No K		NS	NS	NS	NS
K x Cl		*	NS	NS	*
Check vs Some		NS	NS	(P<0.1)	NS

Appendix Table I.13. Fertilizer effects on the harvest indexes of first-and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Fertilizer		Year and Stand Age 1985 1st	1985 2nd	1986 1st	1986 2nd
	($kg\ ha^{-1}$)		- - (%) - -		
Check	0	17.4	15.6	17.9	14.8
KCl	560	16.7	15.7	18.1	14.3
K_2SO_4	660	17.5	15.6	19.1	14.2
$CaCl_2$	415	17.6	15.6	18.0	14.8
LSD .05		1.0	0.6	1.4	1.2
Contrasts					
Cl vs No Cl		NS	NS	NS	NS
K vs No K		NS	NS	NS	NS
K x Cl		NS	NS	NS	NS
Check vs some		NS	NS	NS	NS

Appendix Table I.14. KCl effects on the number of spikes per 15 cm of row, number of seeds per spike, seed weight per spike and dry weight per spike in a 1984 first-year stand of Ovation perennial ryegrass.

KCl rate	Spikes per 15 cm	Seeds per Spike	Seed Wt. per Spike	Dry Wt. per Spike
(kg ha^{-1})	(No)	(No)	(mg)	(mg)
0	158	41	56	539
187	158	38	51	558
560	161	42	61	563
SE (24 df)	107	2.0	3.6	19.0

Appendix Table I.15. Fertilizer effects on the number of spikes per 15 cm of row in first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

		Year and Stand Age			
Fertilizer		1985 1st	1985 2nd	1986 1st	1986 2nd
	($kg\ ha^{-1}$)		- - (No.) - -		
Check	0	153	164	151	122
KCl	560	147	158	142	116
K_2SO_4	660	152	142	132	127
$CaCl_2$	415	138	168	144	135
LSD .05		23	27	23	15
Contrasts					
Cl vs No Cl		NS	NS	NS	NS
K vs No K		NS	NS	NS	NS
K x Cl		NS	NS	(P<0.1)	NS
Check vs some		NS	NS	NS	NS

Appendix Table I.16. Fertilizer effects on the number of seeds per spike in first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Fertilizer		Year and Stand Age 1985 1st	1985 2nd	1986 1st	1986 2nd
	($kg\ ha^{-1}$)	- - (No.) - -			
Check	0	35	35	57	53
KCl	560	34	35	57	47
K_2SO_4	660	36	30	63	48
$CaCl_2$	415	34	35	60	46
LSD .05		6	6	7	8
Contrasts					
Cl vs No Cl		NS	NS	NS	NS
K vs No K		NS	NS	NS	NS
K x Cl		NS	NS	($P<0.1$)	NS
Check vs some		NS	NS	NS	($P<0.1$)

Appendix Table I.17. Fertilizer effects on the seed weight per spike of first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Fertilizer		Year and Stand Age 1985 1st	1985 2nd	1986 1st	1986 2nd
	($kg\ ha^{-1}$)	- - (mg) - -			
Check	0	50.1	48.6	98.3	88.0
KCl	560	50.4	47.2	99.9	77.7
K_2SO_4	660	53.7	39.9	113.6	76.6
$CaCl_2$	415	49.8	54.1	104.3	75.6
LSD .05		9.8	7.2	14.4	13.9
Contrasts					
Cl vs No Cl		NS	**	NS	NS
K vs No K		NS	**	NS	NS
K x Cl		NS	NS	(P<0.1)	NS
Check vs some		NS	NS	NS	**

Appendix Table I.18. Fertilizer effects on the dry weight per spike of first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

		Year and Stand Age			
Fertilizer		1985 1st	1985 2nd	1986 1st	1986 2nd
	($kg\ ha^{-1}$)	- - (mg) - -			
Check	0	440	460	594	642
KCl	560	467	461	644	610
K_2SO_4	660	449	418	663	578
$CaCl_2$	415	446	490	631	613
LSD .05		46	50	64	82
Contrasts					
Cl vs No Cl		NS	*	NS	NS
K vs No K		NS	*	NS	NS
K x Cl		NS	NS	NS	NS
Check vs some		NS	NS	(P<0.1)	NS

Appendix Table I.19. Fertilizer effects on the timing and relative severity of lodging in 1985 and 1986 first- and second-year stands of Ovation perennial ryegrass.

			Fertilizer (kg ha^{-1})				
Date	Year	Stand Age	Check	KCl (560)	K_2SO_4 (660)	$CaCl_2$ (415)	SE (33 df)
			- (1-5 scale: 1 is flat, 5 is upright) -				
3 June	1985	first yr	2.2	2.2	1.7	1.8	0.17
		second yr	1.8	1.9	1.8	1.8	0.11
14 June	1985	first yr	3.2 a*	3.2 a	2.8 b	3.3 a	0.15
		second yr	2.3 b	2.8 a	2.8 a	2.6 ab	0.16
24 June	1985	first yr	3.6	3.6	3.4	3.6	0.17
		second yr	2.9	3.2	3.2	2.9	0.14
5 July	1985	first yr	3.8	3.9	3.8	3.8	0.11
		second yr	3.1	3.4	3.2	3.2	0.18
23 May	1986	first yr	1.1	1.2	1.0	1.1	0.10
		second yr	1.2	1.2	1.2	1.3	0.16
6 June	1986	first yr	1.8	1.9	1.6	1.8	0.11
		second yr	1.7	1.8	1.8	1.8	0.11
13 June	1986	first yr	1.8 ab*	2.2 a	1.7 b	1.8 ab	0.13
		second yr	1.7	1.8	1.8	1.8	0.11
2 July	1986	first yr	3.2	3.0	2.5	2.9	0.24
		second yr	2.3	2.4	2.3	2.2	0.10

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

Appendix Table I.20. Fertilizer effects on plant height of first- and second-year stands of Ovation perennial ryegrass in 1984, 1985, and 1986.

Date	Year	Stand Age	Check	KCl (560)	K_2SO_4 (660)	$CaCl_2$ (414)	SE[1]
				Fertilizer (kg ha^{-1}) - - (cm) - -			
11 June	1984	first yr	76	76	--	--	1.0
22 May	1985	first yr	52	53	52	52	1.0
		second yr	50	51	51	51	0.9
14 June	1985	first yr	84	86	83	84	0.9
		second yr	80	81	79	82	1.1
24 June	1985	first yr	82 b*	85 a	83 ab	83 ab	1.3
		second yr	79	81	79	79	1.0
9 July	1985	first yr	79 b	83 a	81 ab	83 a	0.8
16 May	1986	first yr	41 a	41 a	37 b	39 ab	1.0
		second yr	40	41	40	40	1.3
23 May	1986	first yr	48	47	45	48	1.4
		second yr	45	44	44	44	1.3
30 May	1986	first yr	61	62	58	60	1.4
		second yr	61	63	59	59	1.6
6 June	1986	first yr	67	66	63	68	1.4
		second yr	67	66	66	67	1.6
13 June	1986	first yr	76 a	73 ab	71 b	75 ab	1.2
		second yr	72	70	71	70	1.4
26 June	1986	first yr	78 ab	81 a	74 b	80 a	1.3
		second yr	78 a	76 ab	72 b	76 ab	1.7
2 July	1986	first yr	77	80	77	82	1.9
		second yr	75 ab	76 a	71 b	72 ab	1.7

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

1. 24 df in 1984 and 33df in 1985 and 1986.

Appendix Table I.21. Paclobutrazol effect on the dry weight per spike in 1984, 1985, and 1986 stands of Ovation perennial ryegrass.

		Dry Weight per Spike mg			
		Paclobutrazol rate kg			
Year	Stand Age	0.0	0.56	0.84	SE [1.]
1984	first yr	638 a*	509 b	512 b	19.03
1985	first yr	485 a	443 b	423 b	13.74
1985	second yr	468 a	464 a	439 a	15.10
1986	first yr	697 a	596 b	606 b	19.19
1986	second yr	675 a	604 b	553 b	24.68

*Means within rows within stand age followed by a different letter differ significantly at the 0.05 probability level.

1. 24 df in 1984 and 33 df in 1985 and 1986.

Appendix Table I.22. KCl effects on the timing and relative severity of lodging in a 1984 first-year stand of Ovation perennial ryegrass.

Date	KCl kg ha^{-1}			SE (24df)
	0	187	560	
	(1-5: 1 is upright, 5 is flat)			
11 June	1.5	1.4	1.5	0.09
16 June	2.4	2.8	2.9	0.29
25 June	2.7	3.1	3.4	0.21
18 July	3.8	3.0	3.3	0.17

Appendix Table I.23. Harvest index, total biomass (kg/ha), clean weight (kg/ha), seeds per area, thousand seed weight and bushel weight for first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

	1985			1986		
	1st	2nd	SE (33df)	1st	2nd	SE (33df)
Harvest Index	17.29 a	15.60 b	0.216	18.27 a	14.53 b	0.213
Total Biomass (kg/ha)	10 773 a	9 761 b	111.4	10 854 a	9 515 b	198.7
Clean Weight (kg/ha)	1 846 a	1 518 b	23.5	1 968 a	1 331 b	24.8
Seeds/Area	10 748 a	9 304 b	136.86	10 405 a	7 625 b	144.99
TSW (g/1000)	1.578 a	1.501 b	0.005	1.715 a	1.562 b	0.007
Bushel Wt (kg/bu)	11.75 a	11.42 b	0.067	11.36 a	10.00 b	0.052

Appendix Table I.24. Conversions for Delmhorst[1.] Moisture Tester Model KS-1 and cylindrical gypsum blocks.

Moisture Tension Mpa	Ohms	Meter Reading	Approx. H_2O Used %
0.02	130	9.8	Field Cap.
0.03	260	9.0	
0.04	370	8.5	
0.06	750	7.0	25%
0.08	1100	6.0	
0.10	1700	5.0	
0.15	3400	3.5	
0.18	4000	3.2	50%
0.20	5000	2.8	
0.30	7200	2.2	
0.60	12500	1.5	
1.50	35000	0.6	Wilting point

1. Delmhorst Instrument Company. Towaco, N.J.

Appendix Table I.25. Available soil moisture at three depths in a second-year stand of Ovation perennial ryegrass in 1986.

	Soil Depth (cm)			
	25	51	76	SE (15 df)
	(0-10: 0.6 = wilting point, 9.8 = field capacity)			
16 May	9.4 a*	9.4 a	9.7 a	0.09
30 May	2.7 a	9.5 b	9.6 b	0.23
9 June	0.4 a	4.1 b	9.5 c	0.42
13 June	0.2 a	1.5 b	9.3 c	0.22
19 June	0.2 a	1.2 b	8.9 c	0.19
23 June	0.2 a	0.5 a	8.1 b	0.34
26 June	0.2 a	0.4 a	6.8 b	0.42
2 July	0.2 a	0.6 a	4.7 b	0.50

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

Appendix Table I.26. KCl effects on the seed conditioning recovery percentage, seed purity, light seed percentage, germination, and germination rate of a 1984 first-year stand of Ovation perennial ryegrass.

	KCl ($kg\ ha^{-1}$)			SE (24df)
	0	187	560	
Recovery % (Threshed Wt/Clean Wt)	69.07	69.88	70.06	0.951
Conditioned Seed Purity %	98.59	98.70	98.76	0.075
% Lights (Total lights/Threshed Wt)	16.87 a*	15.78 b	15.59 b	0.349
Germination (%)	94.50 b	96.83 a	97.00 a	0.67
Germination Rate	16.29 b	16.83 a	16.94 a	0.156

*Means within rows within stand age followed by a different letter differ significantly at the 0.05 probability level.

Appendix Table I.27. Paclobutrazol effects on the seed conditioning recovery percentage of pure seed from thresher run seed of first- and second-year stands of Ovation perennial ryegrass in 1984, 1985, and 1986.

Year	Stand Age	Paclobutrazol kg a.i. ha^{-1} 0.0	0.56	0.84	SE[1.]
		- - - -	%	- - - -	
1984	first yr	67.3 b*	69.8 ab	70.9 a	0.95
1985	first yr	70.0 a	69.0 a	70.7 a	0.73
1985	second yr	65.0 b	69.8 a	69.8 a	0.43
1986	first yr	61.6 b	69.9 a	70.1 a	0.99
1986	second yr	57.2 b	71.9 a	71.1 a	1.16

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

1. 24 df in 1984 and 33df in 1985 and 1986.

Appendix Table I.28. Fertilizer effects on the seed conditioning recovery percentage of pure seed from thresher run seed of first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Fertilizer ($kg\ ha^{-1}$)		Year and Stand Age 1985 1st	1985 2nd	1986 1st	1986 2nd
		- - - - -	- - - (%)	- - - - -	
Check	0	69.6	67.8	64.8	65.9
KCl	560	70.5	69.7	68.4	66.6
K_2SO_4	660	69.0	66.7	67.8	66.3
$CaCl_2$	415	70.5	68.7	67.8	68.1
LSD .05		2.4	1.4	3.3	3.9
Contrasts					
Cl vs No Cl		NS	**	NS	NS
K vs No K		NS	NS	(P<0.1)	NS
K x Cl		NS	*	NS	NS
Check vs Some		NS	NS	*	NS

Appendix Table I.29. Paclobutrazol effects on the purity of conditioned seed of first- and second-year stands of Ovation perennial ryegrass in 1984, 1985, and 1986.

Year	Stand Age	Paclobutrazol kg a.i. ha^{-1} 0.0	0.56	0.84	SE[1.]
		- - - -	%	- - - -	
1984	first yr	99.06 a*	98.50 b	98.49 b	0.075
1985	first yr	98.75 a	98.37 b	98.50 b	0.077
1985	second yr	98.83 a	98.70 a	98.71 a	0.056
1986	first yr	97.41 a	97.07 ab	96.80 b	0.149
1986	second yr	96.09 a	96.15 a	95.86 a	0.195

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

1. 24 df in 1984 and 33df in 1985 and 1986.

Appendix Table I.30. Fertilizer effects on the purity of conditioned seed of first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

Fertilizer		Year and Stand Age			
		1985 1st	1985 2nd	1986 1st	1986 2nd
($kg\ ha^{-1}$)		- - - - -	(%)	- - - - -	
Check	0	98.50	98.71	97.00	95.59
KCl	560	98.56	98.91	97.49	96.50
K_2SO_4	660	98.59	98.64	97.00	95.94
$CaCl_2$	415	98.52	98.74	96.88	96.11
LSD .05		0.26	0.19	0.50	0.65
Contrasts					
Cl vs No Cl		NS	*	NS	*
K vs No K		NS	NS	(P<0.1)	NS
K x Cl		NS	(P<0.1)	(P<0.1)	NS
Check vs Some		NS	NS	NS	*

Appendix Table I.31. Effects of paclobutrazol on the amount of light seed as a fraction of the total thresher run seed of first- and second-year stands of Ovation perennial ryegrass in 1984, 1985, and 1986.

Year	Stand Age	Paclobutrazol kg a.i. ha^{-1}			SE[1.]
		0.0	0.56	0.84	
		- - - -	%	- - - -	
1984	first yr	14.61 b*	16.45 a	17.18 a	0.349
1985	first yr	9.93 a	10.42 a	10.43 a	0.298
1985	second yr	10.23 a	9.52 b	9.88 ab	0.169
1986	first yr	10.26 a	9.47 a	9.58 a	0.285
1986	second yr	13.61 a	11.14 b	11.24 b	0.425

*Means within rows followed by a common letter are not significantly different at the 0.05 probability level.

1. 24 df in 1984 and 33df in 1985 and 1986.

Appendix Table I.32. Fertilizer effects on the amount of light seed as a fraction of the total thresher run seed of first- and second-year stands of Ovation perennial ryegrass in 1985 and 1986.

		Year and Stand Age			
Fertilizer		1985 1st	1985 2nd	1986 1st	1986 2nd
($kg\ ha^{-1}$)		-----	(%)	-----	
Check	0	10.39	9.76	10.51	12.34
KCl	560	9.97	9.62	9.31	11.40
K_2SO_4	660	10.63	10.30	9.89	12.55
$CaCl_2$	415	10.04	9.82	9.37	11.69
LSD .05		1.00	0.58	0.95	1.42
Contrasts					
Cl vs No Cl		NS	NS	*	**
K vs No K		NS	NS	NS	NS
K x Cl		NS	(P<0.1)	NS	NS
Check vs Some		NS	NS	*	NS

Appendix Table II.1. OSU soil test values for 3:1 sand to soil potting mix.

	pH	P (PPM)	K (PPM)	Ca (MEQ/100g)	Mg (MEQ/100g)
Lab No 067-004 (4987)	5.9	39	85	4.0	1.1

Appendix Table II.2. Phosphorus effects on the shoot weight per tiller and root weight per tiller of 90-day old Ovation perennial ryegrass seedlings.

	Phosphorus (kg ha^{-1})		
	6	60	SE (42df)
Shoot Wt. per tiller (mg)	20.6 a*	20.8 a	1.00
Root Wt. per tiller (mg)	16.0 a	12.7 b	1.05

* Means within rows followed by a common letter are not significantly different at the 0.05 probability level.