Responses of Two Perennial Ryegrass Cultivars Grown for Seed to Nitrogen, Paclobutrazol and Propiconazole

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ABSTRACT

The effects of nitrogen rates (60, 120 and 180 kg N ha^{-1}), the plant growth regulator (PGR) paclobutrazol, and the fungicide propiconazole on the potential and actual seed yield and seed yield components of perennial ryegrass (*Lolium perenne* L.) cv. Fiesta II and Norlea were investigated near Elora, Ontario, Canada in three experiments (Exp) over two seasons. Paclobutrazol prevented lodging at all N rates. Better control of leaf rust (*Puccinia* sp.) was provided by paclobutrazol than propiconazole. Potential seed yield responses were inconsistent for cultivar, N, PGR and fungicide and were mostly related to changes in the number of fertile tillers m^2. Shed seed amounted to 40% of mean yield. PGR and N effects on seed shedding were variable. Yield differences between cultivars were mostly accounted for by differences in seed shedding which might be attributed to timing of harvest. In Exp 1, PGR application increased yield. In Exp 2, PGR-treated plots tended to yield less. In Exp 3, the PGR increased yield in cv. Norlea only. Lodging and crop morphology were altered by chemical management, but these changes were not associated with seed shedding and yield.

Additional index words: **lodging, yield potential, seed shattering, disease control.**

INTRODUCTION

Perennial grasses are inherently poor seed producers, generally allocating a lower proportion of energy and other plant resources to sexual reproduction than annual species (Van Andel and Vera, 1977). Also, cross pollinated species generally show lower seed/ovule ratios than self pollinating species (Charlesworth, 1989). Seed yield of grasses might be improved by breeding and by cultural manipulation of the crop (Elgersma, 1985). However, grass breeding has been chiefly aimed at improving dry matter yield and quality (Albeke, Chilcote and Youngberg, 1983), and sward persistency, which are related to strong vegetative growth. Unfortunately, there is no correspondence between those objectives and the objective of increasing seed yield, which is mainly related to reproductive development (Griffiths, Lewis and Bean, 1980).

An option for cultural manipulation of crops is the use of chemicals. While combined application of nitrogen (N), fungicides and plant growth regulators (PGRs) has been successfully introduced into several field crops, differences in sensitivity and response to PGRs among species and cultivars prevent the extrapolation of cultural practices from one crop to another. Thus an approach which has become almost standard in cereal production is still under active investigation in grass seed crops (Hebblethwaite, 1987).

It is desirable to optimise the amount of available soil N for grass seed crops, since N is a major determinant of yield (Sinclair and De Wit, 1975). However, N application to perennial ryegrass can cause pre-anthesis lodging (Hampton, Clemence and Hebblethwaite, 1983) and a subsequent reduction in seed yield (Chilcote, Youngberg and Young, 1984). Lodging is charged with poor pollen dispersal (Hebblethwaite, 1977), increased seed abortion (Hampton and Hebblethwaite, 1985a; Hampton, Clemence and Hebblethwaite, 1987), reduced light interception by the crop canopy (Hebblethwaite, 1977) and increased competition for assimilate otherwise available for the ear by promoting the production of vegetative tillers (Burbidge, Hebblethwaite and Ivins, 1978). Lodging may also promote pathogen development resulting in high tiller mortality (Griffiths, 1967) and reduction of floret sites. Control of lodging appears then to be a desirable goal in crop management. Among the PGRs, the triazole derivative paclobutrazol has shown strong lodging control activity in perennial ryegrass. Paclobutrazol is an inhibitor of gibberellin (GA) and ergosterol biosynthesis, and shows a wide range of growth retardant, morphological and fungicidal effects on plants (Davis, Steftens and Sankhla, 1988). However, concurrent seed yield responses have been less consistent (Hebblethwaite, 1987). Another triazole derivate, propiconazole, is a systemic fungicide, used in intensive management of cereal crops. However, the dual growth retardant and fungicidal activity of some triazoles like paclobutrazol, might make redundant the simultaneous application of a fungicide to a seed crop.

This study was conducted to compare the single and combined effects of N, paclobutrazol and propiconazole on the morphology, seed yield, and yield components of two perennial ryegrass cultivars.

MATERIALS AND METHODS

Three field experiments were conducted at the Elora Research Station, University of Guelph, on a silt loam soil (Typic Hapludalf-grey brown podsolic). Perennial ryegrass cv Fiesta II (an early maturing turf type), and cv Norlea (a

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late maturing forage type) were drilled at a rate of 6 kg ha^{-1} in 18 cm wide rows in 7 row plots, 7 m long. Experiment (Exp) 1 was sown in August 1987 and Exp 2 in August 1988. Exp 3 was the second harvest year of Exp 1. In all experiments, N, paclobutrazol [(2RS, 3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl) pentan-3-ol] and propiconazole [1-(2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl-methyl)-1H,1,2,4-triazole] were imposed as chemical management. All combinations of N (60, 120 and 180 kg ha^{-1}), paclobutrazol (0 and 2.0 kg ai ha^{-1}) and propiconazole (0 and 0.125 kg ai ha^{-1}) were applied to experimental units randomised as subplots with cultivars as main plots in a split plot design with four replicates. Nitrogen was applied at the onset of spring growth. Paclobutrazol was sprayed at the spikelet initiation stage in both Exp 1 and Exp 2, following N application. In Exp 3, the PGR was applied at the booting stage. Propiconazole was sprayed at the beginning of ear emergence. Spikelet initiation was monitored microscopically by the dissection of 25 tillers randomly and frequently taken from the experimental area. Intensity and area affected by both lodging and disease were visually rated two weeks before harvest. Intensity was rated on a 1 (absent) to 5 (severe) scale whereas area affected was rated on a 1 (none) to 10 (full) scale. These ratings were converted into lodging and disease indices by multiplying intensity x area affected x 0.2. Plant height was measured at the same time. One week before harvesting, two 20-cm long samples of inner rows were taken for yield component determinations. The total number of reproductive tillers in the samples was counted. From the combined samples, ten tillers per plot were taken to determine the number of spikelets per tiller. Seed yield per sample was determined from the combined 20 cm-long samples per plot in both Exp 2 and Exp 3. From this sample yield, final seed number per spikelet and per tiller was determined. In Exp 1, number of seeds per spikelet and per tiller were calculated from the total plot seed yield. In Exp 1 and 2, 25 phenologically similar fertile tillers per plot were tagged at anthesis. Five tagged fertile tillers were collected two days after tagging. Tillers were preserved in FAA (450 ml distilled water + 450 ml 95% ethanol + 50 ml glacial acetic acid + 50 ml 10% formalin = 1000 ml FAA). Florets were counted, using a dissecting stereomicroscope providing 64X magnification, in a subsample of three spikelets from each tiller. One spikelet was taken from each of the apical (the penultimate spikelet), the intermediate, the basal (the penultimate spikelet) sections of the spike. Exp 1 was direct-combined on July 19 (Fiesta II) and July 27 (Norlea). The following year, Exp 3 and 2 were direct-combined on July 29 and August 3 for Fiesta II and on August 9 and 10 for Norlea. Immediately after the harvesting of Exp 2 and 3, shed seed was recovered from a 0.242 m^2 sampling area per plot, by means of a portable vacuum. Germination percentage and 1000-seed weight (TSW) were determined on a sample of 200 seeds per treatment for both the harvested and the shed seed. Data analysis were performed by analysis of variance and least square regression.

RESULTS

Crop lodging

Paclobutrazol prevented lodging in both cultivars and at all N levels in all experiments, the effect persisting until harvest. In the absence of PGR application, lodging was already severe at anthesis. Control of lodging was associated with a significant reduction in plant height which resulted from an increasing reduction in internode length from the second upper internode down the stem (data not presented). No differences in the length of the uppermost internode were found. No effect of N rate on lodging was found and lodging was severe at all rates in the absence of PGR application.

Disease index

An outbreak of leaf rust affected Exp 2. The incidence of the disease was significantly reduced by both paclobutrazol and propiconazole in Fiesta II but only by the PGR in Norlea (Fig. 1). In Fiesta II, the PGR was more effective than the fungicide. No synergistic interaction between the PGR and the fungicide was recorded.

Theoretical yield potential

Assuming full floret site utilisation (FSU), theoretical potential seed yield is determined by the number of florets/spikelet at anthesis x number of spikelets/spike x number of spikes/m^2 x average seed weight (Elgersma, 1985). No differences in potential seed yield among experiments were found. The mean seed yield potential for Exp 1 and 2 was 11,993 ± 2887 kg ha^{-1}. Mean actual yield for the same experiments was 989 ± 122 kg ha^{-1} or about 8% of the theoretical maximum.

In Exp 1, no cultivar differences in potential yield appeared but a significant N x fungicide interaction with no clear pattern of response was observed (data not presented). In Exp 2, paclobutrazol significantly increased potential yield in Norlea (Table 1). The highest N rate increased potential yield in Fiesta II but not in Norlea, whereas the fungicide increased potential yield in Fiesta II but reduced it in Norlea. Most potential yield differences appeared to be related to changes in the number of fertile tillers m^{-2} but the response of this variable was inconsistent.

Thousand seed weight (TSW) of harvested seed

In Exp 2, Fiesta II had a higher TSW than Norlea (Table 1). No differences between cultivar were found in Exp 1 and 3. In Exp 1, TSW of Fiesta II was significantly reduced by 9% by the PGR. In Exp 2, the PGR significantly decreased TSW in both cultivars. The reduction was 8% for Fiesta II and 7% for Norlea. No effect of the PGR on TSW arose in Exp 3 (data not presented). Nitrogen and propiconazole

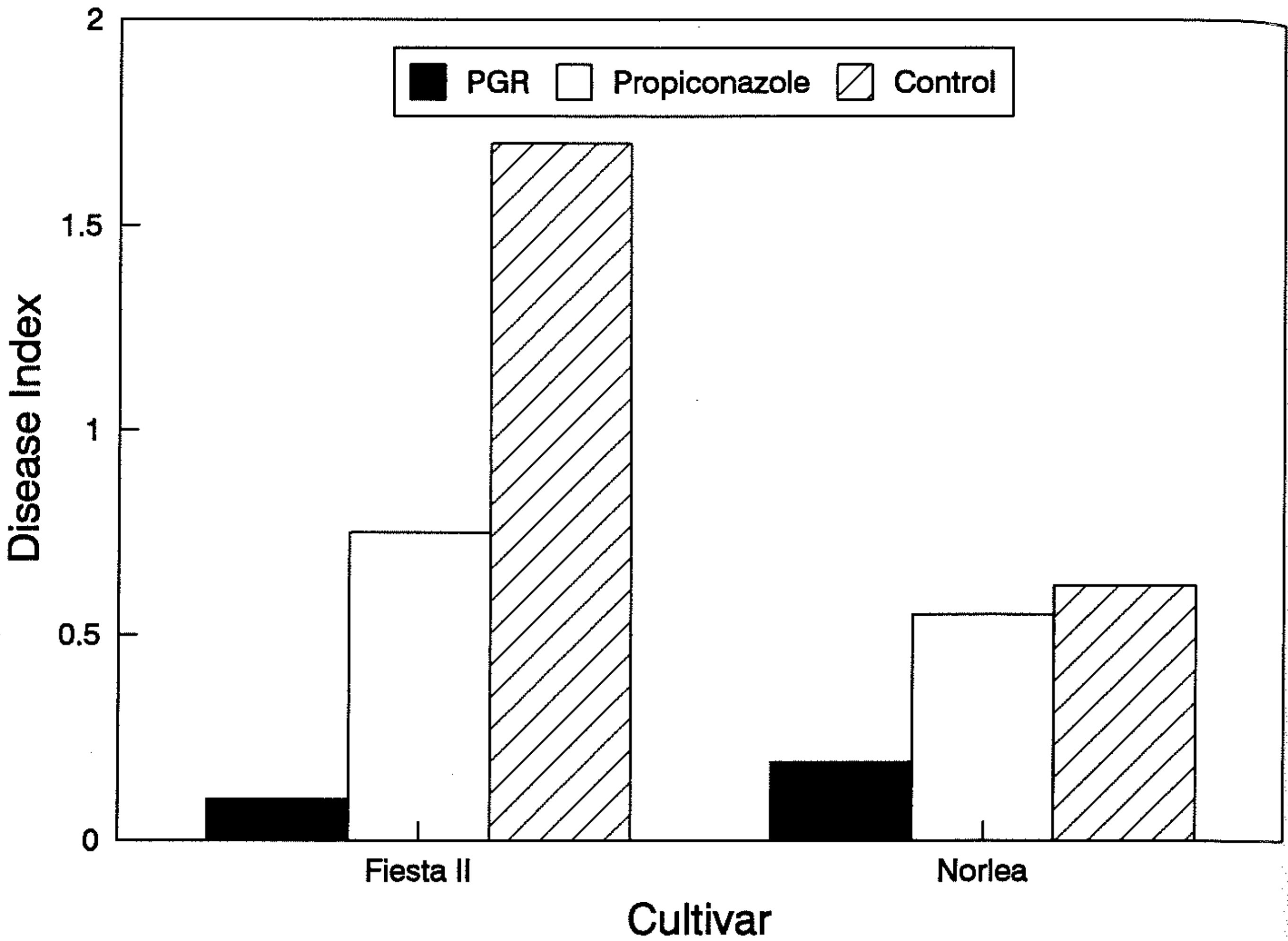

Figure 1.
Disease index response to paclobutrazol and propiconazole application. Exp 2.
LSD ($P < 0.05$) PGR = 0.2
LSD ($P < 0.05$) propiconazole = 0.2
LSD ($P < 0.05$) cv x PGR = 0.2
LSD ($P < 0.05$) cv x propiconazole = 0.2

did not affect TSW in any experiment.

Seed shedding

Significant amounts of shed seed were recovered from the ground after harvesting the two experiments involved (Table 2). Recovered clean seed amounted to 409 ±84 kg ha^{-1} or 41% of the mean yield. Norlea shed 10% less seed than Fiesta II in Exp 2 but shed 40% more seed than Fiesta II in Exp 3 and the differences were significant. Fiesta II shed similar amounts of seed in both Exp 2 and 3.

Significant PGR x N x fungicide and cv x PGR x N interactions occurred in both experiments. Exp 2 suggested a trend of less seed shedding associated with PGR application at the intermediate N rate in both cultivars, regardless of fungicide application, whereas considerable shedding was mostly associated with the low N rate and the absence of PGR application (Table 2). Exp 3 suggested a trend of less seed shedding occurring in Fiesta II at the low and intermediate N rates, in the absence of PGR application and regardless of fungicide use, whilst more shedding appeared to be associated with Norlea, mostly under PGR application (Table 2).

Thousand seed weight and percentage germination of shed seed

Shed seed had consistently lower TSW than harvested seed. Reductions ranged from 10 to 18%. However, significant reductions relative to TSW of harvested seed occurred only in Exp 2 (Table 3). Paclobutrazol caused a reduction in TSW of shed seed and the difference was significant for Norlea in Exp 2. No nitrogen or propiconazole effects were recorded (Table 3).

Percentage germination of both shed and harvested seed was similar. Mean germination was 94% at the seven day count.

Table 1. Mean values of seed yield components and theoretical potential seed yield at day 2 following anthesis as affected by PGR, N rates and fungicide (F) application, Exp 2.

Cv	Factor	Fertile tillers m^{-2}	Spikelets $tiller^{-1}$	Florets $spikelet^{-1}$	TSW	Potential yield
			number		(g)	(kg ha^{-1})
Fiesta II	No PGR	3513	20.6	8.5	2.09	12878
	PGR	3369	20.8	9.0	1.92	12107
Norlea	No PGR	2730	21.7	8.9	1.84	9701
	PGR	2999	23.5	9.5	1.71	11462
LSD (P <0.05)		NS	0.9	NS	NS	1416
Fiesta II	N1*	3527	20.7	8.4	1.99	12057
	N2	3184	20.9	8.7	1.99	11418
	N3	3613	20.6	9.1	2.03	14001
Norlea	N1	2988	23.4	9.0	1.76	11098
	N2	2938	22.4	9.3	1.77	10710
	N3	2666	22.1	9.4	1.79	9945
LSD (P < 0.05)		384	NS	NS	NS	1735
Fiesta II	No F	3247	20.4	8.8	2.00	11678
	F	3635	21.1	8.7	2.01	13306
Norlea	No F	3037	22.6	9.4	1.78	11386
	F	2691	22.6	9.1	1.77	9777
LSD (P <0.05)		313	NS	NS	NS	1416

* N1 = 60 kg N ha^{-1}
N2 = 120 kg N ha^{-1}
N3 = 180 kg N ha^{-1}

Seed yield

Fiesta II yielded significantly more harvested seed than Norlea in Exp 1 and 3 (Table 4). Total yield (harvested seed + shed seed) trends matched those for harvested yield in Exp 2 and 3. Similar results were observed when the tiller samples (from two 20-cm row lengths) were used to estimate plot yields (Table 4).

Experiment 1 suggested that higher yields in both cultivars were associated with paclobutrazol, irrespective of N rate in Fiesta II but in combination with the lowest N rate in Norlea (Table 5a). In Exp 2, however, untreated plots of the two cultivars yielded significantly more than PGR-treated plots except for the lower N rate which produced similar low yields in each cultivar, regardless of PGR application (Table 5a). In Exp 3, the PGR caused a significant yield increase in Norlea, regardless of N rate, whereas in Fiesta II yield did not differ (Table 5a).

Total seed yields produced differences similar to those of harvested yield (Table 5b). In Exp 2, untreated plots of the two cultivars yielded significantly more than PGR-treated plots except for Norlea at the intermediate N level which sustained an intermediate yield, regardless of PGR application. In Exp 3, total yield of Norlea was significantly increased by the PGR, regardless of N rate, and yield of Fiesta II was significantly increased by PGR applied at the intermediate and high N level (Table 5b). Loss of harvestable seed was not affected by treatments, but Norlea generally lost a significantly higher percentage compared to Fiesta II.

Response of harvested yield to N was inconsistent (Table 5a). In Exp 1, in the absence of PGR, Norlea yielded significantly more at the lowest N rate (60 kg ha^{-1}) than at the other rates. When PGR was applied, yield of Fiesta II increased with N up to the intermediate rate whereas Norlea

Table 2. Mean quantity of shed seed as affected by paclobutrazol (PGR), nitrogen rate (N) and propiconazole (F) application.

Exp	Cultivar	PGR	60 kg N		120 kg N		180 kg N	
			F0[1]	F1[2]	F0	F1	F0	F1
					seed (kg ha^{-1})			
2	Fiesta II	0[1]	422	503	348	409	436	286
		1[3]	475	333	207	327	303	400
	Norlea	0	439	608	213	223	413	191
		1	390	209	329	368	349	274
3	Fiesta II	0	365	340	227	243	504	316
		1	357	436	517	517	444	381
	Norlea	0	337	432	244	433	780	569
		1	575	664	712	606	516	664

LSD ($P < 0.05$) cv x PGR x N x F, Exp 2 = 176
LSD ($P < 0.05$) cv x PGR x N x F, Exp 3 = 154
[1] no fungicide or PGR
[2] propiconazole 0.125 kg a.i. ha^{-1}
[3] paclobutrazol 2.0 kg a.i. ha^{-1}

Table 3. Mean seed weight (TSW) of shed seed as affected by paclobutrazol, nitrogen rate and propiconazole.

Experiment	Treatment	Rate	Fiesta II	Norlea
		kg ai ha^{-1}	TSW (g)	
2	Paclobutrazol	0	1.77*	1.59
		2	1.69	1.40*
	Nitrogen	60	1.75	1.46
		120	1.74	1.54
		180	1.70*	1.49
	Propiconazole	0	1.77	1.50
		0.125	1.69*	1.50
3	Paclobutrazol	0	1.55	1.45
		2	1.52	1.39
		60	1.52	1.43
		120	1.48	1.39
	Nitrogen	180	1.50	1.41
	Propiconazole	0	1.48	1.40
		0.125	1.52	1.40

* Significantly lower than TSW of harvested seed ($P < 0.05$)
LSD ($P < 0.05$) cv x PGR, Exp 2 = 0.09

yielded significantly less at the highest N rate. In Exp 2, N had no effect on harvested yield, except that Fiesta II yielded significantly more at the intermediate rate with no PGR. In Exp 3, Norlea did not respond to N rate but in Fiesta II, the two highest N rates significantly outyielded the lowest rate, regardless of PGR application. Total yield (harvested + shed seed) response to N rate did not match harvested yield. In Exp 2, Fiesta II total yield was reduced by increased N when PGR was applied. In Norlea, yield was lower at 120 kg N ha^{-1}, in the absence of PGR. In Exp 3, total and harvested yield responses

Table 4. Mean seed yield of cultivars Fiesta II and Norlea.

Experiment	Cultivar	Yield			
		Harvested	Shed	Total	Sample[2]
			kg ha^{-1}		
1	Fiesta II	1081	na[1]	na	na
	Norlea	676	na	na	na
	LSD (P < 0.05)	103			
2	Fiesta II	1062	371	1432	1860
	Norlea	1136	334	1470	1785
	LSD (P < 0.05)	NS	23	NS	NS
3	Fiesta II	1336	287	1723	2358
	Norlea	766	544	1310	1528
	LSD (P < 0.05)	63	54	74	162

[1] na = not available
[2] yield calculated from two 20 cm row lengths per plot

Table 5. Mean harvested and total seed yield of cv. Fiesta II and Norlea in response to paclobutrazol (PGR) application and N rate.

Experiment	Cultivar	PGR (nil)			PGR (2.0 kg ai ha^{-1})		
		N1	N2	N3	N1	N2	N3
a Harvested				kg ha^{-1}			
1	Fiesta II	1095	1015	1049	1025	1136	1165
	Norlea	707	585	604	771.	725	664
2	Fiesta II	1125	1318	1260	985	841	840
	Norlea	1173	1239	1265	1029	1051	1062
3	Fiesta II	1203	1378	1392	1170	1408	1464
	Norlea	544	648	1265	863	938	946
LSD (P < 0.05) cv x PGR x N, Exp 1 = 1101; LSD (P < 0.05) cv x PGR x N, Exp 2 = 145; LSD (P < 0.05) cv x PGR x N, Exp 3 = 138							
b Total[1]							
2	Fiesta II	1587	1697	1621	1389	1108	1192
	Norlea	1697	1458	1568	1328	1399	1374
3	Fiesta II	1555	1612	1802	1567	1925	1876
	Norlea	928	1073	1328	1482	1511	1536
LSD (P < 0.05) cv x PGR x N, Exp 2 = 172; LSD (P < 0.05) cv x PGR x N, Exp 3 = 149							

[1] harvested plus shed

to N rate concurred, except that for Norlea the highest N rate applied with no PGR, significantly increased total yield over the other two levels (Table 5b). Except for Norlea in Exp 3, the data suggest that maximum yield was achieved at N rates between 60 and 120 kg ha^{-1}. Yield was independent of PGR application in all years and experiments.

No effect of propiconazole on harvested yield arose in either Exp 1 or Exp 3. In Exp 2, which was severely affected by leaf rust, the fungicide significantly increased yield of Norlea by 11% whereas no effect on Fiesta II was evident (data not presented). Fiesta II may have resisted the deleterious effect of disease by its more advanced maturity at the time of rust occurrence.

DISCUSSION

Paclobutrazol provided greater disease control than propiconazole. Whereas paclobutrazol had both growth regulating and fungicidal activity, propiconazole showed no growth regulating activity at the rates and time of application involved. Besides inhibiting gibberellin biosynthesis, paclobutrazol also inhibits the biosynthesis of ergosterol, which accounts for its fungicidal activity (Davis *et al.*, 1988). It appears that at this site in one year, the fungicidal activity of paclobutrazol was strong enough as to make redundant the application of a specific fungicide, allowing for a cost reduction in chemical management.

Contradicting Burbidge *et al.* (1978) who did not consider shedding to be a major factor affecting seed yield, our results showed that 20 to 45% of harvestable yield is lost by shedding of fully developed seed. Seed shedding, which is part of the mechanism of seed dispersal, is a widespread adaptive trait in grasses, favoured by natural selection (Kadkol, Halloran and MacMillan, 1989). The observed effect of paclobutrazol on seed shedding may have resulted from a metabolically mediated modification of the ultrastructure of the abscission layer, or else from changes in the synthesis or rate of activity of hydrolytic enzymes in the abscission layer cells. It has been shown that chlormequat chloride induced changes in the activity of some enzymes in the stem of wheat plants (Firgany, Zaher, Foad and El-Fouly, 1980). Paclobutrazol might induce analogous changes in the abscission layer, which is considered a likely target tissue for PGRs (Roberts and Hooley, 1988). Thought of involvement of abscisic acid (ABA) arises from the suggestion by Osborne (1988) that the abscission zone cells in the rachilla of the gramineae are specific targets for ABA, which activate the genes related to the enzymes that degrade the middle-lamella polysaccharides at the zone. The link with paclobutrazol is suggested by the observation that ABA synthesis (from mevalonic acid, also the precursor of GA) is inhibited by this PGR in the fungus *Cercospora rosicola* (Halmann, 1990); a similar inhibition of ABA biosynthesis might occur in grasses. Variable effects of paclobutrazol on seed shedding have previously been reported. Hampton and Hebblethwaite (1985b) found that seed shed was greater in untreated plots in one year whereas the opposite occurred the following year. In our case, the two experiments were grown during the same season; however, comparable variability arose. Subtle environmental differences between sites, causing a slight out-of-phase growth of the plants in one site with respect to another at the time of PGR application, may account for the observed variability. Discrepancies in the magnitude of the differences between treated and untreated plots, when estimated from harvested yield or from total yield, indicate that seed shedding can greatly influence yield as harvested yield expresses the balance between total harvestable seed and seed shedding. Evidence about the effect of paclobutrazol on seed retention at the ripening stage is still inconclusive (Hampton and Hebblethwaite, 1985a). However, data which suggest that paclobutrazol reduces shedding during early seed development have been produced (Mares Martins and Gamble, 1993). It is plausible that paclobutrazol increases seed retention up to a time after which a burst of seed shedding could offset the initial beneficial effect. If harvesting is carried out too early, paclobutrazol might increase seed retention to the point of affecting the threshability of the heads at seed moisture contents conducive to seed shedding in untreated plots. Thus, Hampton and Hebblethwaite (1985c) observed that direct combine harvest of paclobutrazol-treated perennial ryegrass crops resulted in significant numbers of unthreshed heads passing through the combine. Consequently, direct combining of the treated plots, at the recommended seed moisture content of 35%, yielded significantly less seed than either double combining or swath harvesting. On the other hand, heavy shedding can occur if harvesting is delayed or carried out with improper methods. Thus, timing and method of harvesting can be the most important factor controlling seed shedding. This factor can be even more critical in paclobutrazol treated plots to fully realize any increase seed yield potential.

Effects of paclobutrazol on seed shedding at a single harvesting date, could be attributed to a delay of maturity. Chilcote *et al.* (1984) observed a 2-3 day delay in crop maturation following paclobutrazol application. However, they caution that in many cases of apparent delayed maturity, seed moisture content of treated and untreated plants was the same. Differences in harvested yield between Fiesta II and Norlea appeared to be mostly accounted for by differences in seed shedding rather than being attributable to any difference in yield potential at anthesis. Differences in seed shedding may be attributed to timing of harvesting. Norlea was harvested rather late in Exp 3, compared to Exp 2, and to Fiesta II in all experiments. Likely, the delay allowed heavy seed shedding to occur, reducing harvested yield. It appears that Norlea should be harvested earlier than its late maturity type indicates, in order to prevent heavy shedding. Our results indicate that heavy seed is not more prone to be shed than light seed, as could be expected to happen if the breaking of the abscission layer occurs by passive mechanical action (Kadkol *et al.*, 1989) at all seed positions. Instead, the top section of the spikelets, which hold lighter seed (Hampton and Hebblethwaite, 1985a), might be more exposed to mechanical stress, shedding more seed than other sections. Reductions in TSW caused by paclobutrazol have been previously reported (Hampton and Hebblethwaite, 1984). As GA is involved in cell growth, reduced TSW might arise from a reduced degree of cell expansion causing a reduction in storage capacity in the endosperm of paclobutrazol-treated seeds.

Concerning seed yield responses to N, our results agree with previous reports on perennial ryegrass. Thus, Hebblethwaite and Ivins (1977) found optimum levels of applied N to be between 80 to 120 kg ha^{-1}, and Hampton *et al.* (1983) noted that N application in excess of 120 kg ha^{-1} either reduced or had no effect on yield. The reduction or lack of effect on yield, has been attributed to increased competition by an enlarged population of secondary vegetative tillers, brought about by the higher N rate (Hampton and Hebblethwaite, 1984; Meijer and Vreeke, 1988). Our data suggest that reduced seed shedding at intermediate N rates could also be a factor. No direct evidence of seed shedding responses to N rates can be found in the literature. However, Hampton *et al.* (1983) have reported that N at rates above 40-80 kg ha^{-1} significantly reduced the harvested number of seeds per spikelet. Since they noticed that yield potential at anthesis was increased by nitrogen, their results could indicate a greater seed shedding (or seed abortion) brought about by nitrogen. Our data suggest that seed shed is affected by N rate, tending to be lower at 120 kg N ha^{-1}, compared to lower and higher rates. This could partially explain the higher yields generally obtained at intermediate N rates. It appears that N application to perennial ryegrass seed crops is not limited by any risk of increased lodging but by other more important effects. Hampton *et al.* (1983) reported that lodging increased with increased N rates applied but the effect was significant between 0 and 80 kg N ha^{-1} whereas no significant increase occurred between 80 and 160 kg N ha^{-1}, which supports our observation of no difference in lodging between 60 and 180 kg N ha^{-1}. Although paclobutrazol was consistently effective in lodging control in agreement with previous reports (Hebblethwaite, 1987), it increased yield in just 50% of the cases. This suggests that lodging *per se* does not have a major effect on seed yield in perennial ryegrass as is generally stated (Chilcote *et al.*, 1984). Variability in yield responses to paclobutrazol could be due to variable effects of triazole growth retardants on post anthesis vegetative tillering as reported for paclobutrazol and RSW0411 (Hampton and Hebblethwaite, 1984; Wiltshire, Hebblethwaite, Esslemont and McGilloway, 1989).

In conclusion, paclobutrazol proved consistently active in controlling lodging and reducing stem elongation. However, the general lack of correlation between these variables and seed yield and shattering indicates that crop morphological changes and likely modifications in nutrient allocation caused by PGRs are unlikely to affect seed yield if harvest is not timely.

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