days) after treatment at the recommended rate and 51.8 ppm to 0.10 ppm, respectively, at the higher rate. High residues were detected in the nectar 12 hrs after treatment. However, these high residues were not detected in the pollen-nectar ball or leaf from the cell. In spite of these levels of residues, the bees performed well in the treated plots and the insecticide provided good control of the detrimental insects in the alfalfa. The number of bee cells constructed in 1981 averaged 13% above those from the control (Table 1). Also, the percent cells with cocoons, percent live larvae, and percent pollen balls reflected no adverse effect of oxydemeton-methyl on the bees or their pollination activities. Oxydemeton-methyl was applied again in 1982 with similar results regarding bee activities (Rincker, unpublished data).

In summary, residues in the leaves and/or the pollen-nectar balls show no adverse effect on bee larvae in this study even at 1.5 times recommended rates. Bees from cells retained from the 1980 treated plots performed as well in 1981 as bees from the control plots. The effect of pesticide residues in the pollen-nectar ball on leafcutting bee larvae has not been reported previously. Results from this study are not a basis for using more than the recommended rates of the respective insecticides but are reported as experimental data only.

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Lodging Control and Yield Enhancement in Morex Spring Barley with Paclobutrazol Treatment[1]

L.A. Morrison and D.O. Chilcote[2]

ABSTRACT

Paclobutrazol, an experimental plant growth regulator (PGR), is reported to control lodging through height reduction and stem strengthening and thereby enhance yield. This field experiment tested Paclobutrazol under two levels of nitrogen on a known lodging-susceptible spring barley cultivar (*Hordeum vulgare* cv. Morex).

Paclobutrazol caused significant shortening of the basal internodes but did not improve stem strength. Due to delayed lodging, treated plots reflected significant yield increases over the control plots. The higher treatment rates (800 and 1000 g ha^{-1}) also showed significant yield increases over the lower treatment rates (400 and 600 g ha^{-1}).

The results point to a clear association of reduced height with lodging control and concomitantly with yield increases. The absence of improved stem strength raises questions concerning the mechanism of Paclobutrazol's effect on lodging in the barley species and the mechanism of its effect in combination with nitrogen fertility.

Additional index words: **Height reduction, *Hordeum vulgare*, Parlay, plant growth regulator, stem strength.**

INTRODUCTION

Lodging can be a management problem in intensive cultural systems where high nitrogen levels and optimum moisture relations are used to promote yield (Mulder, 1954; Pinthus, 1973). Under these conditions, lodging-susceptible cereal cultivars , which are typically tall and weak-strawed, show a greater tendency to lodge. Yield losses can be significant, particularly when plants lodge during the early-lodging period that occurs at heading (Laude and Pauli, 1956; Pinthus, 1973).

Plant growth regulators (PGR's) which affect the stem elongation event by manipulating the endogenous hormone systems have proven useful in controlling lodging (Froggatt

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et al., 1981; Humphries, 1968; Pinthus, 1973). The experimental PGR, Paclobutrazol (Parlay), is an inhibitor of gibberellin (GA) synthesis and has been shown to be effective in reducing plant height and thereby controlling lodging in cereal and grass seed crops (Froggatt et al., 1981; Johnston and McLeod, 1980; Chilcote et al. 1982, 1983). Parlay's mechanism of action appears to be similar to that of Chlormequat (CCC), a GA-synthesis inhibitor that is widely used for cereal lodging-control in Europe (Froggatt et al., 1981; Humphries, 1968).

Cereal crop research with Parlay has produced variable results. Most often the grain yield-enhancing attributes of the chemical are realized when the tested cultivars show a susceptibility to lodging (Froggatt et al., 1981; Johnston and McLeod, 1980). When they do not, the data indicate that benefits of Parlay treatment are lessened. In Oregon, Parlay treatment of the typically lodging-resistant semidwarf white winter wheats can cause to yield reductions (Chilcote et al. 1982, 1983). This study was designed to evaluate Parlay on Morex barley, a cultivar known to be susceptible to lodging under growing conditions of the Pacific Northwest.

MATERIALS AND METHODS

Morex is a six-row, spring malting barley with a medium-tall, moderately strong-strawed stem (Anon., 1985). It was planted on March 12, 1984 at the Oregon State University Agricultural Research and Extension Center in Hermiston, Oregon. The soil was an Adkins loamy sand which carried 31 kg ha^{-1} of residual nitrogen.

The experiment was arranged in a split-plot design. The main plots received two nitrogen levels of 112 and 168 kg ha^{-1}, and the subplots received four Parlay treatments and a control. Seed was drilled in 18-cm rows at 45 kg ha^{-1}. Subplots measured 2 x 6 m. Preplant nitrogen of 56 kg ha^{-1} was applied to both main plots. After seedling emergence, nitrogen treatments of 56 and 112 kg ha^{-1}, respectively, were broadcast by hand. Plants were treated with Parlay at rates of 400, 600, 800, or 1000 g ha^{-1} a.i. at Freekes Scale Stage 6 (Large, 1954). Parlay application was made by a Cooper-Pegler backpack sprayer and a hand-held spray boom fitted with 8002LP nozzles. Application pressure was 242 kg cm^{-2}.

Precipitation from planting to harvest totaled 436 mm. A sprinkler irrigation system delivered 326 mm of water at increments of 6, 59, 120, and 141 mm during the months of March, April, May, and June, respectively. Rainfall during this period totaled 110 mm. No rainfall was recorded after July 1984.

Lodging was scored periodically during the growing season following Parlay treatment. A lodging scale of one to five was used. One indicated no lodging and five indicated severe lodging. The degree of lodging was measured by percent of the plot lodged.

Prior to harvest, 30-cm-length row samples were cut by hand sickle. Subsamples of five fertile tillers were selected and measured for stem length, internode lengths, and yield component data. The basal internode region was cut to two 10-cm sections. The sections were weighed to give the specific stem weight (SSW) value which constitutes the dry weight per unit length of stem (Hunter, 1984). SSW is a density measurement which has been shown to correlate with breaking strength (Atkins, 1938). It was used in this study in place of stem strength measurements.

RESULTS

Plant Height

Parlay decreased plant height significantly for all Parlay treatment rates (Table 1). Height reductions ranged from 15 to 27%. The high treatment rates (800 and 1000 g ha^{-1}) also decreased height significantly over the low treatment rates (400 and 600 g ha^{-1}). The number of nodes was decreased significantly from the control in the high Parlay treatment rates due probably to a compression of the lower stem internodes (Table 1).

The most significant shortening attributable to Parlay treatment occurred in the first three internodes (Table 2). Shortening of the first, second, and third internodes was significantly correlated to both treatment rate and height reduction (Table

Table 1. Effect of Parlay treatment rate on yield and stem morphology of Morex barley grown in Hermiston, Oregon under two nitrogen treatments, 1984.

Parlay Rate (g ha^{-1})	Fertile Tillers	TSW[1] (g)	Yield (kg ha^{-1})	CST[2]	Spikelets[3]	Nodes	Height (cm)	SSW[4] (mg cm^{-1})
0	26	40	4395	25	20.8	7.48	124	23.6
400	25	38	5815	34	20.9	7.16	106	17.2
600	31	37	5976	30	20.6	7.13	101	15.7
800	28	37	6704	36	20.9	7.08	95	16.4
1000	27	37	6776	38	20.8	6.93	91	15.4
LSD .01	NS	1	645	10		0.36	5	4.0
LSD .05	NS				NS			

[1]Thousand seed weight.
[2]Calculated seeds per tiller.
[3]The three spikelets at each rachis node were counted as one. Rudimentary spikelets were also counted.
[4]Specific stem weight.

Table 2. Effect of Parlay treatment rate on internode length of Morex barley grown in Hermiston, Oregon under two nitrogen treatments, 1984.

Parlay Rate	Internode 1st	2nd	3rd	4th	5th	6th	7th
($g\ ha^{-1}$)	(cm)						
0	4.2	12.6	17.3	18.7	22.4	30.1	36.4
400	2.1	6.7	11.1	15.7	24.0	35.1	40.7
600	2.4	6.5	10.4	15.1	23.4	34.8	41.7
800	2.0	5.2	8.8	14.1	23.8	33.4	42.6
1000	2.2	5.0	8.6	14.7	24.5	36.2	42.1
LSD .01	0.9	1.3	1.7	2.6	NS	NS	3.2
LSD .05					NS	4.2	

3). Significant increases in length occurred in the sixth and seventh internodes of the Parlay-treated plants (Table 2). The SSW value for the Parlay-treated plants was significantly lower than the control (Table 1).

Grain Yield

Parlay significantly increased grain yield for all treatments over the control (Table 1). Yield increases ranged from 32 to 54%. The high Parlay treatment rates (800 and 1000 $g\ ha^{-1}$) also significantly increased yields over the low treatment rates (400 and 600 $g\ ha^{-1}$). Yield was found to be significantly correlated with Parlay treatment rate and plant height reduction (Table 3).

Tillering tend to increase in the Parlay treatment rates above 400 $g\ ha^{-1}$. Thousand seed weight (TSW) showed a significant decline in the treated subplots (Table 1). No significant differences were evident in spikelet number and seeds per spike although the latter did show a trend for increase with Parlay treatment (Table 1). Another measurement, calculated seeds per tiller (CST), was taken as an empirical calculation of actual yield[1]. CST values for the high treatment rates (800 and 1000 $g\ ha^{-1}$) were significantly increased over the control. CST values for the low treatemnt rates (400 and 600 $g\ ha^{-1}$) did show a trend of increasing values although these were not significant (Table 1).

Lodging

Lodging began in the control subplots during anthesis which started on or about May 30, 1984. Lodging in the treated subplots first occurred between the June 6, and June 20, 1984, lodging evaluations. The control plots were lodged more severely than the treated subplots until July 7, 1984, when they all attained approximately the same lodging score and severity rating (Figure 1). The high Parlay treatment rates (800 $g\ ha^{-1}$ and1000 $g\ ha^{-1}$) received lower scores than did the low treatment rates (400 $g\ ha^{-1}$ and 600 $g\ ha^{-1}$) throughout the evaluation peiod (Figure 1). At harvest on August 1, 1984, plants were lying flat on the ground, and all subplots received a score of 5. Human error in score assignment may account for the decline in the lodging scores for the control on July 7, 1984.

Table 3. Correlation coefficients for Parlay treatment effect on Morex barley 1984[1]

	Parlay Treatment	Plant Height	CST[2]
Yield	0.90	-0.86	0.73
CST	0.61	-0.57	
Height	-0.93	---	---
1st In[3]	-0.65	0.71	
2nd In[3]	-0.89	0.94	
3rd In[3]	-0.90	0.96	
SSW[4]	-0.78	0.77	

[1]R^2 values were nonsignificant for CST. R^2 was significant at the .05 level for the 1st internode/treatment correlation coefficient, and significant at the .01 level for all other coefficients.
[2]Calculated seeds per tiller
[3]Length measurements for first, second, and third internode.
[4]Specific stem weight.

Fertility

The high nitrogen rate caused tiller number to significantly increase and TSW to significantly decrease. High nitrogen also caused a trend toward increased height with a corresponding decrease in yield (Table 4). No interaction between Parlay treatment and nitrogen level was found.

DISCUSSION

Plant Height

The lodging scores showed that Parlay can delay lodging under conditions of high fertility and high moisture. The

[1]Calculated seeds per tiller is derived from TSW, seed yield, and tiller data and calculated by the following formula:

$$\frac{\text{seed}}{\text{gram}} \times \frac{\text{grams of seeds}}{m^2} \times \frac{m^2}{\text{tillers}} = \text{CST}$$

expected inverse relationship of height and SSW was not evident in the plant sample data. Presumably, Parlay would control lodging by reducing plant height and increasing stem strength as has been shown in previous studies of lodging (Mulder, 1954; Pinthus, 1973). However, these data only showed that Parlay delayed lodging by decreasing basal internode elongation.

The decrease in stem unit weight with Parlay treatment, evident from the SSW values, raises questions concerning the mechanism of stem strength vis-a-vis Parlay treatment. The time at which stem weakening occurred cannot be concluded from these data. Changes in stem unit weight may have been progressive. If so, this would help to explain the lodging control during the early-lodging period as a result of both stem shortening and stem strength, the latter decreasing as the plant matured.

Parlay and nitrogen, acting alone or in combination, may have influenced stem weakening. The SSW values generally

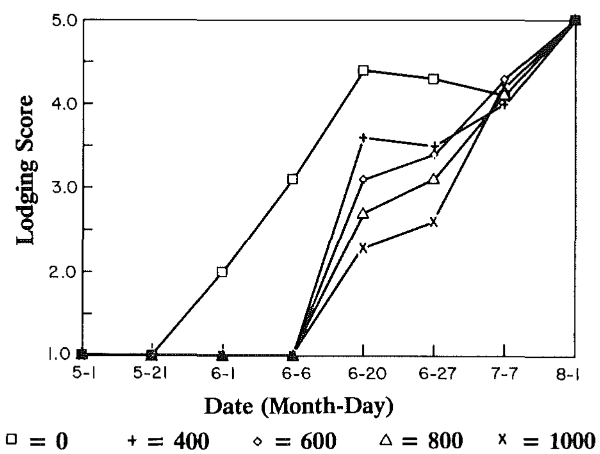

Figure 1. Lodging Scores: Morex Barley, 1984. Average of two nitrogen treatment rates. Parlay rate g ha^{-1}

decreased with increasing Parlay treatment rate (Table 1). Responses to nitrogen application may have been suppressed by a hypernutrition effect which results in an imbalance of the carbohydrate to nitrogen ratio that is associated with stem strengthening (Mulder, 1954; Welton, 1931). Genetics should also be considered since Cenci's work with barley stem morphology and anatomy showed that an inverse relationship between stem height and stem wall thickness does not necessarily hold (Cenci, 1984).

The elongation that occurred in the fifth, sixth, and seventh internodes of treated plants is difficult to explain. The mechanism that apparently causes the plant to grow out of the Parlay-treatment effect may depend on levels and activity of GA during different growth stages, on uptake of Parlay, or on a bioregulatory response. This last response may lead to a higher rate of GA synthesis following a period of chemically-induced inhibition. Interaction between GA and the other endogenous plant hormone systems should be considered with each of these possibilities.

Yield Enhancement

The control plots lodged during the early-lodging period and suffered a significant yield loss. The Parlay-treated plots began to lodge during the late-lodging period (post-heading) and showed a significant increase in yield over the controls. These differences in time of lodging and in yield agree with Laude's distinction between early and late lodging vis-a-vis yield loss (Laude and Pauli, 1956).

According to the literature, the possible methods for grain yield improvement include improved tillering through increased fertile tiller production and survival, improved seed number through delayed head emergence, and improved seed weight through redistribution of dry matter (Humphries, 1968; Pinthus, 1973). Parlay may influence grain yield for each method through its action on the endogenous hormone systems. Since the chemical is usually applied between Feekes Scale Stages 3-5 (Froggatt et al., 1981), a time when the plant is preparing for elongation and entering reproductive development, it would seem likely that Parlay's effect on endogenous hormone systems would not be limited to stem elongation.

Due to weather conditions, Parlay treatment was delayed to Feekes Stage Scale 6 when production of viable fertile tillers was nearing completion and floret structures were differentiated. The failure of the tiller number, seed number, and TSW data to account for the observed grain yield increase supports a conclusion that Parlay in this experiment, by virtue of late application date, did not exert a beneficial influence on the development of individual yield components.

The CST explains the treated plots' grain yield increase (Table 1) as resulting from a greater number of seed produced. This explanation would agree with the conclusion that

Table 4. Effect of nitrogen treatment rate on yield and stem morphology of Parlay-treated Morex barley, Hermiston, Oregon, 1984.

Nitrogen (kg ha^{-1})	Fertile Tillers	TSW[1] (g)	Yield (kg ha^{-1})	CST[2]	Spikelets[3]	Nodes	Height (cm)	SSW[4] (mg/cm^{-1})
112	26	39	6065	33	20.7	7.11	102	17.0
168	29	36	5816	32	20.9	7.20	105	18.3
LSD .05	3	2	NS	NS	NS	NS	NS	NS

[1]Thousand seed weight.
[2]Calculated seeds per tiller.
[3]The three spikelets at each rachis node were counted as one. Rudimentary spikelets also were counted.
[4]Specific stem weight.

seed production was lowered in the controls due to the adverse effects of early lodging on seed development.

Fertility

The absence of a Parlay by nitrogen interaction and the nonsignificant differences for nitrogen effect on plant height and grain yield can be explained in part by the rates of nitrogen selected for the field experiment. The low nitrogen rate apparently was in the upper range of nitrogen fertility required for maximum nitrogen response. Thus, the high and low rates were not sufficiently different with respect to their lodging-promoting effects to produce a variation in plant response.

CONCLUSIONS

Parlay's potential effectiveness as a chemical lodging-control agent for cereals depends upon the lodging susceptibility of the particular crop. Morex barley is a susceptible cultivar (tall and relatively weak-strawed) that lodged under the high nitrogen and moisture conditions of this experiment. Parlay treatment promoted yield by delaying lodging.

The data show that lodging delay was attributable to shortening of the basal internodes. The expected inverse relationship between stem height and stem strength was not found. Questions arise concerning the nature of the stem weakening--was it progressive, was it attributable to Parlay treatment, or a combination of the effect of Parlay treatment with nitrogen or due to barley genetics? Additional research on Parlay rates, timing of application, and the mechanism of stem weakening may resolve these questions and conflicts with previous PGR experiments and provide further tests of its possible beneficial effects on reproductive development.

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