

AN ABSTRACT OF THE THESIS OF

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Title: LODGING CONTROL AND YIELD ENHANCEMENT IN MOREX SPRING
BARLEY WITH PACLOBUTRAZOL TREATMENT

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Lodging in cereals can cause significant decreases in yield. It is both a problem in susceptible cereal cultivars with a tall-stemmed, weak-strawed growing habit and in lodging-resistant cereal cultivars when they are grown under high-nitrogen, high-moisture regimes. Plant growth regulators (PGR's) are chemical growth retardants that offer a method of lodging control. For the susceptible cultivars that are not amenable to genetic shortening through plant breeding, PGR's accomplish on a seasonal basis what has not been possible through gene manipulation. For cultivars that become susceptible in the high-intensive systems of modern agriculture, PGR's can be integrated into the chemical regime to control the lodging-promoting conditions created by yield-promotion practices.

Morex spring barley is a lodging-susceptible cultivar that is tall-stemmed and weak-strawed. This growth habit aggravates the lodging problem when Morex is grown under intensive yield-promoting conditions. In greenhouse and field experiments, chemical control of the Morex lodging tendency was tested with an experimental chemical, Paclobutrazol.

Paclobutrazol acts on the endogenous gibberellin hormone system in the plant by inhibiting its synthesis. The chemical's effect on the cereal plant is reported to occur in the internodes which Paclobutrazol shortens by decreasing longitudinal growth and strengthens by increasing transverse growth. Lodging control is realized through height reduction which lessens the torque effect created by the weather conditions that actually cause the event of lodging to occur.

Paclobutrazol caused significant shortening of the basal internodes in the greenhouse and field experiments.

Uncharacteristic of the expected effect, the PGR did not strengthen the shortened internodes. Specific stem weight and breaking strength values for the treated plants were significantly lower than the corresponding control values.

In the field, Paclobutrazol delayed lodging until after the critical lodging period that occurs from approximately 15 days before anthesis to 15 days after anthesis. Lodging control was

reflected in yield increases. Treated plots yielded significantly higher than did the control plots. The two high treatments of 800 and 1000 g/ha also yielded significantly higher than did the low treatments of 400 and 600 g/ha.

Yield increases in the treated plots can be attributed to improved seed filling given the fact that lodging in the control plots occurred during the period when yield losses are caused by poor seed development. Unfortunately, the data did not give any clear indication of other possible sources of yield enhancement. Beneficial effects of Paclobutrazol on the tillering and inflorescence development that several researchers have reported for the PGR, Chlormequat, were not evident.

The experiments showed that Paclobutrazol is effective on Morex spring barley as a chemical lodging control agent and yield enhancer. A clear association of reduced height with lodging control and concomitantly with yield increases was shown by the data. The absence of improved stem strength raised questions concerning the mechanism of Paclobutrazol's effect on the barley species and the possible mechanism of its effect in combination with nitrogen fertility.

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

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DEDICATION

To family, friends, and fellow bureaucrats who wondered what could possibly take me from the hallowed ground and plump salaries of Washington, D.C., I offer this dry tome on lodging as evidence of my dedication to learning and to the view of Mary's Peak out my office window.

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TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
LITERATURE REVIEW	3
Definition of Lodging	3
Lodging Tendency	4
The Physics of Lodging	5
Plant Characters Associated with Lodging	6
Measuring Lodging Tendency	8
Causes of Lodging	10
Yield Losses from Lodging	14
Chemical Control of Lodging	16
CCC and Paclobutrazol	18
MATERIALS AND METHODS	28
Experiment 1	28
Experiment 2	29
RESULTS	32
Height	32
Stem Strength	33
Yield Enhancement	33
Lodging	35
Treatment Date	35
Fertility	36
DISCUSSION	37
Lodging Tendency	37
Height	40
Yield Enhancement	41
Lodging	46
Treatment Date	48
Fertility	48
CONCLUSIONS	49
REFERENCES	64
APPENDICES	68

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Lodging Scores: Morex Barley, 1984 Average of two nitrogen treatment rates.	62
2	Lodging Scores: Morex Barley, 1984 Low versus high PGR treatment rates.	63

LIST OF TABLES

<u>Tables</u>	<u>Page</u>
1 Effect of Parlay treatment rate applied at two dates on tiller number and stem morphology of Morex barley grown in the greenhouse, 1984.	51
2 Effect of application date on tiller number and stem morphology of Parlay-treated Morex barley grown in the greenhouse, 1984.	52
3 Effect of Parlay treatment rate applied at two dates on internode lengths of Morex barley grown the greenhouse, 1984.	53
4 Effect of application date on internode lengths of Parlay-treated Morex barley grown in the greenhouse, 1984.	54
5 Interaction between treatment date and rate on height of Morex barley grown in the greenhouse, 1984.	55
6 Effect of Parlay treatment rate on yield and stem morphology of Morex barley grown under two nitrogen treatments, Hermiston, Oregon, 1984.	56
7 Effect of nitrogen treatment rate on yield and stem morphology of Parlay-treated Morex barley, Hermiston, Oregon, 1984.	57
8 Effect of Parlay treatment rate on internode length of Morex barley grown in Hermiston, Oregon under two nitrogen treatments, 1984.	58
9 Effect of nitrogen treatment rate on Parlay-treated Morex barley grown in Hermiston, Oregon, 1984.	58
10 Correlation coefficients for Parlay treatment effect on Morex barley grown in the field and in the greenhouse, 1984.	59
11 Comparison of stem and height data taken for Parlay-treated Morex barley grown in the field and in the greenhouse, 1984.	60
12 Climatic data for Hermiston, Oregon from May 25, 1984 to June 20, 1984.	61

LIST OF APPENDICES

<u>Appendix</u>		<u>Page</u>
A	Calculated Seeds per Tiller Formula	69
B	Total Moisture Readings Hermiston, Oregon, 1984	70
C	Average Monthly Temperatures Hermiston, Oregon, 1984	71
D	Average Wind Speed Hermiston, Oregon, 1984	72

PACLOBUTRAZOL TREATMENT OF MOREX SPRING BARLEY FOR LODGING CONTROL AND YIELD ENHANCEMENT

INTRODUCTION

The objectives of the research on which this thesis is based were to test an experimental chemical, Paclobutrazol, on a known lodging-susceptible cereal cultivar to evaluate its effectiveness in controlling lodging and enhancing yield. Previous experience with Paclobutrazol treatment of perennial rye grass varieties (21) showed that the chemical was a successful lodging control agent. Treatment of semidwarf cereal varieties, however, had proved to be unsuccessful (9,10).

The problem with cereal response to Paclobutrazol was considered to be one of susceptibility versus resistance to lodging. The semidwarf wheats tested in Oregon were already genetically shortened and exhibited little, if any, yield losses attributable to lodging. It was presumed that a tall-stemmed, weak-strawed cereal cultivar would be more amenable to chemical lodging control. Therefore, a barley cultivar was selected as a potentially more responsive candidate on which to test the effectiveness of Paclobutrazol.

In 1983, a field experiment was conducted in La Grande, Oregon with Steptoe barley, a feed barley known to lodge. The experiment was discontinued when the field showed evidence of uneven fertilization and water distribution. Paclobutrazol rates

selected in this initial experiment also were too low.

In the fall of 1983, a greenhouse experiment was planted with Morex barley, a tall, malting type also known to lodge. Treatment rates were increased based on the La Grande experience. An experiment was planted in the spring of 1984 in Hermiston, Oregon to test the greenhouse rates under field conditions. Combined, the two experiments were designed to provide information on the effectiveness of several rates in shortening plant height and thereby controlling lodging. The field experiment also was designed to test the yield enhancement benefits of chemical lodging control. The experiments and their results are discussed later in this paper.

Lodging is a complex event that is not a simple matter of cereal stems bending over in the field. It involves many factors within the internal makeup of the plant and within the environment in which the plant grows. These factors are interrelated and produce a phenomenon for which a single causal agent cannot easily be designated. The following literature review discusses the nature of the lodging problem and what is currently known of the mechanism of chemical control.

LITERATURE REVIEW

Lodging in cereals is both an old and modern agricultural phenomenon. Historically, it has been associated with tall-stemmed, weak-strawed cereal cultivars. Through plant breeding efforts, tall cereal cultivars, particularly in the wheats, have been replaced with shorter, stronger-stemmed cultivars more resistant to lodging (20).

Recently, lodging has appeared as a management problem of the intensive cultural methods that employ increased nitrogen and improved moisture relations with irrigation (20). While these inputs will promote yield, they also can create the conditions that promote lodging and thereby detract from the yield increases. For those susceptible cereal cultivars still under cultivation, high production inputs further aggravate the lodging problem. Thus, the nature of the modern lodging phenomenon is addressed appropriately as a problem arising from the emphasis on yield. Given this perspective, several researchers point to the conditions that promote lodging when describing the phenomenon. Pinthus calls lodging an abundance disease (33). Welton attributes increased lodging tendency to hypernutrition (44).

DEFINITION OF LODGING

Lodging, as it is observed in the field, is defined by the physical placement and condition of the cereal plant stem. Lodged stems have left their upright position, displaced by a

slight bending or by a more pronounced angle that can cause them to lie prostrate on the ground (44). Lodged plants usually bend in the basal internode region. At the bend, the stems may collapse or pinch inward (20,32,33). In severe cases, the stem wall actually cracks (26). Lodging also can occur as a disturbance of the root system. Root lodging causes the stem to bend from the crown. It is associated with moist soils (33). This paper addresses the subject of stem lodging.

The phenomenon of lodging is visibly quantified with a lodging score. A numerical rating includes two factors--the degree of bending and the prevalence or percent of lodged plants (33). Bending is rated usually on scales ranging from 1 to 5 or 1 to 10 where 1 indicates upright plants and the high values of 5 or 10 indicate severely lodged plants.

LODGING TENDENCY

Three terms are used throughout the literature--susceptibility, resistance, and lodging tendency. A very important distinction is made between the concepts of susceptible and resistant cultivars versus lodging tendency. Susceptibility and resistance indicate the nature of the morphological and anatomical structure of the plant. Lodging tendency is the plant's expression of its susceptibility or resistance in lodging-promoting conditions. Susceptible cultivars have an inherent tendency to lodge which in turn is influenced by external factors. Resistant cultivars do

not have an inherent tendency to lodge but may be induced to lodge under the appropriate external conditions that may modify the nature of their resistance.

Tendency to lodge depends on the strength of the basal portion of the stem and its resistance to bending, on the development of the root system, and on the presence or lack of proportionality between basal sturdiness and the weight of the upper stem sections, leaves, and head. These factors can be measured in the field and in the laboratory. In conjunction with the external factors influencing the growth of the cereal plants, lodging tendency measurements can provide an index of either resistance or susceptibility.

THE PHYSICS OF LODGING

The direct cause of lodging is an environmental event such as wind, rain, and hail. These events induce a torque by their exertion of a perpendicular force that acts on the plant stem, usually starting at the head. The stem serves as a lever to the torque which increases down the stem to the basal internodes where the "lever attains its greatest value" (33). The torque causes bending in the basal internodal region. The longer the stem, the greater the torque. Likewise, the longer the internodes, the greater the degree of bending they can exhibit.

A plant's resistance to the torque depends on its below-ground anchorage and the bending-resistant moment of the stem, i.e., its

ability to resist irreversible bending (33). The highest bending-resistant moment can be measured to provide a quantifiable value that is useful in lodging tendency evaluations. This value is equivalent to stem straw strength (33).

PLANT CHARACTERS ASSOCIATED WITH LODGING

Researchers disagree on the relative importance of morphological and anatomical characters as indices of lodging tendency. Generally, a greater consensus is found in the conclusions on morphological characters.

The difficulty in identifying characters depends in part on their interrelationship in their response to the environment and growing conditions. The researcher contributes to the difficulty through his failure to recognize either cultivar X environment or plant character X environment interactions and through the lack of standardized methods for sampling, collecting, and evaluating data. In this regard, Pinthus appropriately cautions against an implied causal relationship in the presence of a high correlation between a plant character and lodging (33).

Morphological Characters. Stem length and basal internode structure encompass the range of morphological characters studied. Their response to the environmental and cultural growing conditions is the most critical in assessing lodging tendency, for they will provide an indication of the type of

growth occurring in response to these conditions (32,33). Height is important from the standpoint of torque produced by the environmental events that initiate lodging. The basal internode structure is important with respect to the stem's ability to withstand the torque. Internode length, stem diameter, and stem wall thickness determine the structure of the basal stem region.

Anatomical Characters. The conflicting results of studies of sclerenchymatous tissue, lignification, and vascular bundle number prevent any definitive conclusions concerning the association of these anatomical characters with lodging tendency (33,44). Notwithstanding the inconsistencies, high vascular bundle number and lignification have been noted to provide some indication of lodging resistance (32,33). Pinthus explains the disagreement on lignification as a result of sampling date. Lignin content changes during the growing season, and this fact is not necessarily taken into account.

An association between anatomical and morphological characters may prove difficult to establish. For example, Cenci in comparative morphological and anatomical studies of short and tall barley varieties, found of the characters he studied only sclerenchyma cell wall thickness to be associated with stem length. Interestingly, the taller varieties had the thicker sclerenchyma cell walls (8). Although these findings should not be taken as a broadsweeping characterization of barley stem morphology, they illustrate the fallacy of assuming that height

is always inversely related to stem wall thickness.

MEASURING LODGING TENDENCY

No one morphological or anatomical plant character serves as a universal standard by which to evaluate lodging tendency for the reasons outlined in the preceding section (15,33). Throughout the 60 years of modern lodging research, lodging tendency has generally been evaluated on the basis of either or both plant height and basal internode structure. The latter includes measurable values for internode length, stem density, and breaking strength. The basal internode structure probably provides the most significant information, for it is in this part of the plant that the resistance to the lodging torque occurs.

Breaking Strength. The breaking strength of the straw corresponds to the greatest force that the stem can resist before it reaches the elastic limit, i.e., the point at which bending is irreversible (33). This point represents the highest bending-resistant moment. The instruments that measure this value operate on the principle that the degree of resistance to a measured force constitutes the breaking strength or straw strength of the tested stem. A unit length of stem is subjected to a force to the point of its bending or breaking. Resistance to the force is given as a weight value (33). Many researchers have used a 10-centimeter stem section from the basal internode region, starting with the first upright and measurable internode

above the soil surface (2,11,16,31,37,44).

Correlation of straw strength with lodging resistance varies. Inconsistencies have been attributed to a lack of data (2) and to the change in breaking strength values according to the maturity of the sampled plant (33). Pinthus does note that in comparative studies of resistant and susceptible cultivars, the resistant cultivars generally have higher straw strength values (33).

Stem Density. Together, the stem diameter, stem wall thickness, and the chemical composition of the stem wall constitute stem density (32). The measurable value of stem density is dry weight per unit length of stem. Presumably, a high stem density value indicates a high straw strength value. Atkins found a high correlation between unit basal stem weight and breaking strength and unit basal stem weight and lodging resistance. He suggested the use of stem weight in place of breaking strength, particularly because it is an easier measure to take (2,3).

Stem Length. Length has not been found to be a consistently reliable indicator of lodging tendency. It has been studied because diameter of the basal internodes is often negatively correlated with length. Mulder stresses that length, in this case reduced length, does not necessarily indicate resistance to bending. The structure and chemical composition of the basal stem wall are the more important factors to consider in lodging tendency evaluations (32).

The emphasis on stem length originates in the achievements of plant breeding. According to Pinthus, the most significant advances in breeding lodging-resistant cultivars have been accomplished by shortening stem length. The greatest successes have been with wheats. Short oat and barley cultivars have also been released (33). It can be assumed that in reducing the length of the stem, breeders have also changed other structural factors that give the stem a greater resistance to lodging forces. However, it should not be assumed that shorter stems will carry with them the characteristics of stronger stems. This unreliability of length as a consistent index to stem strength is graphically illustrated by Cenci's barley cultivar studies. He found the tall cultivars to have a thicker stem diameter than the short barley cultivars (8).

CAUSES OF LODGING

A complex of causes are responsible for lodging. The lodging event results directly from a weather condition such as wind, rain, and hail, any one of which can produce a physical force that causes the stem to bend. An indirect set of causes establishes the conditions under which lodging may occur. They involve an interaction of internal factors under genetic control and external factors attributed to environmental conditions and to cultural practices (44). The external factors influence the expression of the genetically controlled factors of plant anatomy, morphology, and physiology.

Genetic Characters A susceptible cereal cultivar is one that shows a high tendency to lodge by virtue of inherited plant structure. Generally, this plant type has a tall-stemmed, weak-strawed growth habit. Such a stem structure is associated with susceptibility by virtue of a low dry matter to unit length ratio (44).

Cultural techniques and climatic conditions influence the expression of the genetic characters. Therefore, a susceptible cultivar may or may not exhibit its inherent tendency to lodge in response to external influences. Likewise, a resistant cultivar, which has an inherently low lodging tendency, may lodge under the influence of external factors.

Cultural Practices. Stand establishment, fertility, and moisture constitute the primary cultural factors that can promote lodging. They are within the control of the grower. Their effect as it relates to lodging concerns plant density.

Dense plant stands reduce light penetration and cause shading within the lower canopy. The plant responds to the lowered light intensity with etiolated growth. The effect on the elongated stem structure is weakening through a low dry matter per unit length distribution. Plant density can be controlled through seeding rate, interrow spacing, and reduced weed infestation.

Nitrogen Fertility and Moisture. In current production systems, the grower increases nitrogen to attain a maximum yield and to

improve protein levels in the grain. The drawback of high fertility is the increased incidence of lodging and the resultant reduction in grain yield (11,12,30,32,33,34).

High nitrogen produces both direct and indirect lodging-promoting effects. The direct or physiological effects change stem strength through the nutritional influences on stem structural growth and lignification. They also stimulate overall growth which leads to increased plant density and to an unfavorable root-to-shoot ratio (33).

Higher density promotes shading which causes an etiolation response, particularly in the basal portion of the stem (32). In both the growth (direct) and etiolation (indirect) responses, stem weakening occurs due to a reallocation of assimilates from structural growth to elongation growth (32,33).

Moisture in the form of rainfall or irrigation water interacts with nitrogen fertility to influence lodging. Improved soil moisture leads to more available nitrates for plant uptake. High temperatures also stimulate nitrate uptake (29).

Hypernutrition, a term Welton introduced, is a function of the abundance of soil nitrates and adequate moisture relations (44). The effect of hypernutrition is seen in the ratio of carbohydrates to nitrogen. Welton linked the reduction of net assimilates to a low carbohydrate-nitrogen ratio in the plant in the presence of high soil nitrogen levels. At high nitrogen

levels, the plant expends assimilates on increased vegetative growth at the expense of cell wall thickening and lignification and other plant processes depending on carbohydrates (32,33). Carbohydrates in relation to nitrogen are reduced and the ratio on a per unit basis is altered in favor of nitrogen. The low ratio can indicate susceptibility to lodging by reason of increased stem height and a relatively low dry matter content per unit of stem length (44).

Nitrogen and moisture through their effect on growth also can contribute to the incidence of leaf and rot diseases that may promote lodging. The shaded, moist microclimate in the lodged crop provides ideal conditions for these types of diseases. For example, *Cercosperella* (eyespot), a stem disease, can both cause lodging and show an increased incidence in a lodged crop (33).

Climatic Conditions. Low light and high temperature create growth conditions that promote lodging. Each produces a similar response. Vegetative growth increases to cause shading in the lower canopy which in turn leads to etiolation and weakening of the stem (32,44).

Light apparently influences elongation through an effect on the endogenous gibberellin (GA) system. GA is one of the plant hormones associated with elongation, an activity which occurs in the subapical meristem. Although it is known that light inhibits elongation activity, the physiological mechanism has not been

defined. One researcher has proposed that light inhibition of elongation is due to effects on some aspect of GA action, synthesis, or destruction (35). Whatever the actual hormonal mechanism, low-light intensity promotes elongation which is evidenced by the etiolation response. This same mechanism would cause etiolation in the dense plant stands created by cultural practices.

High temperatures promote increased vegetative growth. Stem elongation and temperature have been shown to be significantly correlated during the period of seedling emergence to heading (33). Tillering also can increase under high temperatures. The denser plant stand may cause shading of the basal stem sections, which produces an even greater degree of elongation in the basal internodes (32,33,44).

Synergistic Interactions. The interaction of the external factors, both environmental and cultural, that promote lodging is a synergistic one (33). For example, increased nitrogen promotes lodging more under irrigated than under dryland conditions and more in dense than in sparse plant stands (33).

YIELD LOSSES FROM LODGING

The time of lodging as it affects yield can be divided into two categories--early lodging and late lodging. Early lodging occurs during the period from 7 to 14 days before heading to 7 to 14 days after heading. Late lodging occurs during the period from

15 to 20 days after heading to maturity (26). Losses depend on the growth stage, the field conditions, and the weather conditions after the grain lodges (26,32,41).

In early lodging, permanent damage to the stem lowers the plant's ability to transport nutrients and synthesize and store assimilates (26). Yield losses are incurred in quantity and quality of seed. Seed number is reduced by poor fertilization and seed abortion. The seed produced are lighter weight and may be shriveled and shrunken (1,12,26,33,44). The most severe yield losses occur in early lodging (39,43).

Late lodging affects grain size. As in early lodging, assimilates are not reaching the maturing seeds. The period, however, over which lodging will produce adverse yield effects is of shorter duration and at a less critical time in seed development. Additionally, the number of heads carrying grain is already established as are the number of fertile florets, and their potential is not affected (26). Pinthus noted a lesser direct effect on grain yield with late lodging but also a contribution to losses through the difficulties created in harvest (33). The latter factor also contributes to yield losses in early lodging.

The following chart summarizes several studies where lodging was artificially induced. Although these studies were conducted under different experimental conditions and cannot be directly

compared, they illustrate the differences in yield loss between early and late lodging (33).

<u>Crop</u>	<u>Researcher</u>	<u>Early Loss</u>	<u>Late Loss</u>
		(%)	(%)
Wheat	Laude	27	22
Wheat	Weibel	31	20
Barley	Day	40	39
Barley	Sisler	34	24
Oats	Norden	36	23
Oats	Pendleton	37	17

A more dramatic yield difference was shown by a Yugoslavian researcher testing spring barley. Yield decreased 37 to 68% with early lodging compared to an 8 to 9% decrease with late lodging (1).

CHEMICAL CONTROL OF LODGING

Two methods of lodging control are available--cultural management on the part of the grower and manipulation of plant structure through plant breeding and plant growth regulators (PGR's). The grower is limited to the factors within his control, i.e., irrigation, fertility, stand establishment and density, and weed control. He cannot change the climatic factors, but he can take them into account in his selection of species and cultivar and planting date and seeding rate, fertility, irrigation, and pest

control. Plant breeders have already been successful in developing semidwarf wheat cultivars resistant to lodging (20,33). These cultivars provide a means of long-term control. PGR's, on the other hand, provide a method of short-term control, particularly for those cereal species less amenable to genetic manipulation.

PGR's are synthetic chemicals that directly or indirectly affect the plant's hormonal and metabolic systems. They chemically manipulate the biochemical systems that regulate plant growth. Aside from lodging control in cereal crops, benefits to yield enhancement, harvestability, or some other economically desirable agricultural trait are derived.

PGR's have proven to be effective in preventing lodging through height reduction and yield enhancement. European agricultural systems have made more extensive use of PGR-lodging control than have American systems. Approximately 50% of the wheat and 15% of the barley grown in Western Europe is PGR-treated for prevention of lodging (40).

Chemical control of lodging offers several advantages over plant breeding. PGR's have an immediate availability and effect which are in contrast to the more time-consuming efforts of genetic change through plant breeding. Their use is optional (18). Their application is a choice that can be made with each growing season and each set of growing conditions and with each cultivar.

Their effect is transitory (18). PGR's are not known to effect genetic change in future offspring of a treated crop.

With the current emphasis on high fertility, PGR's offer a means to deal with the hypernutrition problem. By inhibiting elongation, PGR's can help initially to control the increased vegetative growth promoted by high nitrogen and thereby reduce the shading effect that will cause etiolation of the basal internodes. One chemical industry publication notes that PGR's hold the key to controlling plant development in high nitrogen systems (6).

PGR's can be classed according to the hormone system at which they are directed. Those used in cereal lodging control generally target either the ethylene or GA systems (23). This discussion concerns PGR's that inhibit GA synthesis.

CCC AND PACLOBUTRAZOL

Chlormequat (CCC) is the most widely used of the GA synthesis inhibition PGR's as well as the most widely used PGR for cereal production. It inhibits the cyclization of transgeranylgeranylpyrophosphate to ent-kaurene, thus causing lowered levels of GA (19,23). The effect evidenced in the cereal plant is reduced height.

CCC's greatest use and effect is on both common and durum wheat cultivars, including tall and semidwarf (33). Variability in

responses is reported and can in part be attributed to time of application and differences in vegetative growth that would affect uptake (33). A variation in species' sensitivity also creates differential responses to CCC. Barley rapidly metabolizes CCC and transports it as a quaternary base to the roots. Initial shortening is then overridden by increased elongation (20). Humphries suggests that if enough CCC can be continuously supplied to the barley plant throughout its growth cycle, shortening comparable to that in wheat will be found. Similar responses to that in CCC-treated barley are found with oats and rye (20).

Paclobutrazol, tradenamed Parlay, is an experimental PGR that like CCC inhibits GA synthesis. It is a triazole compound whereas CCC has an ammonium structure. The difference in chemical structure is probably responsible for Parlay's inhibition block occurring later in GA synthesis than does CCC's. Parlay blocks at the oxidation steps of ent-kaurene to ent-kaurenoic acid (28). The location of the block as well as chemical structure may have some influence on the difference in species' effect of the chemicals, but that fact at this point is purely speculative.

CCC is a foliar-applied chemical; Parlay is a soil-active chemical. Thus, Parlay is available for uptake by the plant for a longer period. This fact may help to explain the greater success of Parlay in height shortening and lodging control of

barley (See page 27). Apparently barley's low sensitivity is at least in part overcome by the continued availability of Parlay. The reported success with Parlay treatment of barley would tend to support Humphries' contention that CCC will effectively shorten barley provided enough chemical is made available during the elongation period.

Mechanism of Action. Most of the research on the bioregulatory effects of GA synthesis inhibitors has been performed with CCC. The absence of a comparable body of literature on Parlay can be attributed to the fact that CCC has been available for study since the early 1960's whereas Parlay is still an experimental chemical only recently introduced as a potential commercial PGR. Given the similarities between CCC and Parlay, the findings for CCC may be applicable to Parlay.

The mechanism of action of CCC presumably focuses on the GA-auxin system. Both GA and auxin are necessary for the elongation event to occur in the subapical meristem (35,42). GA mediates the optimal auxin levels such that a change in the endogenous GA levels--as would be caused by PGR-synthesis inhibition--apparently exerts an effect on auxin levels (35,42). Thus, with PGR treatment, the direct effect is to reduce GA levels through synthesis inhibition; the overall effect is far more complex, involving the interaction of both the GA and auxin hormone systems and their regulation of elongation.

Sach's work with CCC and GA treatments on chrysanthemum stems shows graphically their differences in effect on the elongation event. Sachs found that CCC retarded cell division and cell elongation in the subapical meristem thereby reducing longitudinal growth and causing an increase in wall thickness and stem diameter (35,36). GA, exogenously applied, promoted elongation and reduced transverse growth. Thus, it can be seen that CCC and GA each produce the opposite effect in the subapical meristem.

Timing of application. For effective lodging control, treatment is timed for the beginning of spikelet initiation to early floret initiation, a period represented by Stages 3 to 5 on the Feekes Scale (25). At spikelet initiation, the spikelet primordia are beginning to appear on the growing point. At floret initiation, the floret structures are beginning to differentiate. At approximately the same time that early reproductive growth is initiating in the apical region of the growing point, internode elongation is beginning in the subapical meristem. Although the development of the growing point is used as an application guideline, the PGR as a lodging control is directed to the elongation event.

Lodging Control with CCC. When applied at the onset of reproductive development, CCC inhibits elongation of the basal internodes. This response is usually accompanied by an increase in stem wall thickness and stem diameter (33). It is the

shortening and associated strengthening of these internodes that is most critical for lodging control (20,32,33).

Given that early lodging occurs before full plant height is attained, assessment of CCC effect should be directed to reduction of early crop height rather than to final crop height (7). The structure of the basal internodes at anthesis will determine the plant's resistance to lodging at a time when yield losses can be significant. The degree of PGR shortening of the basal internodes will presumably influence the strengthening factor. Batch notes that strength not length is the appropriate index for evaluation of lodging tendency with PGR treatment (7).

Yield Increases with CCC. Yield increases originate in the prevention of loss of yield from lodging. Other increases may occur as a result of CCC effects on yield components. For example, yield enhancement has been reported in the absence of lodging (17,18). Lowe and Humphries attribute the grain number increase to the delayed heading of approximately seven days (20,27). A higher tiller number may be due to either or both improved tiller survival or tiller production (7,20). For the grain weight component, conflicting results prevent any definitive conclusion. CCC has been reported to increase as well as decrease seed weight (7).

Other more complex physiological processes influenced by CCC treatment may account for the tiller and grain number increase.

Through its effects on the GA-auxin balance, CCC may influence the auxin-mediated apical dominance mechanism which is expressed as asynchrony in tillering and inflorescence development (4,19,45). According to Hofner and Williams, CCC may reverse the apical dominance pattern to produce more synchronous development of tillers and of spikelet and floret structures.

Working with special slow-release, cool-weather CCC formulations, Williams attributed 5 to 25% increases in yield in wheat and barley cultivars in non-lodging conditions to CCC treatment effects on apical dominance. Hofner noted that combined CCC-ancymidol treatments equalized stem length, promoted synchronous spike development, and caused an increase in grain number (19).

Hofner's and Williams' explanation of the nonlodging yield increases is controversial. Batch cautions that the apical dominance theory is premature and speculative (7). The primary argument advanced against their theory is that tiller number increase is due to survival of primary tillers or to equalization of competition, both as a result of CCC-retardation of plant growth (24). However, it would seem that tiller survival and equalization of competition are one and the same with tiller synchrony.

In the absence of a clear understanding of the endogenous hormone systems, it is difficult to definitively prove the full range of CCC's effects. Given the complex interrelationship of the plant

hormones, CCC treatment in all likelihood is not limited to effects on the GA system. Whatever the full range of CCC effects, it also would probably apply to Parlay.

CCC and Fertility. Batch suggests that yield responses reported with combined CCC and high nitrogen inputs (20) have not so much been derived through lodging control as through control of the plant growth enhanced with increased fertility (7). The distinction is a narrow one. CCC is in essence controlling the response to lodging-promoting conditions. With its application, levels of nitrogen closer to the optimum can be applied without the threat of increased lodging tendency. Generally, the benefits of CCC have been found to be most significant in high input systems (7).

Parlay Research. Research with Parlay has produced variable results in cereal crops. Most often the yield enhancing attributes of the chemical are realized when lodging conditions are present. When they are not, the data indicate that benefits of Parlay treatment are lessened.

According to an industry communication, rates of Parlay range from 0.5 to 1 kg/ha for spring barley, 1 kg/ha for winter barley, and 125 to 250 g/ha for winter wheat (38). The differences in sensitivity between these two cereal crops are evident in this range of rates.

On Canada's Prince Edward Island, 1980 trials with Parlay-treated

spring wheat, barley, and oats showed yield increases of 21 to 35%. Lodging conditions had been promoted with high nitrogen fertility. The wheat, barley, and oat Parlay-treated plots lodged 55, 94, 89% respectively versus 100% of the control plots (22). The high percentage of lodging in treated plots and the small height reductions can be explained by a late treatment date. Plants were treated at Feekes Scale Stages 8 to 9, the early boot stage when elongation and stem strengthening is left primarily for the last internode. Parlay was shown to produce more significant lodging control than did CCC.

In 1980, ICI researchers found Parlay to increase yield in lodged winter wheat by 18% and to reduce lodging by 63 to 67%. Stem strengthening and shortening of basal internodes correlated with lodging control. Froggatt notes that these findings suggest "a causal relationship between the shortening and strengthening effects on lower stem internodes and subsequent control of lodging" (14).

Parlay trials in Oregon covering a three-year period have not been as successful with promoting yield in semidwarf white winter wheat cultivars. In 1982, only one of two winter wheat cultivars (Yamhill) planted in western Oregon showed a trend for increased seed yield and seed weight. Although high nitrogen treatments were applied (134 and 178 kg/ha), no lodging occurred. The unusually dry spring can in part account for the absence of lodging (10). The 1983 trials were established in dryland and

irrigated fields located in eastern and western Oregon. Again, yield did not increase significantly in any of the trials although height did significantly decrease. Lodging did not occur at any of the sites (9). In 1984, trials established in eastern and western Oregon also did not show a yield increase in the presence of height reductions. Lodging did not occur in either location (13).

The western Oregon trials with winter oats (1982) and winter barley (1983) showed similar results--no yield increases in the absence of lodging (9,10).

A likely explanation for the wheat trial results lies in the selection of cereal cultivars for treatment. The semidwarf white winter wheat cultivars grown in Oregon generally are lodging-resistant in as much as their tendency to lodge has not been shown to significantly increase under lodging-promoting conditions. Parlay effectively reduced their height but did not increase yield. Parlay and other PGR's apparently are most effective when applied to cereal cultivars that are susceptible to lodging or show a greater tendency to lodge under high fertility and moisture conditions. The results of the trials in England and Canada discussed in this section lend support to this theory.

Parlay Treatment of Spring Barley. In 1984, two field trials were planted in Hermiston, Oregon. Spring barley was treated

with a range of rates for an evaluation of Parlay's height reduction and lodging control effects. A cross-drilled, high-density trial showed yield increases of 36 to 50% over the control in the presence of lodging (13). A nitrogen X Parlay trial also showed significant yield increases. This second experiment will be discussed in greater detail in the following sections of this paper.

MATERIALS AND METHODS

Two experiments were conducted to test the height reduction and associated lodging control effects of Parlay on the spring barley cultivar, Morex. A greenhouse study initially tested rates under two dates of application. The purpose of this experiment was to look at the effectiveness of a range of rates applied at different dates. The second experiment tested the greenhouse rates under field conditions at two nitrogen levels. The purpose of the field experiment was to test the effectiveness of the greenhouse treatment rates under lodging-promoting field conditions.

EXPERIMENT 1

In this experiment, five treatment rates of Parlay (300, 400, 600, 800, and 1000 g/ha) and a control were tested on two dates of application--(1) spikelet initiation (SI) and (2) floret initiation (FI) (See page 21). The Morex barley cultivar was selected as a lodging susceptible variety for its tall-stemmed, weak-strawed growth habit. In November 1983, seeds were planted in 15-centimeter diameter pots filled with a greenhouse soil mix.

Plants were kept in controlled growth chambers for approximately eight weeks after seedling emergence. The growth chamber was operated at a constant 10⁰ C and a 12-hour day length. The SI treatment was made when the spikelet primordia showed visible signs of differentiation. The FI treatment was made when floret

structures were visibly differentiating. Plants were sacrificed and the growing points observed under a dissecting microscope to determine the SI and the FI developmental stages.

Following the FI treatment, the plants were moved to greenhouse benches and arranged in a randomized block factorial design. Fluorescent grow lights were set for a 12-hour day and gradually increased to an 18-hour day.

The plants were harvested at maturity and measured for overall height, number of fertile tillers, and mainstem internode lengths. Two 10-centimeter basal internode sections were cut from the mainstem. The first section measurement began at the crown. The sections were weighed and then tested for straw strength by determining the highest bending resistance moment using the Kiya Seisakusho straw fracture tester, model E0-3.

EXPERIMENT 2

Morex was planted on March 12, 1984 on an experimental plot 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 of residual nitrogen from the previous year's potato crop. A preplant nitrogen application consisted of 56 kg/ha. Bronate was applied for broadleaf weed control during the early tillering stage.

The experiment was arranged in a split plot design. The main

plots were two nitrogen levels of 56 and 112 kg/ha and the subplots were four Parlay treatments and a control. Seed was drilled in 18-centimeter rows at 45 kg/ha per acre. The subplots measured two-by-six meters and were arranged adjacently within two sets of three replications.

The main-plot nitrogen treatments were broadcast by hand after seedling emergence. The barley plants were treated with Parlay at rates of 400, 600, 800, or 1000 g/ha at late FI which is approximately Feekes Scale Stage 6. High wind conditions prevented treatment at the preferred SI stage of development. The control was untreated. Parlay application was made by a Cooper-Pegler backpack sprayer and a hand-held spray boom fitted with 8002LP nozzles. Application pressure was 17 psi.

Lodging scores were taken 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. Severity was measured by percent of the plot lodged.

Prior to harvest, 30-centimeter-length row samples of the mature crop were cut out by hand sickle. Five representative fertile tillers of the total fertile tiller number were selected from the samples and measured for stem length, internode lengths, and yield component data. The basal internode region was cut into two 10-centimeter sections and weighed. The first section measurement began at the crown if that portion of the plant was

present or at the sickle cut.

Irrigation was delivered by a sprinkler system from March through June. The plots were harvested with a Hege plot combine which cut a 1.3 meter swath. Seed was collected and weighed for yield.

RESULTS

HEIGHT

In the greenhouse experiment, Parlay decreased height significantly in the 600, 800, and 1000 g/ha treatments. Height reductions ranged from 5 to 26% (Table 1). The most significant shortening occurred in the first three internodes (Table 3). For both height and internode length, 800 g/ha appeared to be the most effective treatment. No significant differences between control and treated plants for number of nodes were evident.

In the field experiment, Parlay decreased height significantly for all treatments (Table 6). Height reductions ranged from 15 to 27%. The high treatments also decreased height significantly over the low treatments. The number of nodes was decreased significantly from the control only in the high treatments due probably to a compression of the lower nodes to below the soil surface (Table 6). Consistent with the greenhouse results, the most significant shortening attributable to each of the four treatments occurred in the first three internodes (Table 8).

In both experiments, the Parlay-treated stem's fifth, sixth, and seventh internodes were longer than those of the control plants. Significant increases in length occurred in the sixth and seventh internodes of the Parlay treated plants (Tables 3 and 8).

STEM STRENGTH

Two stem strength measurements were taken--breaking strength and specific stem weight (SSW). SSW, a term introduced by Hunter (21), is dry weight per unit length of stem. In this discussion, it is considered an index of stem density (See page 9). Breaking strength was measured on the two 10-centimeter stem sections. SSW was measured for the combined 20-centimeter stem sections.

Except in the 400 g/ha treatment, breaking strength in the greenhouse-treated plants decreased significantly from the control. SSW data did not correlate with breaking strength data. They did show a trend, although not a consistent trend, for a decrease in the treated plants (Table 1).

The SSW value for the field-treated plants decreased significantly from the control (Table 6). In view of Atkins' recommendation for the use of SSW-type values (2) and the correlation of the Morex greenhouse breaking strength and SSW values (Table 10), straw strength was not measured for the field samples. Additionally, damage from bending in the lodged stems would have affected the accuracy of the breaking strength values.

YIELD ENHANCEMENT

In the greenhouse, tiller number generally showed a trend for decrease. The 800 g/ha treatment rate also showed a significant decrease from the control (Table 1). Seed yield was not taken

and the spike yield components were not measured due to poor seed development.

In the field experiment, Parlay significantly increased yield for all treatments over the control (Table 6). Yield increases ranged from 32 to 54%. The high treatments also had significantly increased yields over the low treatments.

Yield was found to be significantly correlated with treatment rate and height reduction (Table 10). The source of the yield increase cannot be explained by a beneficial Parlay effect on the yield components (Table 6). Although a trend for increased tillering occurred in the treatment rates above 400 g/ha, the differences were not significant. Thousand seed weight (TSW) showed a significant decline in the treated plots (Table 6).

No significant differences were evident in spikelets and seeds per head. Seed number did show a trend for increase with Parlay treatment (Table 6). Another measurement, calculated seeds per tiller (CST), was taken as an empirical calculation of actual yield (Appendix A). It provides some information concerning the source of the yield increase. CST was significantly increased over the control except for the 600 g/ha treatment rate (Table 6). It is not possible to explain the inconsistent value derived for this treatment.

LODGING

The control plots began to lodge during the anthesis period which started on or about May 30, 1984. Lodging in the treated plots first occurred between June 6 and June 20, 1984, a period during which no scores were taken. The control plots were lodged more severely than the treated plots until July 7, 1984 when all plots attained approximately the same lodging score and severity rating (Figure 1). The high treatment rates (800 g/ha and 1000 g/ha) received lower scores than did the low treatment rates (400 g/ha and 600 g/ha) until July 7, 1984 (Figure 2). By harvest on August 1, 1984, plants were lying flat on the ground, and all plots received a score of 5.

On July 7, 1984, lodging scores for the control plots declined to a slightly lower value than those for the treated plots. This change in value can be attributed to human error rather than to a change in the lodging pattern of the control plots. The human error can be explained by the relatively arbitrary nature of score assignment which depends on a visual interpretation of field conditions.

TREATMENT DATE

In the greenhouse experiment, data for treatment date were significant only for height and for the third internode measurement. In both cases, the SI treatment caused a greater shortening effect. The SI treatment also produced a trend for

decreased SSW and breaking strength values (Tables 2 and 4).

A treatment date and rate interaction was evident for height and SSW (Table 5). The SI treatment appeared to produce a more consistent effect in height shortening and SSW. The high value for SSW in the 800g/ha FI treatment date is inconsistent and cannot be explained.

FERTILITY

Significant differences between the high and low nitrogen levels were only evident for fertile tiller number and TSW. The high nitrogen rate caused tiller number to increase and TSW to decrease. High nitrogen also caused a trend for increased height with a corresponding decrease in yield (Table 7). No significant difference in internode length between the two nitrogen treatments was found (Table 9). An interaction between Parlay treatment and nitrogen level was not found.

DISCUSSION

LODGING TENDENCY

The lodging scores indicate the relative differences between control and treated plants for the timing of the lodging event and its severity. The scores show that Parlay delays lodging. The yield data show the economically quantifiable effectiveness of delayed lodging.

How Parlay reduced lodging tendency is not clear. The expected inverse relationship of height and SSW is not evident from the plant samples. An interpretation of the data leads to the conclusion that Parlay delayed lodging by decreasing basal internode elongation.

If length was the only lodging parameter controlled by Parlay treatment, it might help to explain the occurrence and severity of later lodging in the treated plots. The full height of the mature barley plant has not been attained at anthesis, for elongation of the last internode is not complete. In this experiment, Parlay reduced the torque effect on early plant height and thereby controlled lodging. Apparently, during the late lodging period, the Parlay-induced shortening may not have been sufficient to lessen the torque effect. Total height may have been too great and basal stem strength too low for the treated plants to resist the greater torque effect of the fully elongated stem.

Plants were not sampled before maturity in either experiment to document any stem density changes that might have occurred between elongation and maturity. By maturity, it is obvious from the SSW data that dry matter was not deposited in such a way as to produce a strong stem in the treated plants.

The stems were either initially weak or became weak as a result of dry matter redistribution. Since the treated plants were shorter, it can be presumed that redistribution, had it occurred, would have been directed to the developing seed head.

Unfortunately, a harvest index measurement was not taken due to the damaged condition of the samples from handling and transport. Harvest index taken on the mature stems would have revealed whether or not dry matter redistribution had actually taken place.

One can only speculate on the cause of stem weakening. It can be attributed to either treatment rate or nitrogen level or a combination of both. Nitrogen may be responsible for stem weakening through a hypernutrition effect such as was described by Welton (44). Admittedly, increased elongation, which Welton associated with hypernutrition, was prevented by Parlay treatment and cannot be the cause of stem weakening in treated plants. However, an imbalance of the carbohydrate to nitrogen ratio not solely limited to increased elongation growth may have operated.

Parlay alone or with nitrogen may be responsible for progressive stem weakening. Barley genetics, which could work alone or in combination with Parlay and high nitrogen treatments, also may contribute to stem weakening. Certainly, this last factor should be considered in light of Cenci's findings (See pages 7-8).

If redistribution of dry matter did not occur, the question to pose deals with the nature of lodging control. Was the lodging control in the Parlay-treated plots only a function of reduced height? If it was, lodging tendency of Morex was reduced solely as a result of a decreased torque effect in the stem and in the shortened basal internodes.

The inconsistency with previous PGR research poses questions concerning the nature of the lodging delay and the source of the yield increase as it relates to assimilate redistribution. With respect to the stems, were the treated stems stronger at anthesis when they remained upright than they were at maturity when they were sampled? If stem weakening did occur progressively throughout the growing season, was it a result of a redistribution whereby a proportionately greater supply of assimilate was drawn from the stem for transport to the head? If stem weakening did not occur as a result of dry matter redistribution, can it be attributable to the hypernutrition effect or a combined Parlay-hypernutrition effect?

For future experiments several changes in the data gathering could be made to help explain the inconsistencies in the effects of Parlay treatment on lodging tendency factors. Stem density and breaking strength measurements should be taken three times during the season--(1) during the early lodging period, (2) during the late lodging period, and (3) at maturity. These measurements would provide information on any changes in dry matter storage in the stem during the growing season. Harvest index also should be taken to verify the relocation, if any, of assimilate. To evaluate the hypernutrition effect, detailed physiological and anatomical studies could be performed to identify changes in the carbohydrate to nitrogen ratio.

HEIGHT

Both experiments indicate a significant height shortening effect with Parlay treatment. Height and treatment rate are inversely correlated (Table 10). have an inverse relationship (Table 11). The range of heights closely corresponds between the experiments although treatment effect appears to plateau at the 800 g/ha rate in the greenhouse (Table 11). The shortening at a significant level occurred in the basal internodes, specifically the first three internodes. Again, a plateau effect is evident in the greenhouse plant's first three internode stem sections at the 800 g/ha treatment rate (Table 11).

The data show that Parlay is effective in reducing height by shortening the basal internodes (Tables 3 and 8). The shortening of these internodes was significantly correlated to both treatment and height although to a lesser degree for the greenhouse data (Table 10). The ideal rate appears to be 1000 g/ha in the field versus 800 g/ha in the greenhouse. Whether the plateau rate is 800 or 1000 g/ha cannot be ascertained from these data. The data do indicate that the high rates are more effective than the low rates. The upper end of the range of effective rates requires further evaluation in the field.

The reverse effect in internode elongation that occurred in the fifth, sixth, and seventh internodes of treated plants in both experiments is difficult to explain. The mechanism that would cause the plant to apparently 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 which leads to a higher rate of GA synthesis following a period of chemically-induced inhibition.

YIELD ENHANCEMENT

The control plots lodged during the early-lodging period and suffered a significant yield loss. The treated plots began to lodge during the late lodging period 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 (26).

Lodging delay establishes the reason for a yield increase. It does not, however, establish the source for the yield increase. For this determination, it is necessary to look at the yield data and interpret them in accordance with the previous findings of PGR research. Here several difficulties arise. Is yield improved solely as a function of lodging delay, or is Parlay treatment beneficially influencing development of the yield components? Humphries also asks this question in his review of CCC research, noting that yield increases are reported in the absence of lodging (20).

Data from non-PGR studies reported by Pinthus showed significant decreases in yield in early lodging plots (See page 16). The losses were incurred in poor seed filling or floret abortion and poor distribution of assimilates both due to a closed canopy created by lodged plants and to damage to the vascular system from bending and collapsing of the lodged stem (33). At maturity these light weight, partially filled seeds or aborted seeds would have been lost during combining.

In the field experiment, it was evident from a visual comparison of the control and treated sample heads that the control heads contained undeveloped seeds which would have been lost in combining. The seed yield per plot, supported by the CST data, verifies that a greater number of seed was produced in the

treated plots. Thus, looking strictly at the increase as a result of lodging delay, it can be explained by comparatively improved seed filling in the treated versus control plots.

The possible sources for yield improvement outside of a prevention of yield loss generally are attributed to 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 (20,27). For each of these sources, CCC, or in this case Parlay, has exerted an effect on the hormonal systems regulating reproductive development. Since these chemicals are applied when the plant is both elongating and entering reproductive development, it would seem likely that their effect on the GA-auxin hormonal systems would not be limited to elongation.

Hofner and Williams ascribe the nonlodging yield increases to a CCC-effect on synchronous development of the tillers and the inflorescence (19,45). Although their theory is contested, it may offer a valid explanation for improved tillering and seed production. The following discussion of yield improvement in the Parlay-treated plots will draw on their findings.

Treatment of the Parlay plots occurred during the late FI period, approximately Feekes Scale Stage 6. Floret structures were fully differentiated. Thus, it is not likely that Parlay had any effect on inflorescence development as would be evidenced in seed

number. Any treatment effect on improved seed filling also is doubtful due to the significant decrease in TSW unless these data are to be interpreted as a reflection of yield component compensation.

It can be presumed then that any nonlodging yield increase effect would have shown itself in tillering. On the treatment date, plants were still at a stage where tillering could be influenced by PGR treatment. Tiller synchrony would contribute to seed yield through an equalization of tiller and mainstem development. Fertile tillers reaching mainstem status would synchronize their reproductive development with the mainstem. They would produce seed approaching in number and size the seed produced on the mainstem (45).

A yield improvement in tiller synchrony could be measured by an increase in the number of tillers and seeds per tiller relative to seeds per mainstem and by an equalization of their development. The data collected in this experiment provide a sketchy picture in this regard.

Tiller number only showed a trend for increase with the highest increase at the low 600 g/ha treatment rate (Table 6). The CST value, as a calculated estimate of seeds per head, was significant only in the high treatments. Although CST was significantly correlated to yield, the value was not strikingly high (Table 10). Spikelet number showed no increase. Seeds per

head, like tillering, showed a trend for an increase (Table 6).

The CST and the seeds per head values do not agree as would be expected (Table 6). The CST values are considerably lower and would seem to indicate a low seed production per tiller.

However, in calculating the CST value with the tiller, TSW, and yield data (Appendix A), a more reliable comparison with seed yield in control and treated plots may have been derived. The high treatment (800 g/ha and 1000 g/ha) CST values were significantly higher than the control CST value. Also, a trend for an increase was evident in the low treatments (400 and 600 g/ha). These data, therefore, show a greater consistency with the yield data than do the nonsignificant differences found in the seed per head data. CST explains the yield increase as resulting from a greater number of seed produced which agrees with the presumption that seed production was lowered in the controls due to the adverse effects of early lodging on seed development.

Unfortunately, these data cannot give any clear indication of the yield increase, if any, from Parlay's effects on tillering.

Moreover, spikelet and seed data have limited reliability.

Because the samples were cut as row lengths, the heads from which the data were taken could not be distinguished by plant or by order of tiller appearance.

In future experiments, data could be collected on both equalization of development and increase in tiller and seed number. It would be important to sample by plant for a comparative analysis of tillers. Tiller synchrony could be measured in the field by following the order of tiller development in representative plants. Mainstem status could be verified by height measurements and comparisons of seed number and size between the mainstem and the respective tillers.

Through a comparative study of seed development on corresponding tillers, data could be collected that would show both equalization of inflorescence development and an increase in seed number. If equalization were to occur, the range of seed size would be reduced. Harvest index measurements would verify redistribution of assimilate to the developing cereal head. From harvest index and seed number, the operation of yield component compensation versus an actual decrease in seed weight could be established. Heading and anthesis dates for the representative samples would give additional information on equalization of whole plant development.

LODGING

Morex is a spring malting cultivar described as medium tall with moderately strong straw. It has a six-row, lax or semi-erect head type (5). Morex is a midwest cultivar known for its susceptibility to lodging in Northwest growing conditions.

Lodging conditions were promoted in the field experiment with the high fertility and a high moisture level maintained with irrigation. The combined fertility and moisture were enough to increase lodging tendency of the variety. This fact is evidenced in the earlier lodging and its more severe nature in the control plots.

It is difficult to determine the exact cause of lodging. Of the weather conditions, wind probably exerted the greatest influence (See Appendices B, C, and D). On May 31, 1984, wind speed reached a daily average of 10 miles per hour, enough to possibly have caused the control plots to lodge. Between June 6 and June 20, 1984 when no scores were recorded for the treated plots, the high average wind speeds ranged from 6.2 to 11.8 miles per hour on four different days (Table 12). Lodging in the treated plots may have occurred on any one of those dates.

Rainfall was insufficient during late May and June 1984 to have caused the lodging event (Table 12). No hail storms in the Hermiston area were reported. Irrigation delivery may have helped to promote lodging by weighting down the lax heads with water droplets.

Experimental design may have contributed to the lodging factor on the basis of a domino effect. Because the plots were not separated by physical barriers, lodged control plants fell into the adjacent treated plots, possibly initiating lodging in those

respective plots. In future PGR experiments, it would be beneficial to the evaluation of lodging to separate plots with borders or ground space to eliminate the possibility for sympathetic lodging.

TREATMENT DATE

Weather conditions can interfere with preferred application dates as was the case in the field experiment. The height and yield data show that the late FI application date was within the range of effective treatment dates. Future experiments could be designed to establish the Feekes Scale Stage at which the expression of the height reduction effect on lodging control and yield enhancement is lessened.

FERTILITY

The absence of a Parlay X nitrogen fertility interaction as well as nonsignificant differences for height and yield can be explained by the rates of nitrogen selected for the field experiment. The low rate apparently was on the upper end of nitrogen fertility. 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

The data in these experiments show that for a lodging-susceptible spring barley cultivar, Parlay is effective in controlling lodging and in enhancing yield. They agree with the findings of research reported by Froggatt and Johnston.

The success of the barley field experiment contrasts with the results for the wheat cultivars tested in Oregon. Between the two cereal species lies the distinction for assessing Parlay's potential effectiveness. Morex is a characteristically tall-stemmed, weak-strawed cultivar which under high fertility and moisture conditions will lodge. Parlay, by shortening the cultivar, controls lodging and prevents a yield loss. The semidwarf white winter wheats grown in Oregon are characteristically short and strong-strawed. Even under high fertility and moisture conditions for which these plants were specifically bred, lodging does not occur to any great degree. Parlay can and has been shown to shorten these wheats. However, it also tends to decrease their yields probably as a result of an excessive effect on the hormonal systems already manipulated genetically to produce the semidwarf growth habit.

Froggatt reported significant stem strengthening in Parlay-treated wheat. The straw strength of the winter wheat also negatively correlated to height which is the plant response already established in the CCC cereal research. Morex barley

showed a response different from the expected. Height was significantly reduced with increasing treatment rate. However, SSW used as an indicator of stem density in these experiments, did not increase, and the expected inverse relationship was not found.

The significant stem weakening that occurred with increasing treatment rate raises questions concerning the nature of the lodging resistance induced by Parlay treatment. Was lodging control, and thus yield enhancement, solely due to height shortening in the basal internodes? A strict evaluation of the data would lead to such a conclusion. However, their inadequacy detracts from any definitive conclusions.

From the data, it is not possible to determine whether dry matter was redistributed during the growing season such that stem weakening was progressive or to determine the presence of an interaction between nitrogen, Parlay, and barley genetics. If such a mechanism did operate, the likely destination for this source of assimilate would be the developing seeds. The question raised by this possibility is whether or not Parlay exerts beneficial effects on seed filling that are realized in yield. If Parlay influences seed filling through some bioregulatory action, might it also influence seed development as has been proposed for CCC by Hofner and Williams? These questions require continued research to answer.

Table 1. Effect of Parlay treatment rate applied at two dates on tiller number and stem morphology of Morex barley grown in the greenhouse, 1984.

Parlay Rate	Fertile Tillers	Nodes	Height	SSW ¹	Breaking Strength ² 1st	2nd
(g/ha)			(cm)	(mg/cm)	(g/cm)	
0	13	8.9	124	15.5	410	335
300	14	8.6	118	12.6	218	173
400	13	8.3	113	14.5	288	248
600	12	8.4	105	14.1	215	188
800	10	8.1	92	15.1	183	195
1000	12	8.4	100	12.6	118	120
LSD .01	ns	ns	12	ns	169	132
LSD .05	2	ns		ns		

¹Specific stem weight.

²Measurements were taken on the first and second 10-centimeter sections cut from the basal internode region.

Table 2. Effect of application date on tiller number and stem morphology of Parlay-treated Morex barley grown in the greenhouse, 1984.

Parlay Rate ³	Fertile Tillers	Nodes	Height	SSW ¹	Breaking Strength ² 1st	2nd
			(cm)	(mg/cm)	(g/cm)	
SI	12	8.4	105	13.8	200	191
FI	12	8.5	112	14.3	277	228
LSD .05	ns	ns	5	ns	ns	ns

¹Specific stem weight.

²Measurements were taken on the first and second 10-centimeter sections cut from the basal internode region.

³SI is the spikelet initiation date and FI is the floret initiation date.

Table 3. Effect of Parlay treatment rate applied at two dates on internode lengths of Morex barley grown in the greenhouse, 1984.

Parlay Rate	1st	2nd	Internode		5th	6th	7th
			3rd	4th			
(g/ha)	(cm)						
0	4.5	8.7	11.7	12.6	13.3	14.9	23.7
300	4.3	7.6	10.2	12.5	14.2	18.8	26.4
400	4.1	7.5	10.4	13.2	15.7	22.6	31.1
600	2.8	5.9	8.4	11.6	15.9	19.9	26.7
800	2.1	4.6	6.7	9.3	13.9	22.7	24.9
1000	3.2	5.4	7.5	10.5	13.3	19.9	23.8
LSD .01	1.5	2.4	3.0	ns	ns	ns	ns
LSD .05				2.7	ns	ns	ns

Table 4. Effect of application date on internode lengths of Parlay-treated Morex barley grown in the greenhouse, 1984.

Treatment Date ¹	1st	2nd	Internode		5th	6th	7th
			3rd	4th			
	(cm)						
SI	3.5	6.2	8.4	11.2	14.7	20.1	24.6
FI	3.4	7.0	9.9	12.0	14.1	19.6	27.6
LSD .05	ns	ns	1.3	ns	ns	ns	ns

¹SI is the spikelet initiation date and FI is the floret initiation date.

Table 5. Interaction between treatment date¹ and Parlay rate on height of Morex barley grown in the greenhouse, 1984.

Parlay Rate	SI	Height FI	SI	SSW ² FI
(g/ha)		(cm)		(mg/cm)
0	120	127	17.2	13.7
300	113	123	12.1	13.0
400	120	106	12.3	16.7
600	96	114	15.2	13.0
800	91	92	13.2	17.0
1000	92	107	12.7	12.5
LSD .05	13	13	3.7	3.7

¹SI is spikelet initiation date and FI is floret initiation date.

²Specific stem weight.

Table 6. Effect of Parlay treatment rate on yield and stem morphology of Morex barley grown under two nitrogen treatments, Hermiston, Oregon, 1984.

Parlay Rate	Fertile Tillers	TSW ¹	Yield	CST ²	Spikelets ³	Seeds/ Head	Nodes	Height	SSW ⁴
(g/ha)		(g)	(kg/ha)					(cm)	(mg/cm)
0	26	40	4395	25	20.8	48.7	7.48	124	23.6
400	25	38	5815	34	20.9	50.8	7.16	106	17.2
600	31	37	5976	30	20.6	50.4	7.13	101	15.7
800	28	37	6704	36	20.9	51.7	7.08	95	16.4
1000	27	37	6776	38	20.8	50.2	6.93	91	15.4
LSD .01	ns	1	645	10			0.36	5	4.0
LSD .05	ns				ns	ns			

¹Thousand seed weight.

²Calculated seeds per tiller.

³The three spikelets at each rachis node were counted as one. Rudimentary spikelets also were counted.

⁴Specific stem weight.

Table 7. Effect of nitrogen treatment rate on yield and stem morphology of Parlay-treated Morex barley, Hermiston, Oregon, 1984.

Nitrogen	Fertile Tillers	TSW ¹	Yield	CST ²	Spikelets ³	Seeds/Head	Nodes	Height	SSW ⁴
(kg/ha)		(g)	(kg/ha)					(cm)	(mg/cm)
112	26	39	6065	33	20.7	50.5	7.11	102	17.0
168	29	36	5816	32	20.9	50.2	7.20	105	18.3
LSD .05	3	2	ns	ns	ns	ns	ns	ns	ns

¹Thousand seed weight.

²Calculated seeds per tiller.

³The three spikelets at each rachis node were counted as one. Rudimentary spikelets also were counted.

⁴Specific stem weight.

Table 8. Effect of Parlay treatment rate on internode length of Morex barley grown in Hermiston, Oregon under two nitrogen treatments, 1984.

Parlay Rate	1st	2nd	Internode		5th	6th	7th
			3rd	4th			
(g/ha)				(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	

Table 9. Effect of nitrogen treatment rate on Parlay-treated Morex barley grown in Hermiston, Oregon, 1984.

Nitrogen Rate	1st	2nd	Internode		5th	6th	7th
			3rd	4th			
(kg/ha)							
112	2.7	7.3	11.3	15.9	23.8	34.2	40.2
168	2.5	7.1	11.2	15.4	23.5	33.7	41.2
LSD .05	ns	ns	ns	ns	ns	ns	ns

Table 10. Correlation coefficients for Parlay treatment effect on Morex barley grown in the field and in the greenhouse, 1984.

	Treatment		Height		CST ¹	SSW ²
	Field	Grh	Field	Grh	Field	
Yield	0.90	---	-0.86	---	0.73	
FSU	0.61	---	-0.57	---	----	
Height ₃	-0.93	-0.53	---	---		
1st In ³	-0.65	-0.61	0.71	0.51		
2nd In	-0.89	-0.55	0.94	0.62		
3rd In	-0.90	-0.64	0.96	0.59		
SSW ⁴	-0.78	-0.69	0.77	-0.30		
Bkstr ⁴	---	-0.21		0.87		0.65

¹Calculated seeds per tiller.

²Specific stem weight.

³First, second, and third internode length measurements.

⁴Average breaking strength for first and second 10-centimeter internode sections.

Table 11. Comparison of stem and height data taken for Parlay-treated Morex barley grown in the field and in the greenhouse, 1984.

Parlay Rate	Internodes									
	Nodes		Height		1st		2nd		3rd	
	Field	Grh	Field	Grh	Field	Grh	Field	Grh	Field	Grh
(g/ha)			(cm)		(cm)		(cm)		(cm)	
0	7.48	8.9	124	124	4.2	4.5	12.6	8.7	17.3	11.7
400	7.16	8.3	106	113	2.1	4.1	6.7	7.5	11.1	10.4
600	7.13	8.4	101	105	2.4	2.8	6.5	5.9	10.4	8.4
800	7.08	8.1	95	92	2.0	2.1	5.2	4.6	8.8	6.7
1000	6.93	8.4	91	100	2.2	3.2	5.0	5.4	8.6	7.5
LSD .01	0.36	ns	5	12	0.9	1.5	1.3	2.4	1.7	3.0
LSD .05		ns								

Table 12. Climatic data for Hermiston, Oregon from May 25, 1984 to June 20, 1984¹.

Date	Wind Avg	Temperature	Rain	Irrigation
	(mph)	(max)	(in)	(in)
May 25	3.8	64		.62
May 26	3.0	61	.04	
May 27	7.2	68		
May 28	1.4	75		.58
May 29	1.9	83		
May 30	3.4	90		
May 31	10.0	70		
June 1	3.2	67		.72
June 2	1.6	72		
June 3	5.3	73		
June 4	3.8	73	.24	.59
June 5	5.6	61	.08	
June 6	5.0	68	.09	
June 7	4.9	68	.03	.67
June 8	11.8	65		
June 9	9.0	69		
June 10	2.8	70		
June 11	4.6	73		.71
June 12	3.4	76		
June 13	1.9	77		
June 14	1.8	77		.55
June 15	2.3	84		
June 16	8.9	83		
June 17	6.2	73		
June 18	1.8	76		.69
June 19	1.8	79		
June 20	2.0	79		.64

¹From data gathered by the Oregon State University Agricultural and Extension Center at Hermiston, Oregon.

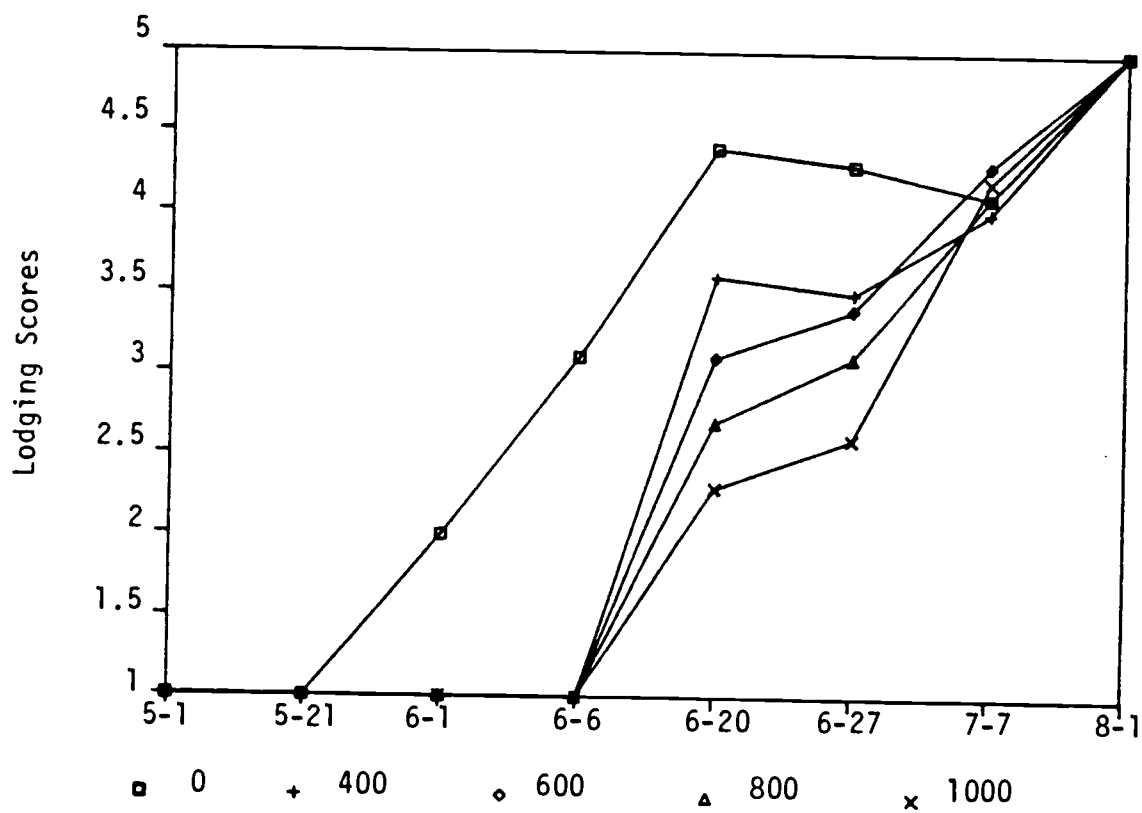


Figure 1. Lodging Scores: Morex Barley, 1984. Average of two nitrogen treatment rates.

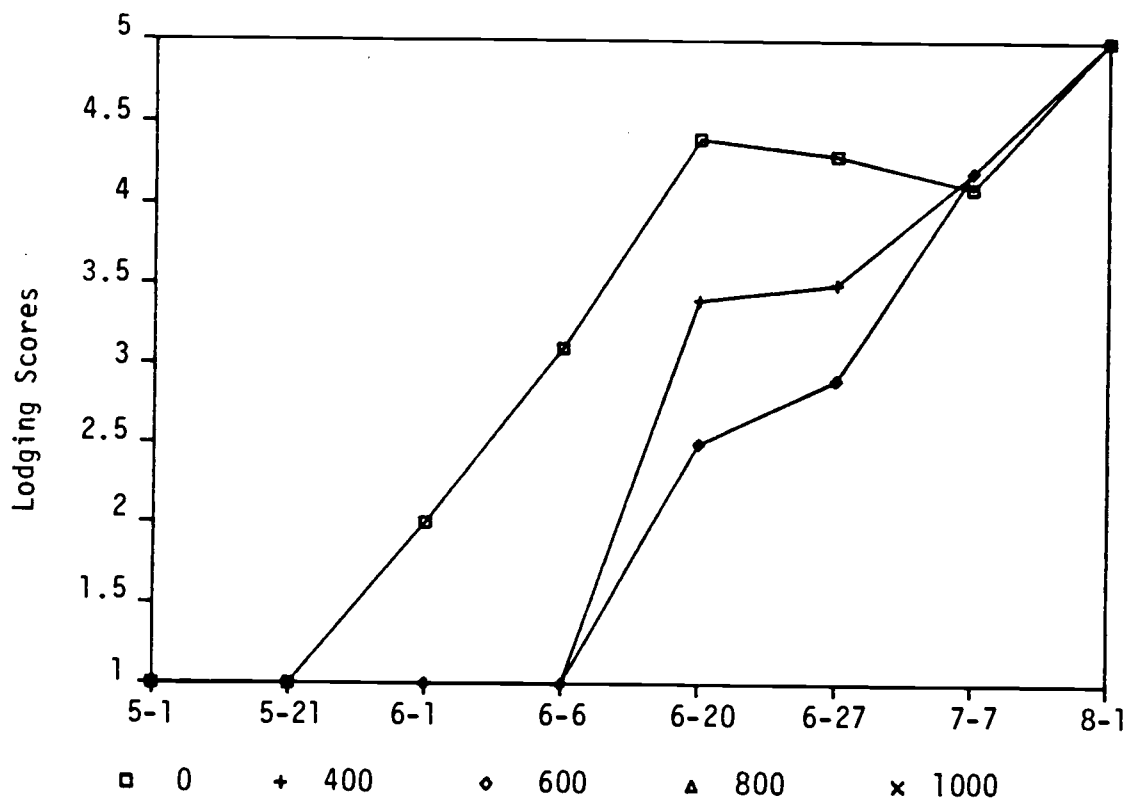


Figure 2. Lodging Scores: Morex Barley, 1984. Low versus high PGR treatment rates.

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APPENDICES

APPENDIX A

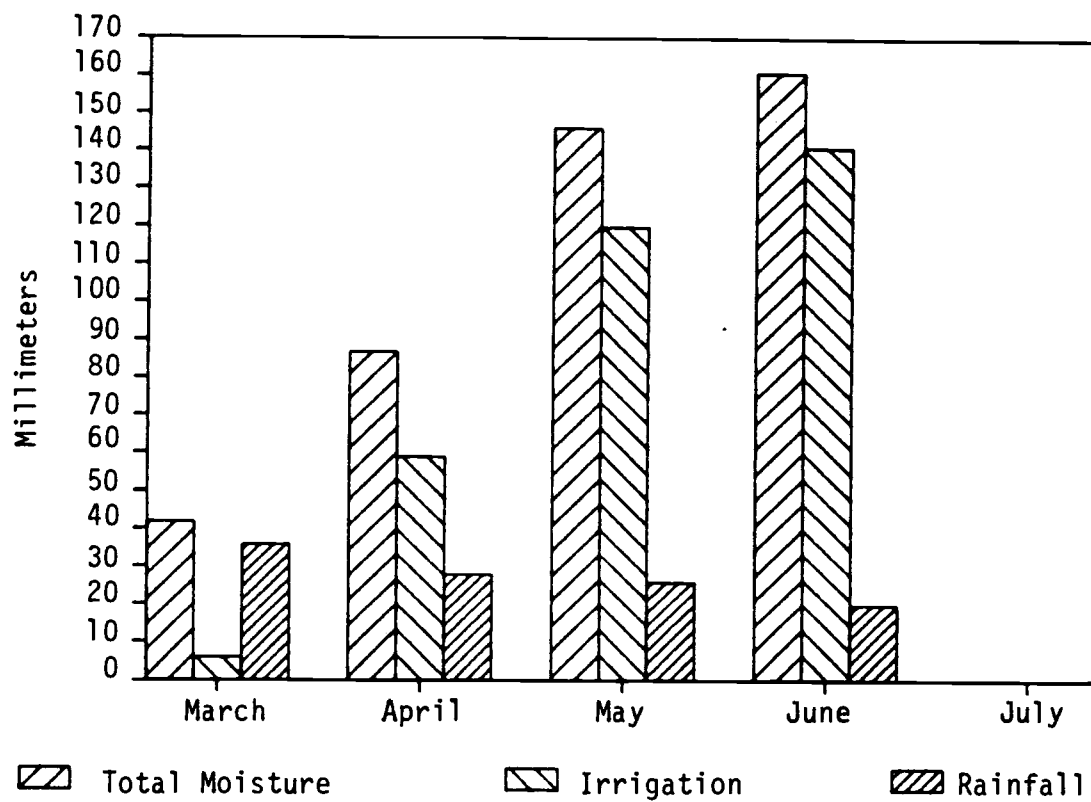
CALCULATED SEEDS PER TILLER FORMULA

$$\frac{\text{Tillers}}{\text{m}^2(\text{ft}^2) \text{ Row Sample}} = \text{Tillers/m}^2$$

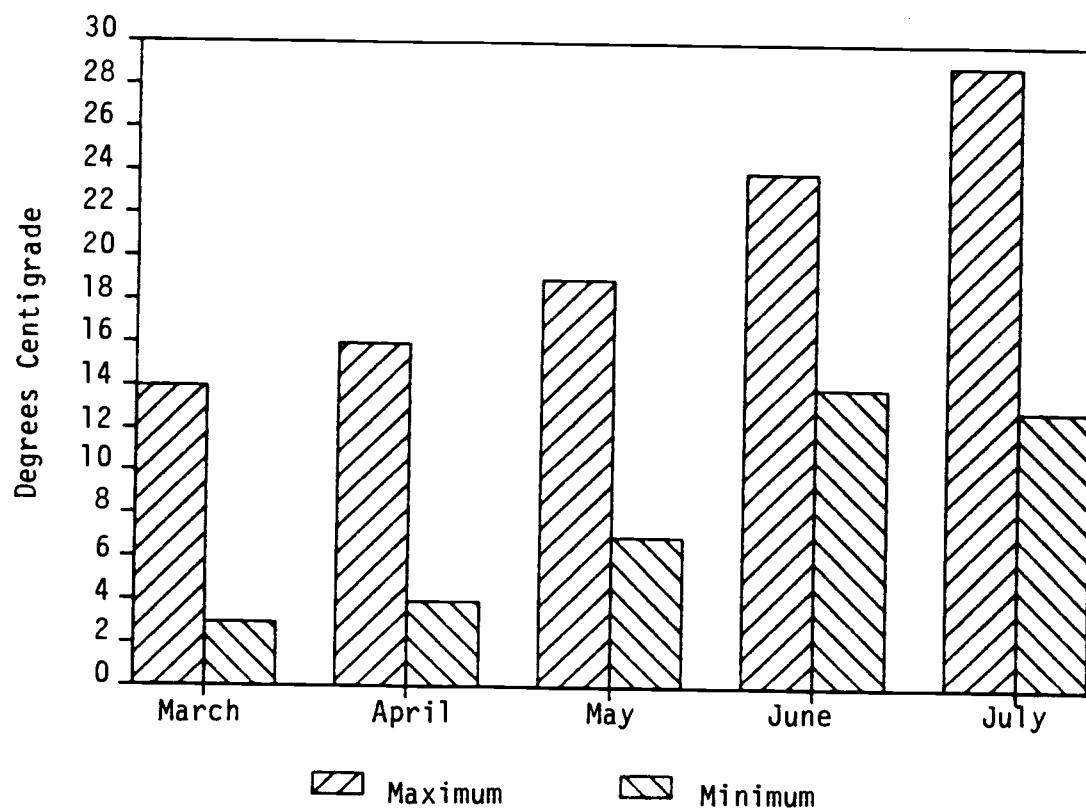
$$\frac{\text{g/Plot Yield}}{\text{Plot Area (m}^2 \text{ or ft}^2\text{)}} = \text{g/Sample area}$$

$$\frac{\text{TSW}}{1000} = \text{g/seed}$$

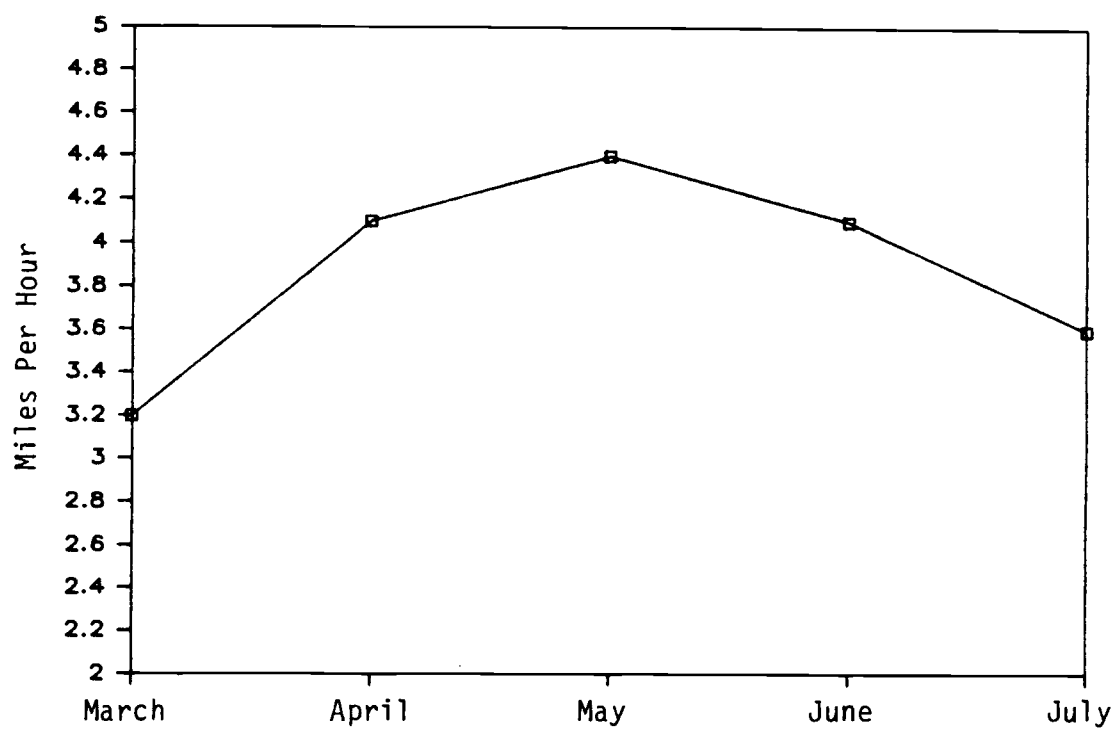
$$\frac{\text{Seed}}{\text{g}} \times \frac{\text{g}}{\text{m}^2} \times \frac{\text{m}^2}{\text{Tillers}} = \text{FSU}$$



Appendix B. Total Moisture Readings. Hermiston, Oregon, 1984.



Appendix C. Average Monthly Temperatures. Hermiston, Oregon, 1984.



Appendix D. Average Wind Speed. Hermiston, Oregon, 1984.