Plant Growth Regulators: What agronomists need to know

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ABSTRACT
Plant growth regulators (PGRs) are synthetic compounds that exhibit hormonal activity to beneficially modify plant growth and development. The PGRs of interest in Canadian cereal cropping systems are intended to produce shorter (2-15cm), thicker, and stronger stems which reduce lodging. Depending on the product, they work by altering a plant's gibberellin biosynthesis or ethylene production. However, PGRs can indirectly alter the plant's natural hormonal activity. As a result, there are reports in the scientific literature of PGRs increasing root growth and yield. On the flip side, there are also reports of PGRs increasing plant height, causing late tillering and yield reductions.

There are many unanswered questions about PGRs, and more work is needed. However, it is known that agronomically beneficial applications of PGRs require careful crop staging and they are not recommended for use under stressful environmental conditions. Understanding when, where and why PGRs work is critical for their success. Because lodging can reduce wheat yields up to 35%, PGRs can be a risk management tool to reduce lodging in intensive management systems.

THE PROBLEM

Lodging can reduce yields from 7-35% with the greatest yield reductions occurring when lodging happens within 20 days after anthesis (Fischer and Stapper, 1987). The magnitude of yield loss depends on: cultivar susceptibility to lodging; growth stage and severity of lodging; amount of wind & rain, early snowfall (Kelbert et al., 2004). We tend to see increased amounts of lodging when there are: insect or disease infections; increased fertilization; higher seeding rates and poor genetics. In addition, lodging during ripening can increase grain sprouting leading to downgrading.

WHAT ARE PGRs?

PGR stands for Plant Growth Regulators. They are synthetic compounds that impact hormonal activity to beneficially modify plant growth and development (Hopkins and Hüner, 2004). They are characterized as being effective at low concentrations and they break-down rapidly.

There are 5 classes of plant hormones: gibberellins (GA), auxins, ethylene, cytokinins, abscisic acid (ABA) and brassinosteroids (Hopkins and Hüner, 2004). The plant growth regulators that are of most interest to western Canadian cereal producers are: ethylene releasing compounds (i.e. Ethephon) and inhibitors of gibberellin biosynthesis (i.e. Chlormequat-chloride and Trinexapac-ethyl) (Table 1).

Table 1. Comparison of Standard PGR Products used in the UK.

	Chlormequat-chloride	**Trinexapac-ethyl**
Mode of action	Inhibits early stages of gibberellin biosynthesis	Inhibits late stages of gibberellin biosynthesis
Minimum temperature	8^{o}C	10^{o}C
Onset of action	Slow	Fast
Residual activity	Long	short

Source: Wilhelm Rademacher - Control of Lodging in Intense European Cereal Production

PGRs which alter gibberellin biosynthesis may also: increase levels of cytokinins; lower ethylene levels; and increase abscisic acid levels (Rademacher, 2000). As a result of altering these other hormone levels in the plant, there may be numerous side effects associated with GA biosynthesis inhibitors. These side effects include: delayed senescence; increased resistance to environmental stress; shifting assimilates to the roots which then leads to increased cytokinin formation. However, it is important to note that these effects are not achieved by all PGRs in all plant species.

PGRs work at the cellular level and impact plant physiology by: reducing stem length; shortening the uppermost internodes and peduncle (Berry et al., 2000). There are occasional reports of PGRs altering stem diameter. While PGR applications are based on the staging of the main stem, PGR activity can be observed on tillers, even if they are not directly exposed to the PGR. As a result, the elongation retarding effect can be observed on tillers (Peltonen-Sainio et al 2003).

Unfortunately there are reports of PGRs causing stem elongation (Clark and Fedak, 1977). This is the result of increased GA precursors building up in response to the chlormequat-chloride application. When the Chlormequat-chloride breaks down and GA synthesis resumes, excess GA precursors move through the biosynthesis pathway resulting in elevated GA levels. This phenomena is associated with Chlormequat-chloride. Other undesirable side effects of PGR use include: short-term height reduction (Rajala and Peltonen-Sainio, 2002) and the development of unproductive tillers. Unproductive tillers can be the result of increased photoassimilate availability or PGR induced changes in hormonal patters, such as ethylene simulating the breakdown of apical dominance due to the inhibition of auxin biosynthesis and movement.

PGR USE

PGRs are not new agri-chemicals. Ethephon was discovered in 1965 and is one of the oldest PGRs on the market. It is used worldwide to: improve lodging resistance, promote fruit ripening, stimulate flowering in horticultural crops, increase rubber yields and improve cotton harvestability. Today, PGRs are widely used in horticultural industries and are standard practice in western European cereal production. In western Canada, chlormequat chloride was recently registered by Engage Agro under the trade name Manipulator. Trinexapac-ethyl is in the process of registration in Canada.

In the UK, PGRs are used on 89% of the winter wheat acres with fields receiving 1.7 PGR applications per year, on average (Department of Environment, Food and Rural Affairs, London, 2006). The high level of PGR use in the UK can be attributed to the fact that severe lodging occurs every 3 to 4 years with average yield losses of 25%.

STAGING IS CRITICAL

Proper plant growth staging is critical to optimize PGR performance and with some products, ensure crop safety. For GA biosynthesis inhibitors, the application window for ideal performance starts when stem elongation begins (BBCH 30) until BBCH 32. BBCH 30 is defined as the beginning of stem elongation when the pseudostem and tillers are erect, the first internode begins to elongate and the top of inflorescence is at least 1cm above the tillering node (Lancashire et al., 1991). BBCH 31 is defined as the time when the first node is at least 1cm above tillering node. BBCH 32 is defined as the time when node 2 is at least 2 cm above node 1.

To properly stage, plants should be pulled for the ground and tillers removed, so staging is based on the main stem. While nodes can be felt as 'bumps' along the pseudostem, it may help to cut the pseudostem lengthwise to observe actual nodes. Please note that new nodes do not start at the base of the plant, they start above the previous node and below the inflorescence.

For ethylene releasing PGRs, applications should be made at a later growth stage, BBCH 37-45. BBCH 37 is defined as the time when the flag leaf is just visible and still rolled (Lancashire et al., 1991). BBCH 39 is defined as the time when the flag leaf is fully unrolled and the ligule is just visible. The application window closes at BBCH 45, late boot when the flag leaf sheath is swollen. Once awns are visible (in awned cultivars), ethylene releasing PGRs should not be applied. Please note these are general recommendations, always follow label directions.

YIELD IMPACTS

The main objective of PGR use is to improve crop standability. However, there are occasional reports of PGRs increasing or decreasing yields. Below is review of a number of studies showing the impacts of various PGRs on yield and other physiological traits.

Table 2 describes a pot experiment where three PGRs were applied to spring wheat (Rajala and Peltonen-Sainio, 2001). None of the PGRs affected yield, and all reduced main stem growth, as intended. However, ethephon and trinexapac-ethyl increased the number of tillers while chlormequat-chloride decreased root weight.

Table 2. Effects of three plant growth regulators on the yield and physiological characteristics of *Mahti* wheat. Data is from a greenhouse and outdoor pot experiments in Helsinki, Finland (Rajala and Peltonen-Sainio, 2001).

PGR use in Wheat	Main Shoot Growth 14 DAT	# of Tillers 14 DAT	Root Weight 14 DAT	Yield vs. control in outdoor pot trials
Ethephon	Reduced	Increased	No effect	No effect
Chlormequat-chloride	Reduced	No effect	Decreased	No effect
Trinexapac-ethyl	Reduced	Increased	No effect	No effect

Figure 1 describes the effect of 2 plant growth regulators on the yield of CPS wheat, cv. *Foremost* (Strydhorst et al., unpublished data). In these 3 growing environments, adequate precipitation (263-425 mm) was received over the growing season. The unnamed PGRB resulted in significant yield increases ranging from 5 to 6 bu/acre over the untreated control. The application of chlormequat-chloride (CCC), had no significant impact on yield compared to the untreated control.

In drier environments (101-194 mm precipitation), a different response was observed (Figure 2). Yields were unaffected with the application of the unnamed PGRB compared to the untreated control, but slight yield decreases were observed with the use of chlormequat-chloride (CCC). It is unclear what factors may have resulted in this yield decrease but it may be attributed to stressful (dry) environmental conditions or it may be cultivar specific.

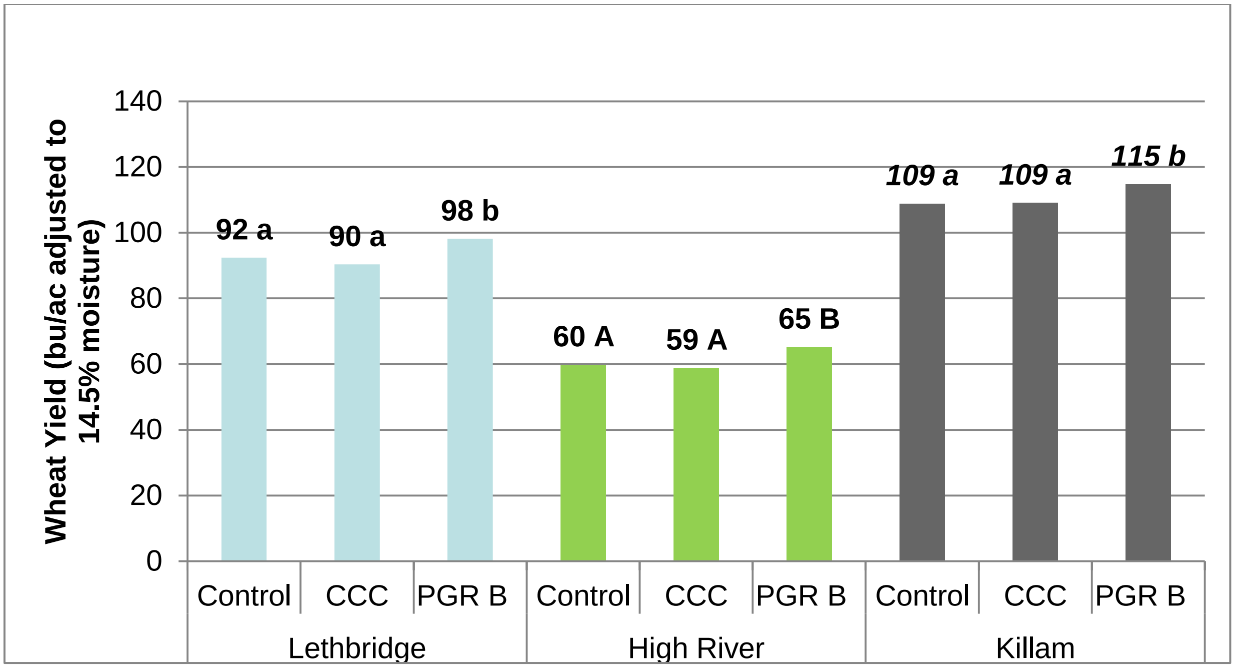

Figure 1. Yields of *Foremost* CPS wheat in response to 2 plant growth regulators, (CCC – Chlormequat-chloride and PGR B) compared to an untreated control. In these 3 growing environments, adequate precipitation (263 - 425 mm) was received over the growing season.

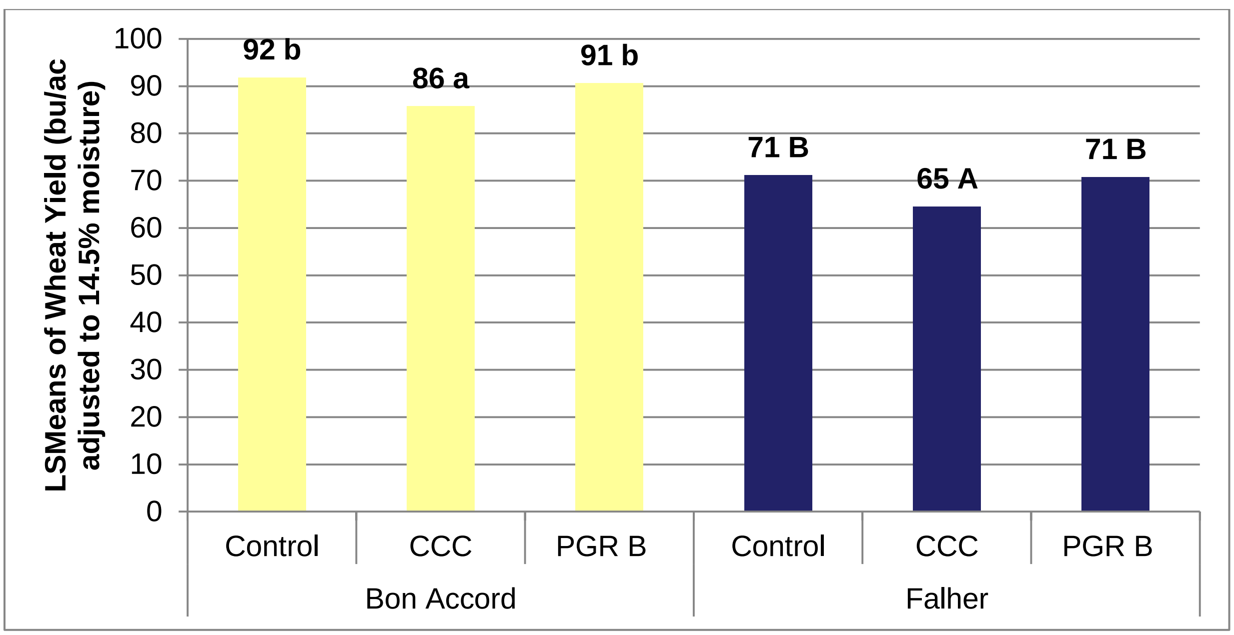

Figure 2. Yields of *Foremost* CPS wheat in response to 2 plant growth regulators, (CCC – Chlormequat-chloride and PGR B) compared to an untreated control. These 2 growing environments were drier and received only 101-194 mm precipitation over the growing season.

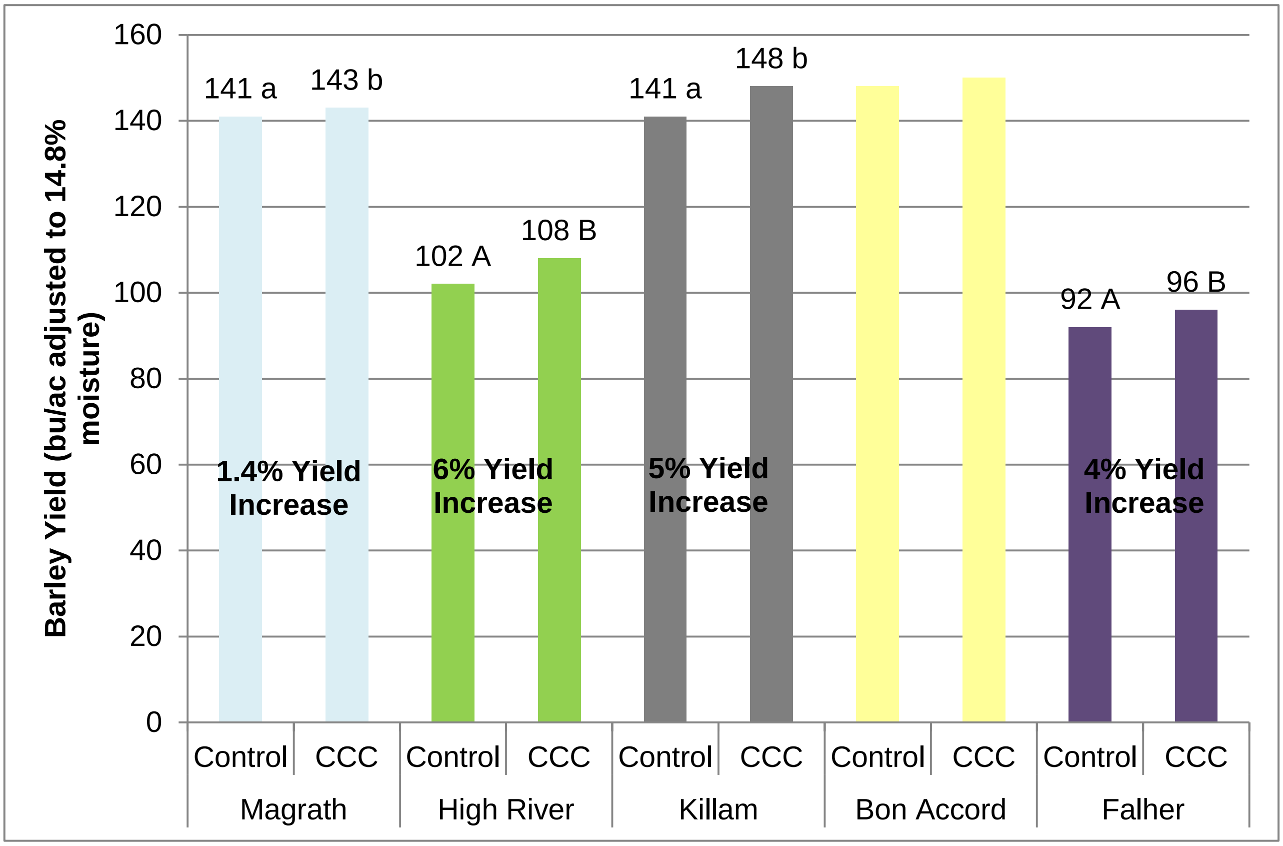

Figure 3. Yields of *Amisk* barley in response to chlormequat-chloride (CCC) compared to an untreated control.

Figure 3 shows the yield response of *Amisk* barley to chlormequat-chloride applications compared to an untreated control (Strydhorst et al., unpublished data). Unlike the wheat response, there was a significant yield increase at four of the five sites (Magrath, High River, Killam and Falher). This response was unexpected and must be reviewed again after additional years of study. It is also possible that the response is cultivar specific and may not occur with all barley varieties in all locations.

Table 3 describes a field experiment where ethephon and chlormequat-chloride were applied to *Max* spring wheat (Caldwell and Starratt, 1987). Both PGRs reduced plant height and neither effected yield. The lack of yield response was attributed to the fact that lodging did not occur in the field trials, therefore the PGR provided no real benefit in this study.

Table 3. Effects of two plant growth regulators on the yield and physiological characteristics of *Max* spring wheat. Data is from field experiments conducted at Truro, Nova Scotia (Caldwell and Starratt, 1987).

PGR use in spring wheat	Plant Height vs. control	1000 kernel weight	Yield vs. control
Ethephon	12 cm Shorter	No effect	No effect
Chlormequat-chloride	20 cm Shorter	Smaller	No effect

Table 4 describes a field experiment where ethephon and chlormequat-chloride were applied to four different winter wheat cultivars (Knapp and Harms, 1988). As with the previous study, lodging was not a serious problem. The study found that cultivar had a bigger impact on results than PGR application. It is interesting to note that chlormequat-chloride increased the yield of one of the four cultivars tested in the study.

Table 4. Effects of two plant growth regulators on the yield, agronomic and physiological characteristics of four wheat cultivars. Data is from field experiments conducted at Lafayette, Indiana (Knapp and Harms, 1988).

PGR use in soft red winter wheat	Spike Density	Lodging	Yield vs. control
Ethephon	No effect	Reduced lodging	Similar or slight decrease
Chlormequat-chloride	No effect	Similar to control or reduced	Increased in 1 of 4 cultivars

SPECIES AND CULTIVAR RESPONSES

PGRs performance depends on crop species and cultivar. Wheat is most responsive, barley has an intermediate response and oats are least responsive (Clark and Fedak, 1977). Studies have also found that not all cultivars show similar height or lodging responses to PGRs. In testing the height response of 53 different barley varieties to chlormequat-chloride, they found 15 varieties became taller, 5 had no change in height and 33 showed some level of height reduction.

STRAW QUALITY

Lignin, cellulose and protein content of chlormequat-chloride treated straw were unchanged with application of chlormequat-chloride (Clark and Fedak, 1977). A second study (Knapp et al., 1987) found similar results with ethephon and chlormequat-chloride changing structural carbohydrates (cellulose, hemicellulose and lignin) by less than 5%, when compared with untreated plants. The improved standability associated with PGRs is not attributed to changes in water soluble or structural carbohydrates. Rather, the use of PGRs may alter the arrangement and interaction of the structural carbohydrates which results in improved standability.

UNANSWERED QUESTIONS and UNREALISTIC EXPECTATIONS

While there is much that we know about PGRs, there are still a number of unanswered questions that should be addressed to ensure optimal performance under western Canadian conditions. These questions include:

- Why do some varieties respond and others do not?
- Is there a benefit with tank mixing chlormequat-chloride and trinexapac-ethyl?
- Do we have the correct growth stage?
- Are dual applications useful?
- How do environmental conditions impact performance?
- Does seeding rate matter?

Many growers and agronomists are looking to ease PGR management with the use of tank mixes. However, tank mixing PGRs and UAN is complicated by the fact that each product requires a different sprayer nozzle. Tank mixing herbicides and PGRs would not be ideal as the correct PGR application timing would correspond with exceptionally late herbicide timing. While the timing of ethylene releasing PGRs corresponds with a flag leaf fungicide application, but the use of ethylene releasing PGRs is very, very sensitive to crop growth stage and environmental conditions. Growers must follow label directions to ensure crop safety and optimum PGR performance.

PGR use on all acres in large farming operations will be complicated by the small application windows and the need to frequently and accurately stage crops. PGRs should be reserved for use on intensively managed acres in high rainfall or irrigated production systems where high rates of fertilizer are used and lodging is a realistic possibility.

SUMMARY

The primary use of PGRs in western Canadian cereal production is as a harvest management aid. They are best suited in environments and management systems that have a high risk of lodging. They produce shorter (2-15cm), thicker, and stronger stems which reduce lodging.

To optimize their use and ensure crop safety, PGRs must be applied at the correct growth stage. This will help to avoid undesirable side effects such as increased tillering and reduction in grain yields. Environmental conditions may have a negative impact on performance, so growers and agronomists must follow label directions. PGR use is further complicated by the fact that different species and cultivars respond differently or not at all. More research work should be conducted to optimize the use of PGRs in western Canada.

REFERENCES

Caldwell, C.D. and Starratt, C.E. 1987. Response of Max spring wheat to management input. Can. J. Plant Sci. 67: 645-652.

Clark, R.V. and Fedak, G. 1977. Effects of chlormequat on plant height, disease development and chemical constituents of cultivars of barley, oats and wheat. Can J Plant Sci. 57:31-36.

Fischer, R.A. and Stapper, M. 1987. Lodging effects on high-yielding crops of irrigated semidwarf wheat. Field Crops Res 17:245-258.

Hopkins, W.G. and Hüner, N.P. 2004. Introduction to Plant Physiology, 3rd Edition. John Wiley and Sons, Inc. 560pp.

Kelbert, A.J., Spaner, D., Briggs, K.G., and King, J.R. 2004. Screening for lodging resistance in spring wheat breeding programs. Plant Breeding 123:349-354.

Knapp, J.S. and Harms, C.L. 1988. Nitrogen fertilization and plant growth regulator effects on yield and quality of four wheat cultivars. J. Prod. Agric. 1:94-98.

Knapp, J.S., Harms, C.L. and Volenec, J.J. 1987. Growth regulator effects on wheat culm nonstructural and structural carbohydrates and lignin. Crop Science. 27:1201-1205.

Lancashire, P.D., Bleiholder, H., Van Den Boom, T., Langeluddeke, P., Strauss, R. Weber, E., and Witzenberger, A. 1991. A uniform decimal code for growth stages of crops and weeds. Ann. Appl. Biol. 119:561-601.

Rademacher, W. 2000. Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. Annu. Rev. Plant Physiol. Plant Mol. Biol. 51:501-531.

Rajala, A. and Peltonen-Sainio, P. 2001. Plant growth regulator effects on spring cereal root and shoot growth. Agron. J. 93:936-943.