CONTROL OF LODGING IN INTENSE EUROPEAN CEREAL PRODUCTION

Wilhelm Rademacher¹

ABSTRACT

Lodging is a significant risk in intense cereal production and may severely reduce seed yield and quality. Lodging is strongly influenced by cultivar and husbandry factors including sowing date, seed rate, drilling depth and rate of nitrogen application. A number of PGRs are known that reduce stem length, thereby lowering the leverage of the ear and other parts of the shoot. Increased stem stability also results from histological changes caused by such PGRs. Improved root growth induced by some compounds may further improve lodging resistance. Products available on the market are based on inhibitors of gibberellin biosynthesis (chlormequat chloride, mepiquat chloride, trinexapac-ethyl, and prohexadione-Ca) and the ethylene-releasing ethephon. The usage of stem stabilizers is general practice in countries with intense production of wheat, barley, rye, triticale, and oats such as France, Germany and Great Britain with well-above 70% of the area under treatment.

DEVELOPMENT OF PRODUCTIVITY IN WHEAT AND OTHER CEREALS

The production of wheat and other small grains has undergone drastic changes since the introduction of science-based agricultural methods. This development is particularly obvious in West Europe with its maritime climate and other growing conditions, which are relatively favorable for winter wheat. Productivity data are almost continuously available for Germany since 1878 (Fig 1). Starting at yield levels of some 13 decitons per hectare (= 1,300 kg/ha), just above 20 dt/ha were reached prior to World War I and, after a post-war dip, again in the 1930s. However, enormous increases in yield levels could be achieved since the beginning of the 1950s: Within approximately six decades, productivity could almost be quadrupled from 20 to 80 dt/ha. Similar degrees of intensification were reached in countries with similar production conditions such as France and Great Britain. Likewise, seed yield per unit of land could also be raised significantly in other small grain species such as barley, rye, triticale and oats. It must also be noted that such achievements have been a major prerequisite for creating modern and wealthy societies in industrialized countries with limited area available for agriculture.

A number of factors have contributed to this success, the main ones being

- improved education of farmers
- less but larger and more specialized farms
- improved mechanization
- better soil management
- availability of synthetic N-fertilizers (mainly produced after the Haber-Bosch process, which was introduced by BASF in 1913)
- continuous introduction of new varieties with improved features
- continuous introduction of new and improved fungicides, herbicides and insecticides
- introduction of stem stabilizers

¹ BASF SE, Agricultural Center, 67114 Limburgerhof, Germany
It is estimated by several authors that the increases in productivity have mainly resulted from increased and better targeted fertilization (40-45%), followed by breeding (25-30%) and crop protection plus soil management (25-30%) (cf. Sturm et al., 1994). These factors for success are closely interconnected with each other. Dispensing, for instance, any use of fungicides would certainly lead to yield reductions of much more than 30% under the given production conditions.

![Figure 1: Average wheat productivity in Germany since 1878 (1 deciton = 100 kg) [sources: Statistical Yearbook of the German Reich (1880-1943), Statistical Yearbook of the Federal Republic of Germany (1952-1962), Statistical Yearbook of the German Democratic Republic (1955-1962), FAOSTAT (1961-2008)].](chart)

According mainly to the availability of arable land and the respective soil and climatic conditions, different degrees of intensities for growing wheat have evolved in different countries. Fig. 2 indicates that, among the major wheat-producing countries, the highest levels of productivity can be found in Great Britain, Germany and France. China is intermediate in terms of productivity but, as a result of area used, represents the leading wheat-producing nation. The average productivity lies only between approximately 25 and 30 dt/ha in India, Russia and the USA. However, comparatively large areas are used for wheat production, making these nations leading producers after China on a worldwide scale.

Globally, the human population and its demand for food are still rising, whereas it is virtually impossible to increase the area of arable land any further. As a consequence, it can be forecast that there has to be further intensification of agricultural productivity wherever possible and meaningful. Wheat productivity is not only a subject of applying high amounts of nitrogen fertilizers and crop protectants. Major limitations are set by soil and climatic conditions. Lack of precipitation does not allow top yields in the Midwest of the USA. Growing high-yielding winter wheat in the Northern part of the USA, in the Canadian prairies or in large parts of the Russian Federation is impossible or highly risky due to the harsh and long winters prevailing. However, relatively good growing conditions for wheat are found in distinct regions of the countries mentioned. For instance, the current average level of productivity is in the range of 40 to 55 dt/ha in
Idaho, Michigan and Ohio (USDA National Agricultural Statistics Service). Further intensification appears possible in these states and some other areas of the USA, where precipitation and other factors are relatively favorable for cultivating wheat. So far, there is no use of anti-lodging products in the USA. However, it is more or less inevitable that the use of such products will become part of more sophisticated production methods aiming for higher yields in suited areas.

LODGING AND ITS IMPACT ON CEREAL PRODUCTION

While increasing productivity in Germany, Great Britain, France and other countries, lodging became more and more a problem in cereal cultivation in the 1950s and 1960s: Heavy ears could no longer be kept upright by long stems, particularly when their leverage was increased by wind and rain. Lodging may occur during the two months preceding harvest and may drastically reduce profitability through reduced yield and quality and increased costs for harvesting and grain drying (Table 1). If lodging occurs early (shortly after anthesis), its impact will be more intense as compared with lodging next to harvesting (Hoffmann, 1992). Two forms of lodging can be differentiated: (i) Stem lodging occurs, when heavy wind and rainfall exert a force that breaks the stem base. Often, stem lodging is found after a severe thunderstorm. Foot rot, caused by *Cercospora herpotrichoides* and other pathogens, may intensify the risk of stem lodging. (ii) Root lodging is typically observed when, after several days of rainfall, the plant’s root system is unable to keep the stem with its heavy, water-soaked ear upright. The risk of both forms of lodging is strongly influenced by cultivar and husbandry factors including sowing date, seed rate, drilling depth, and rate of nitrogen application. In spite of this knowledge, the use of anti-lodging products has become an integral part of the production system in order to secure seed yield and quality. These products reduce stem length, thereby lowering the leverage of the ear and other upper plant parts. Increased stability results also from histological changes caused in the stems (Petry et al., 1989) and by stimulated root growth.
In order to reduce agricultural intensity, thereby lowering potentially negative impacts on the environment, the Swedish government has banned any use of stem stabilizers in wheat since 1989. Whereas Swedish wheat productivity and its increases over the years had been comparable to that of Germany in the past, it became stagnant after this restriction. Meanwhile, a difference of approximately 20% has resulted (Fig. 3).

Table 1: Negative impacts of lodging on wheat yield and quality (typical values after Pinthus, 1973; Anderson, 1979; Jung and Rademacher, 1983; Hoffmann, 1992; Easson et al., 1993; Berry et al., 2004 and after results of BASF field trials).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Effect</th>
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<tbody>
<tr>
<td>Total Grain Yield</td>
<td>Decreased by 10-40% (up to 80% in extreme cases)</td>
</tr>
<tr>
<td>1000-Grain-Weight</td>
<td>Decreased by 8-15%</td>
</tr>
<tr>
<td>Crude Protein Content of Seeds</td>
<td>Relative Increase by 3-20%</td>
</tr>
<tr>
<td>Carbohydrate Content of Seeds</td>
<td>Relative Decrease by 10-17%</td>
</tr>
<tr>
<td>Milling Quality</td>
<td>Decreased</td>
</tr>
<tr>
<td>Presence of Mycotoxins</td>
<td>Significantly Increased Risk</td>
</tr>
<tr>
<td>Costs for Harvesting</td>
<td>Increased by up to 50%</td>
</tr>
<tr>
<td>Costs for Grain Drying</td>
<td>Increased by 20-30%</td>
</tr>
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Figure 3: Development of average wheat productivity in Germany and Sweden (source: FAOSTAT). The arrow indicates the year 1989, in which the use of stem stabilizers has been forbidden in Sweden.
Historically, chlormequat chloride has been the first PGR to be used as an anti-lodging agent in cereal production. Chlormequat chloride was first described in 1960 by N.E. Tolbert from Michigan State University at East Lansing to reduce shoot length in wheat and in other plant species (Tolbert, 1960a,b; Wittwer and Tolbert, 1960). The commercial rights were held at that time by American Cyanamid. The significance of using chlormequat chloride in intense European wheat production was soon recognized. It was introduced under license by BASF as CycoCel® in 1965, being the first anti-lodging PGR. After more than 40 years, this growth retardant is still the most-widely used PGR in cereal production, particularly in wheat, triticale, and oats. Together with uses in other crop plants, it is, in terms of treated area, the number one PGR on a global scale.

Several other PGRs have, since, been introduced for stem stabilization and lodging control in small grains (Table 2). The quaternary ammonium compounds chlormequat chloride and mepiquat chloride are inhibitors of early stages of gibberellin biosynthesis, whereas trinexapac-ethyl and prohexadione-Ca block later stages (Rademacher, 2000). In addition to these inhibitors of gibberellin biosynthesis, ethephon is also of relevance as a stem stabilizer, particularly for use in barley. However, as an ethylene-releasing compound, ethephon has to be used with caution if there is risk of drought or heat stress: Stress ethylene plus ethylene from ethephon may otherwise have a negative impact on seed set. In order to reduce this risk to some extent, ethephon is also available as a ready-mix with chlormequat chloride or mepiquat chloride. Combinations of chlormequat chloride or mepiquat chloride with trinexapac-ethyl or prohexadione-Ca, either by tank-mixing or by using ready-mix formulations, currently represent the best technical solutions for lodging control: Chlormequat chloride and mepiquat chloride act at relatively low temperatures and may be used early in the season. The onset of activity takes a while but lasts for a relatively long period of time. Complementing these compounds, trinexapac-ethyl and prohexadione-Ca act comparatively fast, but are relatively short-lived. Furthermore, they require somewhat higher temperatures for activity. The structures of the compounds used are shown in Fig. 4.

Having access to different anti-lodging products, European farmers pursue different strategies, which relate primarily to the targeted yield level. Dosages have to be adjusted to the respective lodging risk. For instance, Hanhart (2009) recommends three basic options for winter wheat grown in Germany (the chosen examples refer to an intermediate level of lodging risk):

(i) **A proven and cheap solution based entirely on chlormequat chloride**
Chlormequat chloride (e.g. as CycoCel®) is applied in spring at a dosage of 750 to 1000 g/ha of active ingredient, when plants are between growth stages 25 and 29 BBCH (Lancashire et al., 1991) (“five tillers detectable” to “end of tillering”). A second treatment with 250 to 500 g/ha of active ingredient follows between growth stages 30 and 31 (“beginning of stem elongation” and “first node at least 1 cm above tillering node”).

(ii) **An advanced solution based on chlormequat chloride and trinexapac-ethyl**
The first treatment is as in (i). For the second treatment, 25 to 75 g/ha of trinexapac-ethyl (Moddus®) are added to the same amount of chlormequat chloride as in (i). The second treatment is between growth stage 30 and 33 (“third node at least 2 cm above second node”).

(iii) **An advanced solution based on chlormequat chloride, mepiquat chloride and prohexadione-Ca**
Again, the first treatment is as in (i). For the second treatment [timing as in (ii)], the ready-mix product Medax® is applied at 150 to 180 g/ha of mepiquat chloride plus 25 to 30 g/ha of prohexadione-Ca.

When chloromequat chloride is applied between growth stages 21 (“beginning of tillering”) and 25 instead of using it between growth stages 25 and 29, it will, in addition to reducing stem length, increase the number of tillers. This can be of interest after winter losses of plants.

Barley is less responsive to chloromequat chloride and mepiquat chloride than wheat or rye and oats. Therefore, products containing ethephon, trinexapac-ethyl and prohexadione-Ca are primarily used to reduce the risk of lodging in this crop. Applying ethephon relatively late in the season [between growth stages 39 and 51 (“flag leaf stage” to “beginning of heading”)] does not only counteract lodging but also reduces the incidence of stem and ear brackling, which can be a major problem at harvest in a number of barley cultivars. Detailed recommendations for the use of PGRs in barley and also in rye and triticale under German growing conditions are given by Hanhart (2009).

![Chemical structures of compounds used in anti-lodging products in cereal production.](image)

Figure 4: Chemical structures of compounds used in anti-lodging products in cereal production.
Area- and value-wise, stem shortening in small grains (and in Japanese rice production) to reduce the risk of lodging is the main application of PGRs worldwide. It is estimated that some 30% of the global PGR sales (equaling approximately € 210 million) are represented by stem stabilizers (Rademacher, 2010). The usage of such products is general practice in countries with intense production of wheat, barley, rye, triticale, and oats such as France, Germany and Great Britain. For instance, 89% of the winter wheat, 76% of the winter barley, 67% of the oats, and 95% of the rye acreage have been treated with anti-lodging products in Great Britain in 2006 (Garthwaite et al., 2006). Another estimation from Great Britain indicates that lodging costs the British wheat industry about € 50 million per year (Berry, 1998). One may assume that these costs are even higher to date.

Table 2: Products in use for anti-lodging in cereal grain production (additional suppliers and further trade names may exist).

<table>
<thead>
<tr>
<th>Trade Name</th>
<th>Active Ingredient(s)</th>
<th>Basic Producer / Supplier</th>
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<tbody>
<tr>
<td>Cycocel® 750</td>
<td>750 g/l Chlormequat chloride</td>
<td>BASF</td>
</tr>
<tr>
<td>Camposan® Extra</td>
<td>660 g/l Ethephon</td>
<td>Bayer CropScience</td>
</tr>
<tr>
<td>Terpal®</td>
<td>305 g/l Mepiquat chloride + 155 g/l Ethephon</td>
<td>BASF</td>
</tr>
<tr>
<td>Moddus®</td>
<td>250 g/l Trinexapac-ethyl</td>
<td>Syngenta</td>
</tr>
<tr>
<td>Medax® (Canopy® in the UK)</td>
<td>300 g/l Mepiquat chloride + 50 g/l Prohexadione-Ca</td>
<td>BASF</td>
</tr>
</tbody>
</table>

Breeding for short-strawed varieties has only partly contributed to stem stabilization under production conditions targeted for high yield and quality. It is suggested that the optimum mature height of winter wheat in Great Britain is close to 80 cm. Shorter stems would have a negative impact on light interception, encourage leaf diseases and make harvesting more difficult (Flintham et al., 1997; Austin, 1999; Berry et al., 2004). Consequently, breeders are relying to a considerable extent on stem shortening “when needed” by means of PGRs. This is also reflected by the fact that on more than 60% of the area used for producing wheat, barley, rye, triticale or oats, the cultivars used are rated as “susceptible” to “very susceptible” to lodging in Germany (Anonymous, 2009). This situation is similar in other European countries.

CONCLUSIONS / OUTLOOK

Lodging is a serious problem, when wheat, barley, rye, triticale, and oats are produced at high levels of intensity. In spite of achievements made by breeding, the use of anti-lodging products is still indispensable to secure yield and quality. These PGRs allow for an active optimization of plant development and can be applied at adequate dosages “when needed”. The products currently available do not only reduce shoot length, thereby lowering the ear’s leverage. They also improve the mechanical properties of the stem. Intensified root growth, which is particularly induced by prohexadione-Ca, also adds to the standing ability of cereal plants. The latter effect is additionally of interest in situations of moderate drought stress, since it enables the plant to take up more water. It appears likely that stem stabilizers will also be introduced in areas of the USA, where high-intensity production of cereals is possible.
REFERENCES


(see also: http://www.bundessortenamt.de/internet30/fileadmin/Files/PDF/bsl-getreide_2009.pdf )


(see also: http://www.jki.bund.de/fileadmin/damuploads/_veroeff/bbch/BBCH-Skala_englisch.pdf )


