REVIEW

The chemical control of growth, development and yield in *Lolium perenne* grown for seed

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ABSTRACT

The perennial ryegrass crop is inherently a poor seed producer as it is selected by the breeder for its vegetative characteristics. The seed crop is subject to competition between vegetative and reproductive dry matter production, lodging, low seed set and retention. The crop is therefore well suited to chemical manipulation by growth regulators. This paper reviews the work carried out on growth regulators in ryegrass seed crops from 1976 to 1986 in the United Kingdom (UK), United States of America (USA) and New Zealand (NZ). The first part of the paper covers the effects of CCC, PP333 (Paclobutrazol), EL500 (Flurprimidol), RSW0411 and XE-1019 on seed yield. The second part reviews the effects of some of these chemicals on growth and development and the final section speculates on the possible future use and role of chemical manipulation in the ryegrass seed crop.

Additional index words: **perennial ryegrass, CCC, PP333, EL500, RSW0411, XE-1019, Paclobutrazol, Flurprimidol, Ancymidol, seed yield**

INTRODUCTION

The genetic nature of the ryegrass seed crop makes it a poor seed producer. For many years the breeder has concentrated on maximum production of digestible dry matter - seed production being only a means to an end. Consequently, most of the products of photosynthesis are stored in stems and leaves or used for the production of more vegetative tillers. The crop's survival depends more on its ability to produce a never-ending supply of new tillers than on its ability to produce seed. A ratio of straw to seed of 10 to 1 in some cultivars illustrates the problem. In modern cereal cultivars it is common to have ratios of 0.75 to 1.

Ryegrass seed crops produce a large number of rapidly elongating thin stems that usually lodge, often well before anthesis. The crop may become a thick mat of competing fertile and vegetative tillers laid in a flat tangled mass. The crop requires cross pollination mainly by wind in order to set seed and the lodged canopy imposes severe restraints on pollination, seed set, retention and development (Hebblethwaite et al., 1987; Hampton and Hebblethwaite, 1985a). To further complicate matters maturing seeds have low retention and are easily shed under adverse weather conditions.

The above problems have resulted in the crop being an ideal target for the chemical control of growth, development and yield. This paper reviews some of the work that has been carried out at the University of Nottingham and elsewhere over the last 15 years.

SEED YIELD

Early work (Zeigenbein, 1967; Hebblethwaite and Burbidge, 1976) examined the effects of chlorocholine chloride (CCC). This chemical had little effect on length of fertile tillers or lodging but seed yield was slightly increased in some years, possibly due to improved assimilate transfer to the seed (Hebblethwaite and Burbidge, 1976). Work at Oregon State University on perennial ryegrass cv. Linn found no significant effect following application of CCC. There was a slight reduction in lodging at spikelet emergence, but by anthesis no treatment differences were present (Young, Chilcote and Youngberg, 1984). More recent work in New Zealand (Hampton, 1986) has shown however that this chemical can significantly increase seed yield by increasing tiller survival.

Experiments from 1976 to 1978 (Wright and Hebblethwaite, 1979) were carried out using the growth retardant ancymidol. In all years this chemical increased seed yields by increasing the number of seeds per unit area, although this was associated with a delay in the onset of lodging in 1977 and 1978 only. Ancymidol also increased the percentage of total above-ground dry matter harvested as seed, which indicates that this growth regulant may alter the distribution of dry matter within the plant so as to favor the economic yield. This chemical has two disadvantages, the first being its very high cost, and secondly, it gradually loses its effectiveness and the crop is able to 'grow away'. Several applications are therefore usually needed for sufficient lodging control (Wright and Hebblethwaite, 1979).

In 1979 the chemical PP333 (paclobutrazol) was introduced and since then work has been carried out on ryegrasses and other species in the UK, USA and NZ.

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Table 1. The effect of PP333 at 1 or 2 kg a.i. ha^{-1} applied at double ridge, spikelet, or floret initiation on the final dry seed yield of perennial ryegrass at Sutton Bonington from 1979 to 1985.

		Yield t/ha^{-1}		
Year[a]	Cultivar	Nil	PP333	% increase
1979	S.24	1.9#[b]	2.9	52
1980	S.24	1.0#	1.4	40
	Morenne	0.9#	1.5	66
	Majestic	0.7#	1.1	57
	Royal	0.9#	1.6	78
1981	S.24	1.4+	1.8	28
	Morenne	1.5+	1.9	27
	Royal	1.4+	1.8	29
1982	S.24	1.1#	2.6	136
1983	S.24	1.5#	2.3	53
1984	S.24	1.3*	2.7	108
	Aurora	1.2+	1.4	17
	Frances	1.2*	1.9	58
	Talbot	1.2*	1.9	58
	Melle	1.3#	1.4	8
1985	Frances	1.4#	2.4	71
	Talbot	1.1#	1.5	36
	Melle	1.1#	1.4	27

[a]1979 to 1981 2 kg a.i. ha^{-1}; 1982 to 1985 1 kg a.i. ha^{-1}

[b]* Double ridge
Spikelet initiation
+ Floret initiation

Table 1 summarizes the final yield results of the highest response treatments for paclobutrazol for a range of cultivars from 1979 to 1985 at the University of Nottingham (Hebblethwaite and Wiltshire, 1987). Similar responses have been found by workers in Northern Ireland (Faulkner, 1981), the USA (Young, Chilcote and Youngberg, 1984; 1985) and NZ (Hampton et al., 1985).

In spite of the apparent success of the chemical there are problems. Firstly the chemical can produce variable results in some seasons and cultivars (Hampton et al., 1985; Barrett, 1986). Figure 1 summarizes the results of 44 experiments on differing soil types and cultivars carried out in the UK, NZ and the USA from 1979 to 1984. The line across the center of the figure is the mean yield of all the treatments in the experiment. The symbols above this line are the increases above the average yield and those below are the decreases below the average yield. These data show a wide variability of response. They also indicate that large yield increases are more likely at dose rates of above 3 l product ha^{-1} (0.75 kg a.i. ha^{-1}). At this rate and above, the second problem arises. The chemical is residual and some can remain in the soil to affect the next crop. At the 3 l rate the residual effects can last for about 12 months (Barrett, 1986; Hampton, 1987). The magnitude of this problem will depend on the following crop (Barrett, 1986; Hampton, 1987). If it is a second year grass seed, cereal or oilseed rape crop, the residual effects can be an advantage and in cereals may reduce the need for CCC or other growth regulators. However, yields of sugar beet and potatoes can be decreased (Barret, 1986). Commercial recommendation in the UK is to apply at a rate of 1.5 l product ha^{-1} (0.375 kg a.i. ha^{-1}) and at this rate residual effects are unlikely to be a problem. However, examination of figure 1 indicates that yield response is likely to be low in most years at this dose rate. However, rates of 0.5 kg a.i. ha^{-1} applied to perennial ryegrasses have resulted in good responses in yield in the USA (Young et al., 1984; Young et al., 1985) and rates of 0.75 kg a.i. ha^{-1} have been shown to decrease yield (Young et al., 1984).

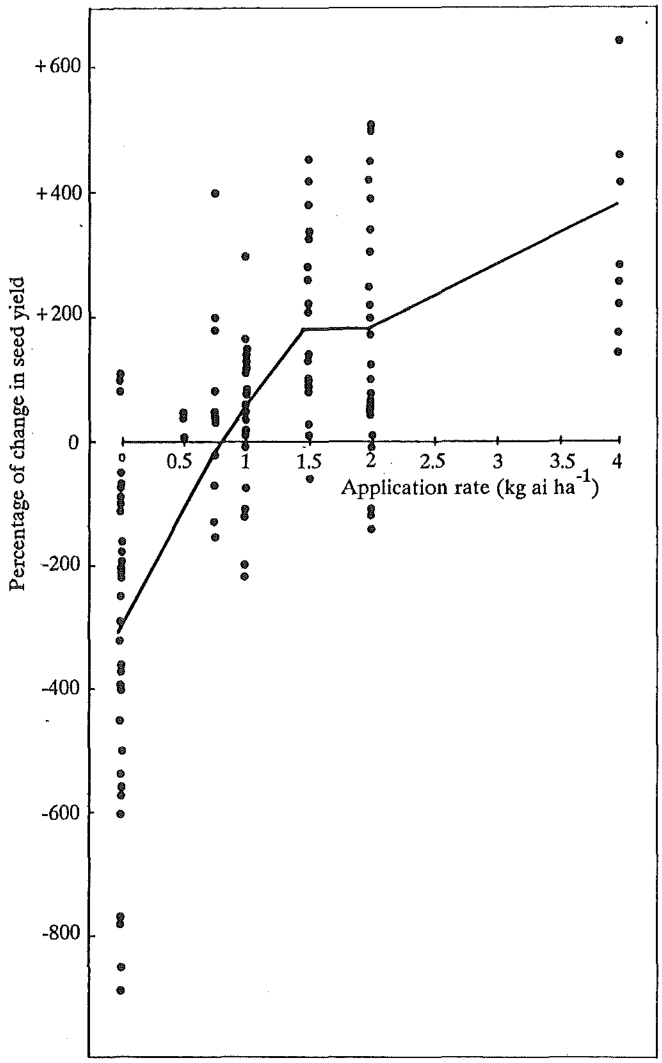

Figure 1. The increase and decrease in yield from the trial mean yield in plots sprayed with paclobutrazol from 44 experiments.

This compound is soil active (Shearing and Batch, 1982), and therefore requires adequate moisture in the upper part of the soil for uptake, xylem transport and seed yield increase (Hampton and Hebblethwaite, 1984a). Responses to late application (floret initiation) are therefore less likely under dry conditions (Hebblethwaite et al., 1982; Young et al., 1984; Barrett, 1986).

Paclobutrazol has fungicidal properties (Froggat et al., 1982; Hampton and Hebblethwaite, 1984a; 1985b), and consequently the chemical has been shown to reduce the level of infection by leaf pathogens, and slow down the rate of leaf tissue senescence (Hampton and Hebblethwaite, 1985b). The chemical can control powdery mildew (*Erysiphe graminis* DC) even when soil moisture levels are too low for root uptake, indicating that leaf uptake is adequate for fungicidal control (Hampton and Hebblethwaite, 1984a).

Work started in the early 1980s on the Eli Lilly compound flurprimidol (Chilcote et al., 1982; Hampton and Hebblethwaite, 1985c; Hebblethwaite et al., 1985). The mode of action of flurprimidol is similar to that of paclobutrazol, both being gibberellin inhibitors. For comparable effects on perennial ryegrass plant growth and seed yield, flurprimodol had to be applied at about double the active ingredient rate of that required for paclobutrazol (Hampton and Hebblethwaite, 1985c). Like paclobutrazol this chemical can be successfully applied from double ridge to floret initiation; however, lack of rain can decrease its effectiveness in some years if applied at floret initiation (Hebblethwaite et al., 1985).

Since 1984 two other growth regulators have been successfully used in ryegrass seed crops. The Chevron Chemical Company's experimental chemical XE-1019 (10% W.P.) increased yields of Linn and Caravelle perennial ryegrass (Young et al., 1984; 1985). In 1983 work started on the Bayer chemical RSW0411 at the University of Nottingham. This chemical is similar to paclobutrazol but is less residual. Results from this work have been promising (Barrett, 1986; Hebblethwaite and Wiltshire, 1987) and is reported elsewhere (Wiltshire et al., 1987).

SEED YIELD COMPONENTS

In the case of all growth regulators yield increases were a direct result of increases in seeds harvested per unit area. This response is either associated with increases in number of fertile tillers or seeds per spikelet (seed set) and consequently seeds per fertile tiller (Wright and Hebblethwaite, 1979; Hebblethwaite et al., 1982; Hampton and Hebblethwaite, 1985a; Chilcote et al., 1984; Hampton et al., 1985).

Fertile tiller number increases were due to greater fertile tiller production particularly where paclobutrazol was applied early (i.e. at or before spikelet initiation) and not to greater fertile tiller survival (Hampton and Hebblethwaite, 1985a). This is not surprising as this chemical is known to increase tillering by decreasing apical dominance (Froggatt et al., 1982).

The increase in the number of seeds per spikelet with paclobutrazol application was due to a decrease in the number of seeds aborted during seed development (Hampton and Hebblethwaite, 1985a; 1985d). In treated plants more seeds were retained at each spikelet position from the base to the ear apex. Furthermore, assimilate recovery was increased in the terminal section of the ear in treated plants compared to the control. There is increasing evidence that competition for supply of assimilate is the most important factor in determining seed numbers prior to the onset of seed shedding (Hampton and Hebblethwaite, 1985b; 1985d; Hampton et al., 1987).

Detailed discussion of possible reasons for these responses in seed yield components can be found elsewhere (Hampton et al., 1985; 1987).

GROWTH AND DEVELOPMENT

Crop development

Ancymidol was found to delay harvest date by about 2 days, but the dates of attainment of other developmental stages were unaffected (Wright and Hebblethwaite, 1979). Paclobutrazol applied at spikelet initiation delayed floret initiation, ear emergence and peak anthesis by 2-5 days, the time of delay being rate dependent. Seed maturity, as determined by seed moisture content at harvest, was also delayed (Hampton and Hebblethwaite, 1985a; Barrett, 1986).

Lodging and stem measurements.

Ancymidol, paclobutrazol and flurprimidol all delay or prevent lodging (Hebblethwaite et al., 1978; 1982; 1985; Wright and Hebblethwaite, 1979; Hampton and Hebblethwaite, 1985a; 1985c; Hampton et al., 1985; Barrett, 1986). In the latter two chemicals the extent of prevention can depend on dose rate (Hampton and Hebblethwaite, 1985a; 1985c; Hampton et al., 1985; Barrett, 1986), and timing (Hampton et al., 1985; Barrett, 1986; Hebblethwaite et al., 1985), lodging being less at higher rates and earlier dates of application. Delay and prevention of lodging is directly related to the chemical effect of decreasing and prevention of lodging is directly related to the chemical effect of decreasing stem length (Hebblethwaite et al., 1978; Hampton and Hebblethwaite, 1985a; 1985c). Paclobutrazol reduces the length of internodes and also increases the width and dry weight of the base of the stem (Hampton and Hebblethwaite, 1985a; Barrett, 1986).

Tiller production

Examination of tiller production data over time indicates that responses are not consistent. However, all growth retardants tend to increase vegetative tiller number prior to anthesis and decrease secondary vegetative tillers after anthesis in wet years (Hebblethwaite et al., 1978; Wright and Hebblethwaite, 1979; Hampton and Hebblethwaite, 1985a; 1985c; Barrett, 1986). Decreases in secondary vegetative tillering in paclobutrazol treated crops can be attributed to the increased ability of the ear and stem to compete for assimilates with vegetative tillers (Hampton and Hebblethwaite, 1986d). Sink activity of secondary vegetative tillers is reduced by paclobutrazol and this may even occur despite an increase in actual numbers (Clemence and Hebblethwaite, 1984; Hampton et al., 1987). Furthermore, in upright crops light penetration to vegetative tillers is reduced and these tillers would be less likely to survive (Ong, 1978).

Dry matter accumulation and distribution

The effects of growth retardants on dry matter accumulation are inconsistent (Wright and Hebblethwaite, 1979; Hebblethwaite et al., 1982; Hampton and Hebblethwaite, 1985a). In most cases no differences occur in dry matter accumulation of vegetative tillers, but in fertile tillers less dry matter is usually found in paclobutrazol-treated plots in harvests until the end of anthesis. This decrease is associated with lower levels of dry matter in the stems. No difference in dry matter of leaf and ear have been found. By final harvest total dry weights between treated and untreated plots were found to be the same (Hebblethwaite et al., 1982; Hebblethwaite and Hampton, 1985a). Data from soil cores have shown that dry matter accumulation of roots at all rooting depths in paclobutrazol treated plots was increased compared to the control (Hampton and Hebblethwaite, 1985a).

Photosynthetic area index (PAI)

Data regarding PAI are again variable, but paclobutrazol decreases PAI before ear emergence due to reductions in stem PAI. After anthesis, the chemical increases PAI because of increased fertile tiller leaf area. The chemical can also increase green area of the ear at final harvest and increase the leaf area duration of the crop (Hampton and Hebblethwaite, 1985a; Barrett, 1986).

THE FUTURE

In ryegrass seed production the age of chemical manipulation seems to be near. Paclobutrazol is already commercial and a number of new chemicals look promising.

An area which must be mentioned before completing this paper is that of multichemical use. GA_3 has been shown to increase apical dominance and therefore reduce excess vegetative tillering and paclobutrazol to reduce stem length (Hampton and Hebblethwaite, 1984c). At present we are also looking at chemicals that can reduce shattering and seed shedding particularly in chemically treated upright crops. A combination of all these chemicals would mean that growers could have completely upright crops consisting of fertile tillers only, that can be disease free and retain their seeds until final harvest. This approach is not too far distant from commercial reality. The speed at which it takes place will depend on the future development of chemicals and funding of research work for this minor crop.

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