Seed yield response of annual ryegrass to stem shortening plant growth regulators

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Abstract

Seed yield response of annual ryegrass was increased from 1,652 to 3,341 kg/ha following application of stem shortening plant growth regulators. Trinexapac-ethyl (TE) was applied at a single application timing in 200 g a.i./ha increments to 600 g, as split applications with double or triple splits with total applications of either 400 or 600 g a.i./ha, or with chlormequat chloride added to the TE. Split applications of 600 g TE did not increase (P<0.05) seed yield. The optimum TE rate was 389 g TE/ha. Seed yield was correlated with delayed lodging (R^2= 0.88) and stem length reduction (R^2=0.86). The seed yield response to TE (102% increase in seed yield) was higher than reported previously, possibly because the untreated control lodged earlier, before anthesis.

Additional keywords: chlormequat, trinexapac-ethyl, Moddus, *Lolium multiflorum*

Introduction

Trinexapac-ethyl (original trade name Moddus® and generic TE products) are widely used in perennial (*Lolium perenne* L.) and Italian/annual (*Lolium multiflorum* Lam.) ryegrass seed crops to delay lodging and enhance seed yields (Chynoweth *et al.*, 2014; Rolston *et al.*, 2016). In perennial ryegrass, seed yield response to TE has been attributed to delayed lodging (Rolston *et al.*, 2010) and the associated increase in light interception in the seed head and upper canopy. In Italian ryegrass, seed yields are increased by 20-50% with 200-400 g TE/ha (Rolston *et al.*, 2016; Trethewey *et al.*, 2016). A triple split application of TE (200 g/ha x 3 applications from Zadoks growth stage GS31) increased seed yield by 750 kg/ha compared with a single application of 600 g TE/ha (Rolston *et al.*, 2016). The response was highly correlated to stem shortening and delayed lodging. The research reported in this paper repeated the treatments used by Rolston *et al.* (2016) in a seed grower's field to determine if split TE applications and TE + chlormequat chloride (CCC, original trade name Cycocel®) enhanced seed yields. A secondary purpose was to determine if the response was a result of stem shortening or delayed lodging.

Materials and Methods

The trial was undertaken 6 km west of Ashburton (43°54'2"S; 171°40'15"E, 111 m above sea level) with the annual tetraploid ryegrass cv. 'Hogan'. The trial was sown on 30 March 2016 at 12.5 kg/ha in 15 cm rows. The soil type was a 'Mayfield silt loam' (Cox, 1978) and the trial site was regularly irrigated using a Roto-Rainer applying 40 mm at each application. All the inputs, except the plant growth regulator (PGR) treatments (trt), were managed by the grower.

Three applications of nitrogen were applied: 57.5 kg N/ha on 4 October, 92 kg N/ha on 2 November (closing) and 69 kg N/ha on 24 November giving a total applied N of 218.5 kg N/ha. The paddock was grazed with rising one year old heifers between 12 - 17 July; it was heavy rolled two days later. The paddock was mown for silage on 10 October and then grazed by 779 lambs between 28 October and 2 November. The fungicide programme consisted of Opus® (active ingredient (a.i.) 125 g epoxiconazole) applied at growth stage (GS) 32 (22 November) followed by an application of Proline® (a.i. 250 g/l prothioconazole) and Amistar® (a.i. 250 g/l azoxystrobin) applied at full ear emergence.

There were nine PGR treatments (Table 1), with four replicates in a randomised block design. The plot size was 3.33 m wide by 11 m long. Zadoks growth stages were used to determine the application dates of the PGR trials (Zadoks *et al*., 1974). TE equivalents (g/ha) were calculated by adding the a.i. weight of TE and for CCC 750 g a.i. (1 l/ha) was equated to 50 g TE, to enable a comparison of rates between different PGR active ingredients and trial treatments.

Assessments

Reproductive stem length was measured on 14 December. Lodging percentage was visually assessed (0 = nil lodging; 100 = crop lying horizontal to the ground) starting eight days before anthesis on 14 December with weekly scoring until 19 January. From this the days from anthesis (22 December) to 50% lodging (DL50) were calculated. Pre-harvest mass (dry matter) and head density were assessed from a 0.25 m^2 quadrant cut on 23 January. Spikelet numbers from the same sample were counted on 15 heads per plot.

Harvest

The plots were windrowed on 30 January using a small plot windrower cutting an area 1.65 m wide by 11 m in length. Harvest occurred on 5 February using a 'Sampo' plot combine harvester at a seed moisture content of approximately 13%. From the field dressed seed sample, a 150 g subsample was cleaned using a screen cleaner to remove light seed and inert matter. Thousand seed weight (TSW) was assessed on 100 seeds per plot weighed to 3 decimal places. Previous trials showed no significant difference in seed moisture contents and purity, thus no adjustments are made for these variables (Rolston *et al*., 2016).

Data analysis used Genstat version 18 (VSN International Ltd, UK) for ANOVA statistical analysis with means separation using the least significant difference (LSD) test.

Results

Seed Yield

The trial machine dressed average yield was 2,810 kg/ha. Seed yield increased ($P<0.001$) from 1,652 kg/ha in the untreated control to 3,327 and 3,341 kg/ha for triple split applications of 600 g TE/ha and 600 g TE/ha plus 1,500 g/ha CCC respectively (Table 1). This is an increase of 101% and 102% over the untreated control. However, these treatments were similar ($P<0.001$) to other treatments applying similar TE quantities at single and double applications. On average the PGR treatments increased seed yields by 1,305 kg/ha, a 79% increase over the untreated control. Adding chlormequat to the TE treatments (#9) or applying split applications did not increase seed yield. However when 400 g TE/ha was split into three applications (#6), 200 g TE/ha at GS31 and 100 g TE/ha at GS32 and GS33 the yields decreased from 2,974 to 2,490 kg/ha compared with a single application (#3). Seed yields from a single application of TE gave a linear plateau response with a breakpoint of 389 g TE/ha (Figure 1) where seed yield increased by 331 kg/100 g TE/ha.

Table 1: Seed yield of annual ryegrass cv. 'Hogan' following treatment with nine plant growth regulator treatments (g a.i./ha) applied at up to three Zadoks growth stages (GS) when grown near Ashburton, Canterbury, New Zealandin the 2016/2017 growing season.

Trt #	GS31 14-Nov	GS32 22-Nov	GS33 30-Nov	TE equiv[1] (g/ha)	Seed yield (kg/ha)	Harvest index (%)
1	0	0	0	0	1652	13.0
2	0	200 TE	0	200	2358	16.2
3	0	400 TE	0	400	2974	25.8
4	0	600 TE	0	600	3072	21.2
5	300 TE	300 TE	0	600	3158	22.4
6	200 TE	100 TE	100 TE	400	2490	18.2
7	200 TE	200 TE	200 TE	600	3327	22.8
8	200 TE	200 TE	0	400	2934	20.6
9	200 TE+1500 CCC	200 TE+1500 CCC	200 TE	800	3341	23.7
				Average	2812	20.39
				$LSD_{0.05}$	401	5.91
				P-value	<0.001	0.004

TE = Moddus®(trinexapac-ethyl 250 g/l); CCC = Cycocel (chlormequat chloride 750 g/l)
[1]750g CCC = 50 g TE
GS31 = First node detectable; GS32 = Second node detectable; GS33 = Third node detectable

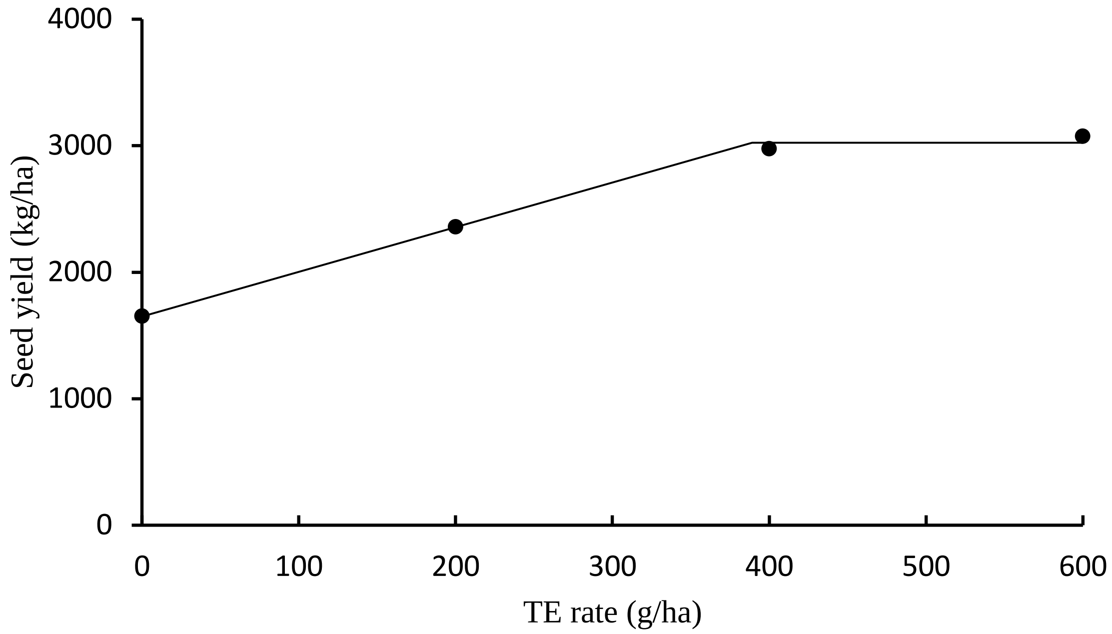

Figure 1: Seed yield response of annual ryegrass cv. 'Hogan' to single application treatments of trinexapac-ethyl (TE) applied at GS 32 grown near Ashburton, Canterbury, New Zealand in the 2016/2017 growing season.

Crop height and lodging

Increasing rates of PGR reduced stem lengths and delayed lodging (Table 2). Seed yield increased by 52.1 kg/ha for each 1 cm in stem reduction (Figure 2). The reduction in stem length with increasing PGR rates was 4.2 cm per 100 g of TE (data not presented). Increasing the PGR rate increased ($P<0.001$) the days to 50% lodging from 4 days before anthesis to 30 days after the start of anthesis (Table 2), each 100 g TE/ha delaying lodging by 5.6 days (Figure 3). For each day's delay in reaching 50% lodging, seed yield increased by an extra 56 kg/ha. There was a strong relationship (R^2=0.96) between reduced stem length and delayed lodging ($y = -0.9712x + 85.785$).

Harvest mass and components of yield

The PGR treatments had no effect ($P<0.05$) on harvest mass (average 13,910 kg DM/ha), seed head density (average 1,030 heads/m^2) and spikelets per head (average 22.3/head). PGRs increased the total amount of seeds per m^2 and seeds per spikelet. The seeds per m^2 increased from 35,338 to 81,026 when comparing the untreated control treatment (#1) with the highest yielding split rate treatment with Cycocel (#9) (Table 3). Number of seeds/m^2 was highly correlated (R^2=0.99) to seed yield (y = 37.328*seed count + 376,854). The number of seeds per spikelet increased form 1.91 seeds for the untreated control to between 2.11 and 3.89 for the PGR treatments and was also correlated (R^2=0.72) to seed yield (y = 831,056*seeds/spikelet + 338,033).

Table 2: Influence of nine plant growth regulator treatments applied at up to three Zadoks growth stages (GS) on reproductive stem length and days to 50% lodging after anthesis of annual ryegrass cv. 'Hogan' grown near Ashburton, Canterbury, New Zealand in the 2016/2017 season.

Trt #	GS31 14-Nov	GS32 22-Nov	GS33 30-Nov	Stem length (cm)	Days to 50% lodging
1	0	0	0	89	-4
2	0	200TE	0	77	13
3	0	400TE	0	70	22
4	0	600TE	0	63	23
5	300TE	300TE	0	68	20
6	200TE	100TE	100TE	74	15
7	200TE	200TE	200TE	62	26
8	200TE	200TE	0	74	15
9	200TE+1500 CCC	200TE+1500 CCC	200TE	55	30
			$LSD_{0.05}$	6	5
			P-value	<0.001	<0.001

GS31 = First node detectable; GS32 = Second node detectable; GS33 = Third node detectable

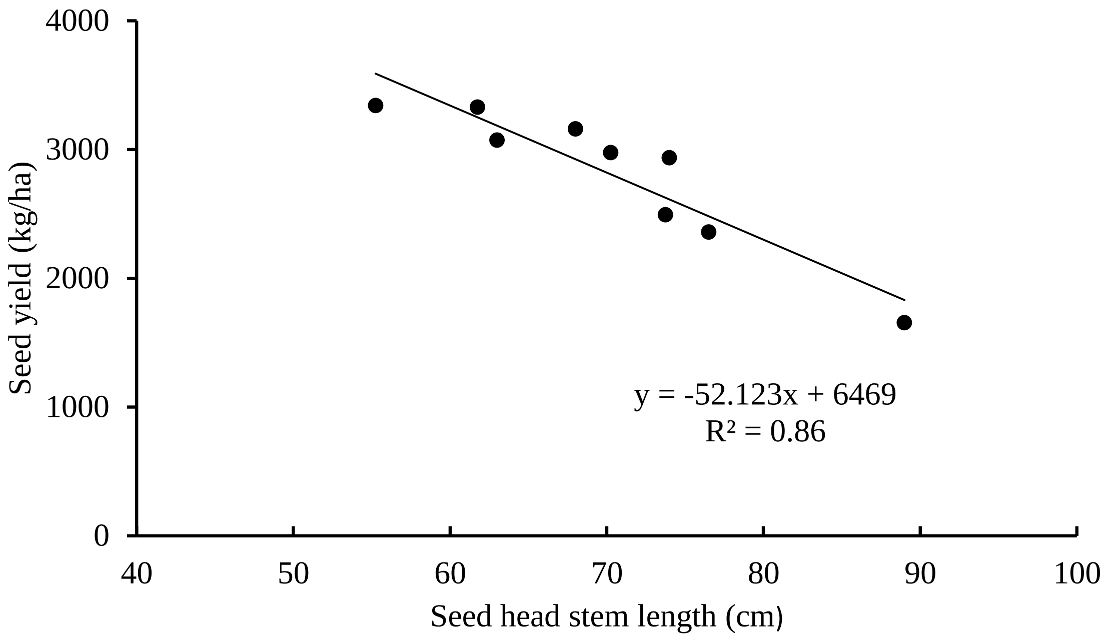

Figure 2: Relationship between seed yield and reproductive stem length for annual ryegrass cv. 'Hogan' when treated with nine plant growth regulator treatments in the 2016/2017 season grown near Ashburton, Canterbury, New Zealand.

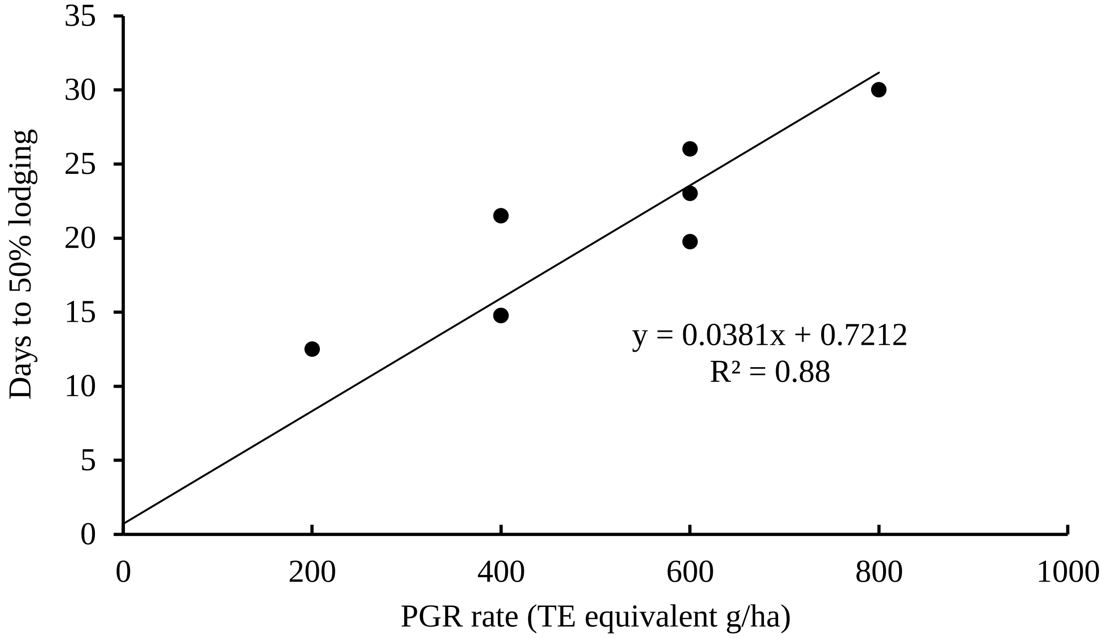

Figure 3: Relationship between PGR rates expressed as g TE equivalent and days to 50% lodging for annual ryegrass cv. 'Hogan' grown near Ashburton, Canterbury, New Zealand in the 2016/2017 season.

Table 3: Number of seeds per area (m^2), seeds per spikelet and thousand seed weight (TSW) for annual ryegrass cv. 'Hogan' when treated with nine plant growth regulator treatments applied at up to three Zadoks growth stages (GS) when grown near Ashburton, Canterbury, New Zealand in the 2016/2017 growing season.

Trt #	GS31 14-Nov	GS32 22-Nov	GS33 30-Nov	Seed count (000' m^2)	TSW (g)	Seeds (/spikelet)
1	0	0	0	35.3	4.69	1.91
2	0	200TE	0	53.2	4.44	2.05
3	0	400TE	0	70.5	4.24	3.17
4	0	600TE	0	71.7	4.30	2.76
5	300TE	300TE	0	74.6	4.24	3.89
6	200TE	100TE	100TE	54.7	4.54	2.03
7	200TE	200TE	200TE	78.3	4.26	3.23
8	200TE	200TE	0	67.7	4.35	3.25
9	200TE+1500CCC	200TE+1500CCC	200TE	81.0	4.12	3.39
			$LSD_{0.05}$	10.5	0.32	0.99
			P-value	0.001	0.039	0.003

GS31 = First node detectable; GS32 = Second node detectable; GS33 = Third node detectable

Harvest index was increased (P<0.01) by PGR application from 13% in the untreated control to ~23% in the highest yielding treatments as a result of increased seeds/m^2 and conservative DM production between treatments.

PGR decreased the TSW from 4.69 g for the untreated control to 4.12 g for the triple split application with Cycocel. There was also a high correlation (R^2=0.90) to seed yield (y = -2966.9*TSW + 15723).

Discussion

Seed yield was increased by up to 102% above the untreated control when multiple applications of PGR were applied to Italian ryegrass cv. 'Hogan' in New Zealand (Table 1). The increase in seed yield resulted from an increase in the number of seeds per spikelet, harvested seeds/m^2 and an associated increase in harvest index (Tables 1 and 3). These results are similar to those presented by Trethewey *et al*. (2016), for Italian ryegrass grown in New Zealand. Trethewey *et al*. (2016) showed an increase of 72% in harvested seeds/m^2 compared with the untreated control when 400 g TE/ha was applied. The increase was associated with an increased number of seeds/spikelet and increased harvest index. Remaining harvest components were similar with the exception of TSW which decreased as seed yield increased, a result not supported by Rolston *et al*. (2016). The seed head number of 1,030 heads/m^2 was lower than reported by Rolston *et al.* (2016) (1,270 heads/m^2) suggesting in this trial the November closing date may have removed some developing seed heads. The lower head number resulted in a higher number of seeds/spikelet, 2.65 compared with 2.23 seeds/spikelet for Rolston *et al.* (2016), required to optimise seed yield. The increase in harvest index was highly correlated with seed yield (R^2=0.83) suggesting the shorter stems and delayed lodging created better carbohydrate partitioning to the seed.

The seed yield increase reported here is higher than the results reported by Rolston *et al.* (2016) and Trethewey *et al.* (2016) who showed increases of 51-65% with the use of up to 800 g TE/ha. However the optimum yields are similar between this study and that of Rolston *et al.* (2016) and the large yield response can be attributed to the low seed yield in the untreated control plots in this trial (1,652 kg/ha) compared with the Rolston *et al.* (2016) trial (2,280 kg/ha). The optimum application rate, for a single application, was 389 g TE/ha (Figure 1) which equated to a seed yield of 3,023 kg/ha, an 83% increase in yield compared with the untreated control. The low seed yield in the untreated plots is likely a result of early lodging seen in this trial (Table 2). This may have been initiated by a rainfall event that the untreated control never recovered from (approximately 25 mm of rain fell on 11-12 December prior to both anthesis and the first lodging score). Secondly, a frost occurred on 7 January which could have affected those plots which were more heavily lodged where cold air 'sinks' into the lower areas.

Splitting the 600 g TE/ha rate into two even splits and three even splits increased the yield by 86 and 255 kg of seed/ha respectively (Table 1). Although the increase was not statistically significant in this trial, Rolston *et al*. (2016) reported an extra 750 kg seed/ha (LSD=410). If averaged over the two years this would equate to an extra $804/ha of seed revenue given a price of $1.60/kg of seed. Dry matter cuts at closing and at GS-32 were not taken but it is hypothesised that the high

DM accumulation rates of Italian ryegrass during early summer is the reason that there may be an advantage of splitting the application rates (Chynoweth *et al*., 2014). However, at the lower rates TE applied at the early stem extension stage may be insufficient to reduce stem length and reduce lodging. Further research should be carried out to confirm the possible trend in the difference in yields when splitting the applications of TE.

The results from this trial support those of Rolston *et al*. (2016) suggesting there is no benefit of adding Cycocel to increase yield although the stem length was significantly shorter than the other treatments (Table 3). The same treatment also had significantly less lodging than any other treatment suggesting another factor limiting yield.

Conclusion

Seed yield of annual ryegrass was increased by the application of TE through the production of more harvested seeds/m^2. Stem shortening, delayed lodging and a greater harvest index are the main drivers of the increase in seed yield. This is the second trial looking at whether split applications of TE in annual ryegrass increased seed yield above single applications. This trial suggests a single application is adequate compared with Rolston *et al.* (2016) who showed an increase of 750 kg/ha when TE was applied in three applications each of 200 g/ha. Further work is required to identify if there is a consistent benefit from split applications of TE compared with single applications of TE for increasing seed yield of annual ryegrass.

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