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Performance of trinexapac-ethyl on *Lolium perenne* seed crops in diverse lodging environments

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ABSTRACT

Application of trinexapac-ethyl (TE) plant growth regulator (PGR) for lodging control in perennial ryegrass (*Lolium perenne* L.) is a widespread practice, but information on how this PGR increases yield is limited. The objective of this study was to determine how TE application rate and timing influences seed productivity over nine diverse lodging environments in Oregon's Willamette Valley. Four field trials were conducted to examine TE effects on seed yield and yield components. Stem length, a key factor in lodging control, was reduced incrementally with increasing rate of TE to a maximum of 28%. TE consistently reduced lodging but had no effect on the seed yield components spikes m^{-2}, spikelets $spike^{-1}$, and florets $spikelet^{-1}$. Over environments, TE increased seed yield by an average 43% over the untreated control at 400 g ai ha^{-1} TE. Best seed yield results across environments were attained with TE applied between BBCH 32 and 51. The number of seeds $spikelet^{-1}$, seed mass $spikelet^{-1}$, and seed set were increased by TE. TE-induced seed yield increases were attributable to increased seed number m^{-2} and improved seed set, but not seed weight. A better understanding of TE-induced seed yield increases will aid in improving use efficiency and economy of this important PGR.

1. Introduction

Production of perennial ryegrass turf and forage seed crops is an important economic enterprise in several countries including the USA, New Zealand, Denmark, Australia, and others. Under certain growing conditions, especially when high soil moisture from either excessive rainfall or from irrigation is accompanied by high N availability, the structure of the culm cannot support the increasing weight of the developing spike and seed. As a result, the tiller together with the spike that it supports lodges or falls to the ground under its own weight. Lodging affects pollination and seed development in perennial ryegrass and consequently, seed yield is reduced (Hebblethwaite et al., 1978). Seed number but not seed weight was affected by lodging because the number of seeds produced per spikelet was reduced in lodged perennial ryegrass. Lodging was also found to reduce seed yield in perennial ryegrass as a result of reduced seed number (Griffith, 2000), but unlike the findings of Hebblethwaite et al. (1978), seed weight was increased by lodging.

Trinexapac-ethyl [4-(cyclopropyl-α-hydroxymethylene)-3,5-dioxo-cyclohexanecarboxylic acid ethylester] (TE) is an acylcyclohexanedione inhibitor of the 3β-hydroxylation of gibberellic acid and has been shown to reduce stem length in *Lolium* spp. (Evans et al., 1994; King et al., 2004). Trinexapac-ethyl has been developed as a plant growth regulator and has been widely adopted for use as a lodging control agent in forage and turf grass seed production (Silberstein et al., 2000; Zapiola et al., 2006; Rolston et al., 2010). Borm and van den Berg (2008) and Rolston et al. (2010) also showed that culm length reductions by TE treatment and the reduction in lodging resulted in increased seed yield in perennial ryegrass. Though widely used, a better understanding of how TE applications affect seed yield and yield characteristics in perennial ryegrass would allow for greater use efficiency and economy. Knowledge of TE application rates and timings across diverse environments is incomplete at this time.

Seed yield components of perennial ryegrass such as spikes m^{-2}, spikelets $spike^{-1}$, and florets $spikelet^{-1}$ have been unaffected by applications of TE (Silberstein et al., 2000; Rolston et al., 2010). Chynoweth et al. (2010) reported more spikes m^{-2} following TE application, but this response was presumably due to increased survival rather than more spikes produced. Seed weight was also not affected by TE treatment in perennial ryegrass (Silberstein et al., 2000; Borm and van den Berg, 2008; Rolston et al., 2010).

Other management practices might interact with TE application. Zapiola et al. (2006) found that a combination of TE and open-field burning of crop residues produced the highest seed yield in strong creeping red fescue (*Festuca rubra* L. subsp. *rubra*). Partitioning of dry matter in the crop canopy was manipulated by this combination of residue removal practices after the previous seed harvest

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Abbreviations: TE, trinexapac-ethyl; HI, harvest index; PGR, plant growth regulator; BBCH, Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie.

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Table 1
Cultivars, crop stand age, and nine April–June lodging environments examined in trinexapac-ethyl PGR trials in perennial ryegrass seed production. Mean rainfall and temperatures used to characterize the nine different lodging environments are compared to the 122-year mean for Corvallis Oregon.

Trial	Harvest year	Cultivar	Stand age (year)	Rainfall (% of mean)	Temperature (°C)	
					Mean	Departure
1	1998	Affinity	4th	148	12.8	−0.3
	1998	Buccaneer	4th	148	12.8	−0.3
2	1999	Cutter	1st	67	12.0	−1.1
	2000	Cutter	2nd	100	13.7	0.6
	2001	Cutter	3rd	94	12.3	−0.8
	2002	Cutter	4th	82	12.8	−0.3
3	2001	Cutter	1st	94	12.3	−0.8
	2002	Cutter	2nd	82	12.8	−0.3
	2003	Cutter	3rd	140	13.4	0.3
4	2010	Evening shade	1st	179	12.0	−1.1
	2011	Evening shade	2nd	151	11.7	−1.4
	2012	Evening shade	3rd	163	13.0	−0.1

and application of TE in the following spring resulted in significant increases in HI. Other management practice and TE interactions reported include closing date in perennial and Italian ryegrasses (*Lolium multiflorum* Lam.), and nitrogen application (Rolston et al., 2007; Chynoweth et al., 2010; Rolston et al., 2012).

Position of the seed within the inflorescence has been shown to be an important consideration in seed development in perennial ryegrass. Warringa et al. (1998) found that seed produced in central and distal positions within the spikelet of perennial ryegrass had 26% and 62%, respectively, lower seed weight than seed produced in proximal positions. Differences in seed weight among seed positions within the spikelet were in part accounted for by lower rates of seed growth and lower duration of seed filling in the central and distal seed positions. But differences in the initial weights of ovules at anthesis were an additional underlying cause of seed weight differences among seed produced in the various positions within the spikelet.

Since the studies to date suggest that seed yield has not been influenced by TE through seed yield components of perennial ryegrass in a conventional manner, further investigation of this phenomenon is warranted, particularly with regard to the various seed positions within the inflorescence. There is no information on possible differential effects of TE on the expression of seed yield components in the various morphological seed positions within the spike or spikelet. The objective of this study was to determine how TE application rate and timing influences seed productivity over nine diverse lodging environments in Oregon's Willamette Valley.

2. Materials and methods

2.1. Experimental design and plot maintenance

Four field trials were conducted at Hyslop Crop Science Research Farm near Corvallis, Oregon, to characterize the effects of TE on seed yield and yield components of perennial ryegrass (Table 1). Trial 1 was conducted in a single harvest year, 1998; Trial 2 was conducted from 1999 until 2002; Trial 3 was conducted from 2000 until 2003; and Trial 4 was conducted from 2010 until 2012. The soil at the site is a Woodburn silt loam (fine-silty, mixed, mesic, Aquultic Argixeroll).

Crop management was based on common production practices for perennial ryegrass seed production in Oregon's Willamette Valley. Development stages of the perennial ryegrass seed crops in relation to management practices and experimental treatments were characterized by using the BBCH scale (Hess et al., 1997). All trials were sown in October at rate of 5.6 kg ha^{-1} by using an eight-row plot-sized drill with 30-cm spaced rows. A pre-plant application of fertilizer (16-20-0) was made at a rate of 224 kg ha^{-1} during seedbed preparation. Applications of 45 kg N ha^{-1} (applied as 16-20-0) were made in October of each crop year on established crops (BBCH 20–29). Spring nitrogen needs were met by splitting applications over two dates during March prior to stem elongation (no later than BBCH 29) in each of the years for a total N rate of 180 kg N ha^{-1} (applied as 33-0-0-12).

The experimental design in each trial of the four trials was a randomized complete block with four replications. Plots in each trial were 3 m × 30 m. Three rates of TE and an untreated control were examined in the trials: 0, 200, 400, and 600 g ai ha^{-1}. The PGR was applied by using a bicycle-type boom sprayer operated at 138 kPa with XR Teejet 8003VS nozzles. The spray volume used in the PGR applications was 194 L ha^{-1}. The effect of TE timing was tested with applications made at the following 5 stages of crop development: BBCH 29 (pre-node), BBCH 32 (2 nodes), BBCH 37 (initial flag leaf emergence), BBCH 51 (spikes 10% emerged), and BBCH 59 (spikes fully emerged).

2.2. Canopy modification and lodging

Above-ground biomass was determined on two crop rows hand harvested at peak anthesis (BBCH 65) in 30-cm^2 quadrats and oven-dried at 65 °C for 48 h in all 4 trials. Stem length reduction by TE was determined by comparing the untreated control with TE-treated plots on samples taken at the same time as biomass. Lodging severity was assessed during late anthesis (BBCH 69) on a five-point scale (Young et al., 1999) where 1 = not lodged (fully upright) and 5 = most severe lodging (horizontal).

2.3. Spikes m^{-2}

Spikes m^{-2} was determined in all 4 trials. Two samples were taken from each plot in Trials 1, 2, and 4 and eight samples were taken from each plot in Trial 3 at ground level using a 30-cm^2 quadrat at the onset of anthesis (BBCH 60). The number of spikes in each sample was recorded and used to determine spikes m^{-2}.

2.4. Seed yield components

The number of spikelets spike^{-1} and florets spikelet^{-1}, and spike length were determined in the 4th-year stand of Trial 2 and in every year of Trial 3 for the control and the 400 g ai ha^{-1} rate. Ten spikes were collected near peak anthesis (BBCH 65) from each plot in Trial 2 and sixty spikes in Trial 3. Spikes were frozen at −15 °C before analysis. The number of spikelets spike^{-1} was counted and the length of the spike was recorded. Paired spikelets were selected