Seed Yield Response of Perennial Ryegrass to Spring Applied Nitrogen at Different Rates of Paclobutrazol

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ABSTRACT

Seed yield response of perennial ryegrass (*Lolium perenne* L.) to high rates of spring-applied nitrogen (N) is limited primarily because of increased lodging. The effects of increased N rates when applied at spikelet initiation, in combination with different rates of the growth retardant paclobutrazol applied at floret initiation, on seed yield and seed yield components of perennial ryegrass cv. Pennfine were investigated in two experiments during 1983-1985. Increasing N rates above 60 kg ha^{-1} did not affect seed yield at 0 and 0.50 kg a.i. paclobutrazol ha^{-1}. At 0.75 kg a.i paclobutrazol ha^{-1}, however, seed yield increased by about 35% in both years when N rate was increased from 60 to 120 kg ha^{-1}. Increasing N rate above 120 kg ha^{-1} did not increase the seed yield even when 0.75 kg a.i. paclobutrazol ha^{-1} was applied. Averaged between years, application of 0.75 kg a.i paclobutrazol ha^{-1} increased seed yield 92% when 60 kg N ha^{-1} was applied and 124% when 120 kg N ha^{-1} was applied. Lodging data suggested that 0.75 kg a.i. paclobutrazol ha^{-1} may not be sufficient to reduce lodging to the extent necessary to ensure maximum seed yield under growing conditions that stimulate severe lodging. The yield component most affected by N rates depended on the rates of paclobutrazol applied. In the absence of paclobutrazol, increasing N rates did not affect the number of fertile tillers at anthesis or spikes at maturity, whereas these yield components showed progressively greater response to increased N rates as the rate of applied paclobutrazol was increased. Regardless of paclobutrazol rate, N increased the number of florets per spikelet, but had no effect, or decreased, the number of seeds per spike. Conversely, paclobutrazol application primarily increased the seed yield through increases in the number of seeds per spike.

***Additional index words*: *Lolium perenne*, growth regulators, PP 333, seed yield components.**

INTRODUCTION

Spring nitrogen (N) application in perennial ryegrass seed crops is a common practice to maximize seed yield. Grasses, however, have been selected primarily for leafiness and tillering capacity that contribute to their value for forage and turf production, but make them vulnerable to lodging at N rates required to maximize seed yield (Griffiths, Lewis and Bean, 1980). Seed yield responses of perennial ryegrass to spring N rates in excess of 100 kg ha^{-1} are usually limited, primarily because of increased lodging or increased development of new vegetative tillers after reproductive growth is started, which result in low seed set (Hebblethwaite and Ivins, 1977; Nordestgaard, 1980; Hebblethwaite, Hampton and McLaren, 1982; Hampton, Clemence and Hebblethwaite, 1983; Hampton and Hebblethwaite, 1985a). On the other hand, it is well established that paclobutrazol applied at early stages of reproductive development reduces plant height and lodging in perennial ryegrass, and also decreases production of secondary vegetative tillers (Hebblethwaite *et al.*, 1982; Hampton and Hebblethwaite, 1984; Hampton and Hebblethwaite, 1985a).

Few studies have investigated combined effects of spring-applied N and paclobutrazol on perennial ryegrass seed yield. Hampton *et al.* (1983) investigated the influence of N rates and paclobutrazol on perennial ryegrass and reported seed yield was increased by the same amount in paclobutrazol treated plots regardless of N levels when compared to untreated plots at the same N rate. They concluded that failure to increase seed yield at high N rates was not because of lodging that results in poor pollination, but was because of seed abortion as a result of competition for assimilate supply by secondary vegetative tillers. Albeke, Chilcote and Youngberg (1983) investigated the effect of paclobutrazol under different spring N levels in fine fescue (*Festuca rubra* L.) and found that paclobutrazol increased potential yield at higher N rates, and increased seed yield at all N rates.

We recently reported (Young, Chilcote and Youngberg, 1995a) that in western Oregon the seed yield of perennial ryegrass cv. Pennfine did not respond positively to spring N rates higher than 60 kg ha^{-1} in years when the crop was prone to lodging. We also found that paclobutrazol applied at early stages of reproductive development reduced lodging and significantly increased the seed yield of this cultivar (Young *et al.*, 1995b). In this paper we report the effect of N rates when applied at spikelet initiation, combined with different rates of paclobutrazol applied at floret initiation, on cv. Pennfine seed yield and yield components. The objectives were to determine (i) whether seed yield of perennial ryegrass cv. Pennfine would respond to higher rates of spring applied N when followed by paclobutrazol application, and (ii) identify the yield components most affected by N and paclobutrazol.

MATERIALS AND METHODS

Two experiments were conducted at the Oregon State University Hyslop Crop Science Field Laboratory (about

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45°N) using the cultivar Pennfine. The soil type was a Woodburn silt-loam (fine-silty, mixed, mesic Aquultic Argixerolls). Detailed experimental procedures including growth stage determination, yield component measurement technique, lodging estimates, and harvesting procedure used in both experiments have been reported elsewhere (Young *et al.*, 1995b).

Experiment I

After one year of fallow, perennial ryegrass cv. Pennfine was planted in October 1981 at 6.0 kg ha^{-1} in rows 0.3 m apart. Forty eight kg ha^{-1} N, 60 kg ha^{-1} P, and 45 kg ha^{-1} S as ammonium phosphate-sulphate fertilizer were incorporated during seedbed preparation. Standard cultural practices during the establishment year included a late-January application of a tank mix of 2,4-D [(2,4-dichlorophenoxy) acetic acid] low volatile ester at 0.56 kg a.i. ha^{-1} plus dicamba (3,6-dichloro- 2-methoxybenzoic acid) at 0.28 kg a.i. ha^{-1}. In early-July the stand was flail chopped to a height of 0.1 m to remove any reproductive tillers, and stubble residue was removed in late-August using a close-clipping technique described by Young, Youngberg and Chilcote (1984).

Treatments were a factorial arrangement of three rates of N applied at the spikelet initiation stage, and three rates of paclobutrazol applied at the floret initiation stage. Nitrogen rates were 60 (N_{60}), 120 (N_{120}), and 180 (N_{180}) kg ha^{-1}, and paclobutrazol rates were 0 ($P_{0.0}$), 0.50 ($P_{0.50}$), or 0.75 ($P_{0.75}$) kg a.i. ha^{-1}. Treatments were arranged in a randomized complete block and were replicated six times. Plot size was 2.5 x 6.0 m. The experiment was conducted during the second (1982-83) and the third (1983-84) crop years, using the same randomization. In the autumn of 1983, we saw no residual effects in plots where paclobutrazol was applied during the previous spring. Also, perennial ryegrass is a good scavenger of soil N and residual N in perennial ryegrass fields in Oregon is negligible (Horneck, Young and Hart, 1992).

Cultural practices during the 1982-83 and 1983-84 crop years included applications of atrazine (6-chloro-N-ethyl-N-(1-methylethyl)-1,3,5-triazine-2,4-diamine) at 1.35 kg a.i. ha^{-1} in mid-October, and 48 kg ha^{-1} N, 60 kg ha^{-1} P, and 45 kg ha^{-1} S as ammonium phosphate-sulphate fertilizer in late-October. In addition, a tank mix of 2,4-D low volatile ester at 0.56 kg a.i. ha^{-1} plus dicamba at 0.28 kg a.i. ha^{-1} was applied in mid-February. Propiconazole fungicide (1-[[2-(2,4dichlorophenyl)-4-propyl-1,3-dioxolan -2-yl]methyl]-H1,2,4-triazole) was applied at 0.126 kg a.i. ha^{-1} to control rust (*Puccinia* spp.) when needed.

Plots were harvested at about 35% seed moisture content using a small plot harvester. Bagged plant material was air-dried, threshed, cleaned, and weighed. Straw residue was removed with a flail chopper immediately following seed harvest in each year, and the stubble was burned with a propane flamer (Chilcote and Youngberg, 1975) to simulate open field burning. Analysis of variance was performed and the main effects of N and paclobutrazol rates applied, and their interactions were tested. Fisher's protected LSD values were calculated to compare mean values for the main effects.

Experiment II

A second experiment was conducted during the 1983-84 and 1984-85 crop years, again using cv. Pennfine that was established in the autumn of 1981 as described in Experiment I. Therefore, treatments were applied on the third (1983-84) and the fourth (1984-85) crop years. Cultural practices were the same as in Experiment I. Results from the first year of Experiment I indicated that the greatest rate of paclobutrazol applied resulted in higher seed yield. Therefore, only 0 and 0.75 kg a.i. ha^{-1} paclobutrazol were applied at floret initiation. Furthermore, a broadcast application of an additional 60 kg N ha^{-1} was given to all plots at floret initiation to test whether seed yield would respond to higher rates of spring-applied N. Thus, total spring N rates were 120, 180, and 240 kg ha^{-1}. The six factorial treatments were arranged in randomized complete blocks and replicated six times. The same randomization was used in both crop years.

RESULTS

Mean monthly temperature and precipitation from February through July varied considerably among the three years of the two experiments (Table 1). The mild and wet February and March in 1983 resulted in excessive early growth and caused severe lodging in all plots by anthesis. Lodging data were not recorded in that year, but observation indicated that paclobutrazol delayed lodging. May and June of 1984 were considerably wetter than the 30-yr mean. Paclobutrazol application delayed and reduced lodging at all levels of N applied in both experiments (Table 2). Considerable lodging, however, occurred by crop maturity even at the highest rate of paclobutrazol applied. Similar trends were observed in 1985, although lodging was not as severe (data not shown).

Table 1. Mean monthly temperatures and total precipitation for Corvallis, Oregon, during the experiment period.

	Mean temperature (°C)				Total precipitation (mm)			
	1983	1984	1985	30-year mean	1983	1984	1985	30-year mean
February	7.6	6.6	4.6	5.9	262	125	93	122
March	9.6	9.5	6.4	7.2	223	97	125	116
April	10.1	9.0	11.1	8.9	76	87	27	75
May	13.9	11.7	12.0	12.0	38	93	24	50
June	15.2	14.4	16.3	15.5	35	110	56	30
July	17.3	18.9	20.9	18.4	65	5	14	14

Table 2. Effects of paclobutrazol and nitrogen application rates on lodging of the Pennfine perennial ryegrass seed crop in two 1984 experiments.

Paclobutrazol	Nitrogen	Plot area lodged: Full heading (14 May)	Peak anthesis (7 June)	Seed filling (22 June)	Seed maturity (5 July)
	kg ha^{-1}		%		
Experiment I					
0.00	60	0	78	83	86
	120	27	85	87	90
	180	45	87	90	89
0.50	60	0	14	18	34
	120	0	39	65	68
	180	0	56	78	82
0.75	60	0	0	5	23
	120	0	0	23	39
	180	0	5	56	58
	LSD (P<0.05)	14	6	10	10
Experiment II					
0.00	120	57	70	85	90
	180	72	81	87	90
	240	73	87	91	92
0.75	120	0	3	28	33
	180	0	5	51	60
	240	0	11	55	63
	LSD (P<0.05)	8	8	12	11

Experiment I

Seed Yield and Harvest Index

For $P_{0.0}$ and $P_{0.50}$ treatments, N application rates did not affect seed yields in either year (Table 3). For the $P_{0.75}$ treatment, however, N_{120} resulted in the highest seed yield in 1983, whereas both N_{120} and N_{180} outyielded N_{60} in 1984. Averaged over N rates in 1983, seed yield for $P_{0.75}$ was 20% higher than $P_{0.50}$ and 205% higher than $P_{0.0}$. In 1984, seed yield for $P_{0.75}$ was 13% higher than $P_{0.50}$ and 200% higher than $P_{0.0}$. Regardless of N treatments, paclobutrazol increased harvest index, whereas N application did not affect it at $P_{0.0}$ and decreased it at $P_{0.50}$ and $P_{0.75}$.

Fertile Tillers at Anthesis and Spikes at Maturity

In both 1983 and 1984, the number of fertile tillers at anthesis was not affected by N rates for the $P_{0.0}$ treatment, but for the $P_{0.50}$ and $P_{0.75}$ it increased as N rates were increased (Table 3). In 1984, regardless of paclobutrazol treatments, fertile tillers at anthesis increased as N rates were increased. The highest levels of paclobutrazol and N applied resulted in the greatest number of fertile tillers at anthesis. Variations in the number of spikes at maturity among treatments were similar to those for the number of fertile tillers at anthesis (Table 3).

Florets per Spikelet, Seeds per Spike, and Floret Site Utilization

Treatments did not affect the number of spikelets per spike (data not shown). Regardless of paclobutrazol rate, florets per spikelet increased as N rates were increased in both years. Paclobutrazol did not affect the number of florets per spikelet in either year (Table 3). In 1983, N rates did not affect the number of seeds produced per spike for the $P_{0.0}$ treatment, but N rates decreased seed number per spike for the $P_{0.50}$ and $P_{0.75}$ treatments. Nitrogen treatments did not affect seeds per spike in 1984. In both years, $P_{0.50}$ increased seeds produced per spike over the $P_{0.0}$ treatment, while the $P_{0.75}$ treatment provided no increase over the $P_{0.50}$ treatment. Treatment effects on floret site utilization were similar to their effects on seeds per spike. In general, N did not affect floret site utilization at $P_{0.0}$, but increasing N to 180 kg ha^{-1} decreased floret site utilization at $P_{0.50}$ and $P_{0.75}$. The $P_{0.50}$ treatment increased floret site utilization over $P_{0.0}$ by 43% in 1983 and by 59% in 1984; increasing paclobutrazol rate to 0.75 kg a.i. ha^{-1} did not improve floret site utilization, compared with the $P_{0.50}$ treatment.

Total Seeds Produced and Weight per Seed

Total seeds produced per unit area were influenced by the treatment effects on the numbers of both spikes at maturity and seeds per spike. Within the $P_{0.0}$ and $P_{0.50}$ treatments, N rates did not affect the total number of seeds produced (Table 3). At the $P_{0.75}$, N_{120} increased total seed number compared to N_{60}, while further increases in N applied had no effect. Averaged over N rates, $P_{0.50}$ increased total seed number over $P_{0.0}$ by 98% in 1983 and 81% in 1984. In both years, $P_{0.75}$ increased the total number of seeds produced per unit area over the $P_{0.50}$ treatment by about 10%. In 1983, N application at $P_{0.0}$ increased weight per seed, while it had no effect on weight per seed for the $P_{0.50}$ and $P_{0.75}$ treatments. Paclobutrazol resulted in a small but significant decrease in weight per seed in 1983. Treatments did not affect weight per seed in 1984.

Table 3. Effects of three nitrogen rates applied at spikelet initiation and three paclobutrazol rates applied at floret initiation on seed yield and yield components of Pennfine perennial ryegrass in 1983 and 1984 (Experiment I).

		Seed yield		Harvest index		Fertile tillers at anthesis		Spikes at maturity		Florets per spikelet		Seeds per spike		Floret site utilization		Seeds per unit area		Weight per seed	
Paclo-butrazol	Nitrogen	1983	1984	1983	1984	1983	1984	1983	1984	1983	1984	1983	1984	1983	1984	1983	1984	1983	1984
		kg ha^{-1}		%		No. m^{-2}				No.				%		(X10^{3}) No. m^{-2}		mg	
0.00	60	539	818	13	17	1636	1076	1980	1883	5.6	6.6	14	28	10	17	277	527	1.95	1.63
	120	625	936	14	15	1873	1113	2077	1991	6.4	7.8	16	31	10	16	332	617	2.04	1.58
	180	578	1022	14	16	1614	1195	1808	1948	7.4	8.3	15	35	8	18	271	681	2.22	1.58
0.50	60	1070	1631	27	28	1894	1044	2012	1937	6.3	7.3	28	57	17	32	563	1104	1.93	1.56
	120	1081	1670	27	24	2293	1313	2476	2335	6.5	7.9	23	47	14	26	569	1097	1.90	1.56
	180	918	1618	27	21	2540	1506	3046	2518	7.3	8.6	20	44	9	22	609	1108	1.90	1.52
0.75	60	1089	1510	29	30	1808	969	2185	1862	6.5	7.4	27	52	16	30	589	968	1.93	1.57
	120	1461	2038	29	27	2346	1550	2755	2465	6.9	8.0	26	53	17	30	706	1306	1.88	1.52
	180	1131	2001	29	24	2626	1765	3240	2551	7.1	8.5	19	52	10	26	615	1326	1.86	1.53
N rate (a)		**	*	NS	**	**	**	**	**	**	**	**	NS	**	*	*	**	**	NS
Paclobutrazol rate (b)		**	**	**	**	**	*	**	**	NS	NS	**	**	**	**	**	**	**	NS
a x b		**	*	NS	*	**	NS	**	*	NS	NS	**	NS	**	*	**	*	**	NS
LSD (P<0.05)		107	274	2	3	334	128	290	292	0.6	0.5	4	16	5	9	61	163	0.06	

Table 4. Effects of three nitrogen rates applied at spikelet initiation (including a broadcast application of 60 kg N ha^{-1} at floret initiation) and two rates of paclobutrazol applied at floret initiation, on seed yield and yield components of Pennfine perennial ryegrass in 1984 and 1985 (Experiment II).

		Seed yield		Harvest index		Fertile tillers at anthesis		Spikes at maturity		Florets per spikelet		Seeds per spike		Floret site utilization		Seeds per unit area		Weight per seed	
Paclo-butrazol	Nitrogen	1984	1985	1984	1985	1984	1985	1984	1985	1984	1985	1984	1985	1984	1985	1984	1985	1984	1985
		kg ha^{-1}		%		No. m^{-}				No.				%		(X10^{3}) No. m^{-2}		mg	
0.00	120	1036	1329	14	15	950	1047	1685	2408	7.3	6.3	35	34	18	27	590	818	1.80	1.84
	180	1023	1303	15	15	1015	1091	1955	2268	8.0	6.8	29	31	14	21	567	703	1.78	1.84
	240	979	1502	18	17	972	745	2073	2851	8.6	6.9	29	31	13	22	601	884	1.76	1.86
0.75	120	1926	1809	27	22	1112	864	2181	2548	7.6	7.0	56	46	30	34	1221	1172	1.59	1.73
	180	2009	2167	24	22	1210	972	2494	2698	7.7	6.5	52	67	25	33	1297	1807	1.61	1.75
	240	1830	2023	24	21	1296	918	2646	2818	8.1	7.6	41	50	20	31	1085	1409	1.70	1.75
N rate (a)		NS	NS	NS	NS	NS	NS	NS	NS	*	NS	*	NS	**	NS	NS	*	NS	NS
Paclobutrazol rate (b)		**	**	**	**	**	NS	**	NS	NS	NS	**	**	**	*	**	**	**	**
a x b		NS	*	*	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	*	*	NS
LSD (P<0.05)		152	235	4	2	15		29		0.6		6	13	4	12	82	133	0.08	0.04

Experiment II

Seed Yield and Harvest Index

Regardless of paclobutrazol rate, N rates did not affect seed yield in either year (Table 4). When averaged among N rates, paclobutrazol increased seed yield by 96% in 1984 and 42% in 1985. Similarly, N did not affect harvest index in either year, but paclobutrazol increased it by 60% in 1984 and 38% in 1985.

Fertile Tillers at Anthesis and Spikes at Maturity

Nitrogen treatments did not affect the number of fertile tillers at anthesis or the number of spikes at maturity (Table 4). Averaged over N rates, paclobutrazol increased fertile tillers at anthesis by 23% and spikes at maturity by 28% in 1984, but it did not affect these components in 1985.

Florets per Spikelet, Seeds per Spike, and Floret Site Utilization

Increasing N rates increased the number of florets per spikelet in 1984, but not in 1985 (Table 4). Paclobutrazol did not affect the number of florets per spikelet in either year. Within each level of paclobutrazol in 1984, increasing N rates decreased the number of seeds per spike. Nitrogen rates did not affect the number of seeds per spike in 1985. Averaged over N rates, paclobutrazol increased the number of seeds per spike by more than 60% in both years. Increasing the rate of N decreased floret site utilization in 1984 but not in 1985. Conversely, paclobutrazol improved floret site utilization in both years.

Total seeds produced and weight per seed

Nitrogen application did not affect the number of seeds produced per unit area in 1984, and the response was variable in 1985 with N_{180} resulting in the greatest number of seeds per unit area (Table 4). Averaged over N rates, paclobutrazol more than doubled the number of seeds produced in 1984 and increased seed number by 82% in 1985. Weight per seed was not affected by N rates in either year, whereas paclobutrazol resulted in small but significant decreases in weight per seed.

Correlations

Seed yields in 1984 and 1985 were not correlated with the number of fertile tillers at anthesis, number of spikelets per spike, or the number of florets per spikelet (Table 5). Seed yield was positively correlated with the number of spikes in 1984, but not in 1985. In both 1984 and 1985, seed yields were strongly correlated with floret site utilization, number of seeds per spike, and consequently with the number of seeds per unit area. Seed yield was negatively correlated with weight per seed in both years.

DISCUSSION

Results from Experiment I confirm our previous conclusion (Young *et al.*, 1995a) that under the management and climate condition of western Oregon and in the absence of paclobutrazol, spring applied N rates above 60 kg ha^{-1} do not improve the seed yield of perennial ryegrass cv. Pennfine. When paclobutrazol was applied at 0.75 kg a.i. ha^{-1}, however, seed yield in both years was maximized at 120 kg N ha^{-1}. The results from experiment II further indicate that increasing the spring N rate above 120 kg a.i. ha^{-1} would not improve the seed yield of perennial ryegrass cv. Pennfine even when 0.75 kg a.i. ha^{-1} paclobutrazol was applied. Lodging data in both experiments in 1984 suggest that 0.75 kg a.i. ha^{-1} paclobutrazol may not be sufficient to reduce lodging to the extent necessary to ensure maximum seed yield under growing conditions that stimulate severe lodging. In England, the degree of lodging in perennial ryegrass was reduced (Hampton and Hebblethwaite, 1985a), and seed yield was increased (Hebblethwaite *et al.*, 1982) as paclobutrazol rate was increased to 2 kg a.i. ha^{-1}. At paclobutrazol rates higher than 0.75 kg a.i. ha^{-1}, the seed yield of this cultivar may respond positively to spring N rates above 120 kg ha^{-1}.

Increases in perennial ryegrass seed yield by application of paclubutrazol have been attributed to reductions in lodging (Hebblethwaite *et al.*, 1982) and subsequent decreases in seed abortion (Hampton and Hebblethwaite, 1985b), and also to increases in the number of fertile tillers in some years (Hampton and Hebblethwaite, 1985a). Our results indicate that the yield component most affected by paclobutrazol depends on the level of N available and, consequently, on the potential for lodging. At 60 kg N ha^{-1}, the number of fertile tillers at anthesis and spikes at maturity was not affected by the rates of paclobutrazol applied. As the rate of applied N increased, however, these yield components showed progressively greater response to increased rates of paclobutrazol. Conversely, the greatest increases in the number of seeds per spike with the application of paclobutrazol occurred at the lowest rate of N used. This suggests that when perennial ryegrass is subject to lodging, paclobutrazol improves seed set primarily because of reduced lodging, and the number of fertile tillers are increased only if adequate N is available. If lodging does not occur and adequate N is available, the primary effect of paclobutrazol on perennial ryegrass seed yield would be through increases in the number of fertile tillers and the number of spikes at maturity. Similarly, Albeke *et al.* (1983) found that in fine fescue paclobutrazol increased seed yield at all N rates primarily by reducing lodging and increasing seed set, whereas it also increased potential yield at higher N rates.

Table 5. Coefficients for the correlations among seed yield and yield components of perennial ryegrass in Experiment II. All the reported coefficients were significant at P<0.01.

	1984	1985
No. of fertile tillers at anthesis	NS	NS
No. of spikes at maturity	0.56	NS
No. of spikelets per spike	NS	NS
No. of florets per spikelet	NS	NS
No. of seeds per spike	0.75	0.63
Floret site utilization	0.74	0.69
No. of seeds produced per unit area	0.99	0.99
Weight per seed	-0.57	-0.63

Production of secondary vegetative tillers is also attributed as a primary reason for failure to increase perennial ryegrass seed yield at high N rates (Hampton *et al.*, 1983). Vegetative tillers subtending fertile tillers in perennial ryegrass compete directly with the growing seeds for assimilates (Clemence and Hebblethwaite, 1985). Paclobutrazol may reduce the number of vegetative tillers formed after anthesis (Hampton and Hebblethwaite, 1984). We did not monitor production of vegetative tillers after anthesis, but the treatments did not affect the number of vegetative tillers measured at anthesis (data not shown). A comprehensive economic analysis is needed to determine the optimum rates of N and paclobutrazol application for the maximum return to the growers.

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