Effects of Paclobutrazol on 'Grasslands Maku' Lotus (*Lotus uliginosus* Schk.) Grown for Seed Production

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ABSTRACT

The effects of the plant growth regulator paclobutrazol applied at different rates and times on vegetative and reproductive growth, yield components and seed yield of *Lotus uliginosus* Schk. cv. Grasslands Maku were investigated in a field experiment. The chemical, applied at 0.5 and 1.0 kg a.i. ha^{-1} in October or November (mid-late spring) and at 1.0 kg a.i. ha^{-1} in December significantly increased seed yield by an average of 70%. This seed yield increase was predominantly a result of increased flower density through the effect of the chemical in changing plant morphology, but pods per umbel and seeds per pod were also increased. Paclobutrazol had no detrimental effects on seed quality. The implications of these findings are discussed.

Additional index words: **apical dominance, abortion, plant morphology, seed yield components, seed quality.**

INTRODUCTION

Grasslands Maku lotus (*Lotus uliginosus* Schk.) is a tetraploid herbage legume bred in New Zealand and commercially released in 1975. It has high potential for use in acidic (pH < 5.2), phosphate-deficient soils and has traditionally been widely sown on moist, low fertility hill country. The species has also performed well in subtropical areas in Queensland, Australia (Cook and Jones, 1985). Maku lotus tolerates high levels of soil aluminium, has greater nutritive value for animals than lucerne, red clover and perennial ryegrass and is non-bloating. It also has valuable tolerance to grassgrub (*Costelytra zealandica* White) and porina (*Wiseana cervinata* Walker) (John and Lancashire, 1981).

Despite these agronomic advantages, low seed yields often limit seed supply and wider agricultural use. The plant's indeterminate growth habit, protracted flowering and pod shattering behaviour often make it difficult to select optimum harvest date. The use of plant growth regulating chemicals has shown considerable potential for increasing commercial seed production (Hampton, Li and Hare, 1989; Tabora and Hampton, 1992). One of these, paclobutrazol, known commercially as Cultar, has been shown to increase seed yields in this species principally through an increase in stem density and umbel numbers (Clifford and Hare, 1987) or by increasing seeds per pod, contracting the flowering period and preventing lodging (Hampton et al., 1989; Tabora, 1991).

Despite this, there is still a need to determine how paclobutrazol influences vegetative and reproductive growth, the development of yield components and ultimately seed yield and quality in Maku lotus.

MATERIALS AND METHODS

The experiment was conducted at Massey University, New Zealand (Latitude 40°S Longitude 170°E). Certified basic seed of lotus cv. Grasslands Maku was inoculated and sown in March 1988 using a cone seeder at a 50 cm row spacing. Details of agronomic management are provided in Table 1. No irrigation or fertilisers were applied and pollinators were not introduced. Paclobutrazol was applied at 0.5 or 1.0 kg a.i. ha^{-1} by knapsack sprayer in 350 l water ha^{-1} at each of three plant growth stages, ie

- during active vegetative growth (50-60 d before flowering)
- floral bud primordia appearance at shoot apices (about 20-25 d before flowering)
- at the onset of flowering.

Control plants were sprayed with water alone. The experiment was laid out in a split-plot design with time of application assigned to the main plots and treatments to the subplots. All treatments had three replicates. The number of inflorescences which developed was recorded every three days during the flowering period in permanent 50 x 50 cm quadrats. Plants from a 0.5 m^2 randomly placed quadrat were dug out at 7 days after peak flowering (DAPF) for growth analysis in the laboratory to evaluate vegetative and reproductive growth. Numbers of florets and pods per umbel were determined at three stages, ie flower buds (14 days before flowering), florets per flower (at full bloom) and pods per umbel (30 days after peak flowering). Seeds per pod were determined using X-ray radiography (Tabora and Hampton, 1992). Seed weight was determined by weighing 8 x 100 seeds and was corrected to 8% seed moisture content.

Hand harvesting of cut 0.5 m^2 quadrats was carried out 30 days after peak flowering when the majority of pods were brown and prior to the onset of shattering (Tabora, 1991; Tabora and Hampton, 1992). Plant material was dried at ambient temperature for 15-20 days before being threshed using a laboratory thresher (Westrup type LAH). Seed samples were then machine cleaned to 99.9% purity minimum prior to seed yield assessment and seed germination tests (ISTA, 1985).

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Table 1. Management and experimental details.

Soil type	Tokomaru silt loam
Site soil analysis	pH 5.8; Olsen P - 13 Exch K - 0.32, SO_4 - 5.8
Seed source	DSIR Grasslands, Palmerston North
Sowing rate	1.5 kg ha^{-1}
Sowing date	30 Mar 1988
Plot size	2.5 x 5.0 m
Plants m^{-2}	45 m^{-2}
Row spacing	50 cm
Last grazing	15 Aug 1988
Inter-row cultivation	30 Sept 1988
Weed control	2,4-DB at 3 kg a.i. ha^{-1} propryzamide at 1.5 kg a.i. ha^{-1} on 15 Oct 1988
Paclobutrazol application date	7 Oct 1988 2 Nov 1988 1 Dec 1988
Insect control	fluvalinate at 1.6 kg a.i. ha^{-1} on 15 Dec 1988
Harvest date	30 days after peak flowering (2-4 Feb 1989)

RESULTS

A significant increase in reproductive main shoots was induced by both rates of paclobutrazol applied in November and by the high rate applied in December (Table 2). The chemical also inhibited apical dominance of main shoots, as the November application significantly increased the number of primary lateral shoots which became reproductive. Early application (October) also increased the number of reproductive secondary lateral shoots. Paclobutrazol did not significantly affect the number of vegetative lateral shoots.

The most obvious morphological effect following paclobutrazol application was a reduction in internode length, plant height and total dry matter (data not shown; Tabora, 1991). There was a significant promotion of flower numbers (Table 3) following paclobutrazol application (particularly in October and November), and this response was also accompanied by an increase in the number of pods per umbel and the number of seeds per pod but not in seed weight. These effects occurred irrespective of time of application and were generally not affected by rate of application.

The flowering period of the crop lasted for 45 days from 3 December to 17 January. Early application (October) of paclobutrazol at the higher rate shortened flowering duration by 8 days, while late application (December) delayed peak flowering by 9-12 days (data not presented).

The number of ovules per carpel at flowering did not differ significantly among treatments (range from 49-56). Only approximately one third of ovules survived to seed maturity, an average of 53 ovules per carpel at flowering resulting in around 17 seeds per pod at harvest.

Seed yield of Maku lotus was significantly and consistently increased by paclobutrazol applied in October and November at both rates, and by the high rate in December (Table 4). The greatest response (70%) came from the October application of 1.0 kg a.i. ha^{-1}, but this result did not differ significantly from the November and December application at this rate, or the first two applications at the lower rate.

DISCUSSION

The effect of paclobutrazol in increasing main shoot numbers while also removing apical dominance of main shoots is particularly important. The greater number of reproductive primary, and to a lesser extent, secondary lateral shoots contributed to the improvement in flower density and subsequent seed yield. Some tertiary lateral shoots also developed following November or December paclobutrazol application. Whilst these may appear beneficial in augmenting the number of sites for flowering, they were in fact, generally infertile. As a result, they are likely to be counter-productive from a seed production point of view, since they compete for available assimilates when their formation coincides with flower bud development. This conflict is likely to induce considerable flower abortion since young flower buds compete poorly with vegetative shoots in terms of assimilate partitioning (McGraw and Beuselinck, 1983; Chanprasert, Coolbear and Hill, 1989; Tabora and Hill, 1991; Tabora and Hampton, 1992). The most obvious observed morphological effect following paclobutrazol application was the greatly reduced stem internode length, plant height and dry matter production (Tabora, 1991). This confirms the gibberellin biosynthesis

Table 2. Paclobutrazol effects on the number of main and lateral shoots m^{-2}.

Rate (kg a.i. ha^{-1})	Time of application 7 Oct	2 Nov	1 Dec	Rate Means
A. Reproductive main shoots (Rate x Time = *)				
Control	24.3 b	25.3 b	23.3 b	24.3 n
0.5	29.3 ab	40.3 a	24.3 b	31.3 m
1.0	24.7 b	33.3 a	36.3 a	31.4 m
Time Means	26.1 y	32.9 x	27.9 y	(29.0)
B. Reproductive primary lateral shoots (Rate x Time = NS)				
Control	111.6 c	115.0 c	127.3 c	118.0 n
0.5	175.7 abc	230.3 a	124.3 bc	176.8 m
1.0	161.7 bc	185.0 ab	175.7 abc	174.1 m
Time Means	149.7 y	176.8 x	142.4 y	(156.3)
C. Vegetative primary lateral shoots (Rate x Time = NS)				
Control	57.3	56.0	56.7	56.7 NS
0.5	64.3	79.0	56.7	66.7
1.0	51.3	73.3	95.0	73.2
Time Means	57.6 NS	69.4	69.5	(65.4)
D. Reproductive secondary lateral shoots (Rate x Time = *)				
Control	126.3 cd	128.7 cd	129.0 cd	128.0 n
0.5	278.3 a	191.3 bc	105.3 d	191.7 m
1.0	214.3 ab	198.3 abc	174.7 bcd	195.8 m
Time Means	206.3 x	172.8 xy	136.3 y	(171.8)
E. Number of vegetative secondary lateral shoots (Rate x Time = NS)				
Control	8.9	7.7	5.9	7.4 NS
0.5	11.3	7.7	9.8	9.9
1.0	7.6	9.8	8.0	8.9
Time Means	9.3 NS	8.2	7.9	(8.7)

Mean values having the same letter are not significantly different at $P < 0.05$.
* - significant at $P < 0.05$. NS - not significant.

inhibition effect of paclobutrazol reported in a wide range of crops, eg *Lotus corniculatus* (Li and Hill, 1989), rice (Kwon and Yim, 1986), winter wheat (Froggatt, Thomas and Batch, 1982), perennial ryegrass (Hampton and Hebblethwaite, 1985) and white clover (Marshall and Hides, 1987). Despite this, inconsistent responses to paclobutrazol application have been reported (Marshall and Hides, 1987; Hampton, Tolentino and Hill, 1992). It seems that sufficient rainfall following application is necessary for its activation (Hampton and Hebblethwaite, 1984) since this chemical is

Table 3. Paclobutrazol effects on the number of inflorescences m^{-2} present at 7 DAPF, pods per umbel, seeds per pod and thousand seed weight.

Rate (kg a.i. ha^{-1})	Time of application 7 Oct	2 Nov	1 Dec	Rate Means
A. Number of inflorescences m^{-2} at 7 DAPF (Rate x Time = NS)				
Control	344.0 c	301.0 c	299.0 c	314.7 n
0.5	537.3 ab	539.7 ab	452.1 bc	509.7 m
1.0	539.7 ab	581.1 ab	660.0 a	593.8 m
Time Means	473.7 NS	473.9	470.4	(469.4)
B. Number of pods per umbel (Rate x Time = NS)				
Control	8.4	7.7	6.7	7.6 n
0.5	8.7	8.4	8.6	8.5 m
1.0	8.6	8.7	8.6	8.6 m
Time Means	8.5 NS	8.3	7.9	(8.2)
C. Number of seeds per pod (Rate x Time = *)				
Control	15.0 b	14.9 b	15.5 b	15.2 n
0.5	16.9 ab	17.4 ab	17.5 ab	17.3 m
1.0	18.4 a	17.3 ab	17.7 ab	17.8 m
Time Means	16.8 NS	16.5	16.9	(16.7)
D. One thousand seed weight (Rate x Time = NS)				
Control	0.7587	0.7818	0.7865	0.7757 NS
0.5	0.7579	0.7668	0.7843	0.7697
1.0	0.7712	0.7517	0.7868	0.7699
Time Means	0.7626 NS	0.7668	0.7859	(0.7718)

Mean values having the same letter are not significantly different at $P < 0.05$.
DAPF - days after peak flowering. * - significant at $P < 0.05$. NS - not significant.

Table 4. Paclobutrazol effect on seed yield (kg ha^{-1}).

Rate (kg a.i. ha^{-1})	Time of application[1] 7 Oct	2 Nov	1 Dec	Rate Means
Control	327.0 b	316.1 b	253.8 b	298.9 n
0.5	473.2 a	508.4 a	441.8 ab	474.5 m
1.0	557.9 a	516.2 a	494.6 a	522.9 m
Time Means	452.7 x	446.9 x	396.7 y	(432.1)

[1] rate x time = significant at $P < 0.05$.
Mean values having the same letter are not significantly different at $P < 0.05$.

mostly root-absorbed and xylem translocated (Shearing and Batch, 1982).

The number of ovules per carpel at flowering ranged from 49-56 and was not affected by paclobutrazol application. Only a low percentage (around 33%) survived to seed maturity (16.7 seeds per pod). This represents a nearly two-thirds loss of initial seed potential. Precisely what causes this effect is unclear, although it is known that abortion rates vary with time of flower appearance, a higher pod abortion occurring in early and late formed flowers (Tabora and Hill, 1991). This occurred irrespective of whether paclobutrazol had been applied or not, although paclobutrazol does reduce pod loss per umbel in mid-season flowers (Tabora, 1991).

The germination percentage of Maku lotus seeds was not affected by paclobutrazol treatment (data not presented). Normal germination ranged from 17-28%, hard seeds from 65-78% and viable seeds from 93-95%. The percentage of hard seeds was high because the seed was hand harvested and air dried for 60 days (February to March) after harvest at ambient temperature prior to testing. Similar findings have been reported in the same cultivar (Clifford and Hare, 1987) and also in *Lotus corniculatus* (Li and Hill, 1989).

The increase in seed yield obtained following paclobutrazol application was primarily associated with an increase in the number of flowers, an effect also observed by Clifford and Hare (1987). Hebblethwaite, Batts, Barret and Wiltshire (1986) have suggested that in ryegrass, it is important that plant growth regulators should be applied early, to ensure the chemical is available in the plant when rapid stem growth begins. In *Lotus uliginosus* the October application of paclobutrazol coincided with rapid plant growth, but yield increases were recorded from all three application times, and particularly at the 1.0 kg a.i. ha^{-1} rate, inflorescences were also significantly increased irrespective of application time. This suggests that paclobutrazol application in Maku lotus is not stage of growth specific, unlike cycocel application (Tabora and Hampton, 1992), but this requires confirmation from other sites and in more than one season.

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