Paclobutrazol and white clover seed production: a non-fulfilled potential

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Abstract

Seed yield in white clover depends largely on the number of ripe inflorescences per unit area, and the plant growth regulator paclobutrazol has been used in an attempt to both increase and concentrate inflorescence production, and hence increase seed yield. However results reported from both New Zealand and Europe have been inconsistent, with seed yield responses ranging from highly significant increases to no effects. The current high cost of the chemical ($1280/ha) requires a seed increase of over 300 kg/ha to ensure an economic return. Similarly no consistent effects of paclobutrazol on white clover vegetative and reproductive growth and development have been established. Possible reasons for this variable response of white clover to paclobutrazol application are presented and discussed.

Keywords: inflorescence production, Parlay, reproductive growth, seed yield components, Trifolium repens, vegetative growth

Introduction

White clover seed yield depends largely on the number of inflorescences produced per unit area (Clifford 1986; 1987). Management practices should therefore be directed at obtaining the high, uniformly distributed stolon tip density needed by the time of closing the crop so that there is a short but prolific flowering span (Clifford 1985; 1987). However achieving the desired stolon tip density is often difficult and efforts to provide the required amounts of mineral nutrients (Clifford & Rolston 1990) and water (Deschamps & Wery 1988) can result in excessive vegetative growth. This subsequently reduces inflorescence density and fertility due to the shading effects of competitive leaves (Pasumarty & Thomas 1990).

A further complication is the intermittent pattern of inflorescence production (Thomas 1987) which dictates that inflorescences appear over a period of time. Seed production in white clover is therefore typical of indeterminate plants (Hollington et al. 1980) in that the extended flowering period and resultant range of inflorescence ripeness categories in the crop makes the determination of optimum harvest time difficult (Budhianto et al. 1995).

The manipulation of white clover to both increase and condense inflorescence production without necessarily producing excessive vegetative growth could be expected to increase seed yield. This hypothesis has been explored using plant growth regulators (e.g. Budhianto et al. 1994a; 1994b). Internationally the most widely trialled plant growth regulator has been paclobutrazol. In this paper, the effects of paclobutrazol on seed production in white clover are reviewed and discussed.

Effects on vegetative growth

Marshall and Hides (1991a) and Budhianto et al. (1994a) found that paclobutrazol increased nodes per unit area. This response was considered to come from increased stolon production. However, in a study of individual plants in the field, Budhianto (1992) found no increase in main stolon number following paclobutrazol application, but did record a significant increase in the production of fertile secondary and tertiary branches off the main stolons. Whether this occurs in a sward situation is unknown. Both Marshall and Hides (1991a) and Budhianto et al. (1994a) reported an increase in the number of reproductive nodes along main stolons, although Marshall and Hides (1987) and Budhianto (1992) reported that paclobutrazol did not directly induce the initiation of inflorescences.

Paclobutrazol inhibits gibberellin biosynthesis (Hedden 1990) and thus reduces cell elongation. Paclobutrazol reduced white clover petiole length but not peduncle length (Marshall & Hides 1986; Hampton 1991; Budhianto et al. 1994a), the net effect being to elevate inflorescences above the canopy. While new plant organs which develop following paclobutrazol application are often reduced in size, white clover leaf size and total dry matter at peak flowering were not reduced (Budhianto et al. 1994a).

Effects on reproductive growth and seed yield

Paclobutrazol application has produced significant white clover seed yield increases in trials reported from Belgium (Rijckaert 1991), Denmark (Boelt & Nordestgaard 1993), New Zealand (Hampton 1991; Budhianto et al. 1994b) and UK (Marshall & Hides 1991b). These increases have ranged from 13–350%
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(Table 1), and in most cases have been explained by an increase in the number of inflorescences at harvest and/or an increase in the number of seeds per floret or inflorescence (Table 2).

Increased inflorescence production in response to paclobutrazol has generally been a consistent feature (Table 3), but increases in seeds per inflorescence have been more variable (e.g. Hampton 1991; Marshall & Hides 1991b). This improvement in floret site utilization has been considered to have resulted from a reduction in seed abortion (Hampton 1991), although this is yet to be substantiated. There has generally been no change in the number of florets per inflorescence or in thousand seed weight, but Budhianto et al. (1994b) did report a significant reduction in thousand seed weight in one of two years of trials at the same site.

### Variability of results

While the seed yield responses reported in Table 1 are impressive, nil responses have also been reported. Marshall and Hides (1986) found no increase in cv. Olwen following paclobutrazol application, but also reported (Marshall & Hides 1991b) that paclobutrazol significantly increased the seed yield of cv. Olwen but not cv. Menna in two consecutive years. Similarly while Hampton (1991) reported a significant increase in the seed yield of cv. G. Pitau, Budhianto et al. (1994b) recorded a non-significant increase in one year and a nil response in the following year for the same cultivar at the same site.

A number of reasons have been suggested for this variability in response to paclobutrazol. They include application rate and time, soil type, cultivar, environmental conditions and time of harvest.

### Application rate and time

Rijckaert (1991) recorded significant seed yield increases at paclobutrazol application rates of 0.25, 0.5 and 1.0 kg/ha in two out of three years of trials in Belgium, but Marshall and Hides (1986) found no increase in seed yield at any of these application rates in a trial in UK. Data for paclobutrazol application rate responses are limited, but while most of the significant seed yield responses have come from the 1.0 kg ai/ha application rate, nil responses at this rate have also been recorded.

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**Table 1:** Effect of paclobutrazol on harvested seed yield of seven white clover cultivars, 1987–1990.

<table>
<thead>
<tr>
<th>Year of harvest</th>
<th>Cultivar</th>
<th>Country</th>
<th>Seed Yield (kg/ha)</th>
<th>% inc</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>Milkanova</td>
<td>Denmark</td>
<td>543</td>
<td>13</td>
<td>Boelt &amp; Nordestgaard 1993</td>
</tr>
<tr>
<td>1987</td>
<td>Merwi</td>
<td>Belgium</td>
<td>124</td>
<td>350</td>
<td>Rijckaert 1991</td>
</tr>
<tr>
<td>1987</td>
<td>G. Kopu</td>
<td>NZ</td>
<td>422</td>
<td>205</td>
<td>Hampton 1991</td>
</tr>
<tr>
<td>1987</td>
<td>G. Pitau</td>
<td>NZ</td>
<td>476</td>
<td>763</td>
<td>Hampton 1991</td>
</tr>
<tr>
<td>1987</td>
<td>G. Huia</td>
<td>NZ</td>
<td>518</td>
<td>1053</td>
<td>Hampton 1991</td>
</tr>
<tr>
<td>1987</td>
<td>G. Tahora</td>
<td>NZ</td>
<td>399</td>
<td>716</td>
<td>Hampton 1991</td>
</tr>
<tr>
<td>1988</td>
<td>Olwen$^2$</td>
<td>UK</td>
<td>205</td>
<td>578</td>
<td>Marshall and Hides 1991b</td>
</tr>
<tr>
<td>1989</td>
<td>Merwi</td>
<td>Belgium</td>
<td>909</td>
<td>1200</td>
<td>Rijckaert 1991</td>
</tr>
<tr>
<td>1989</td>
<td>G. Pitau</td>
<td>NZ</td>
<td>394</td>
<td>498</td>
<td>Budhianto et al. 1994b</td>
</tr>
</tbody>
</table>

1 applied at 1 kg a.i./ha  
2 potential yield calculated from yield components

**Table 2:** Major seed yield component increases following paclobutrazol application.$^1$

<table>
<thead>
<tr>
<th>Year of</th>
<th>Cultivar</th>
<th>Increase in seeds/ % increase</th>
<th>Increase in thousand seeds/ inflorescences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvest</td>
<td></td>
<td>(floret or seeds/</td>
<td>at harvest (%)</td>
</tr>
<tr>
<td>1987</td>
<td>Milkanova</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>1987</td>
<td>Merwi</td>
<td>60</td>
<td>64</td>
</tr>
<tr>
<td>1987</td>
<td>G. Kopu</td>
<td>21</td>
<td>53</td>
</tr>
<tr>
<td>1987</td>
<td>G. Pitau</td>
<td>28</td>
<td>83</td>
</tr>
<tr>
<td>1987</td>
<td>G. Huia</td>
<td>54</td>
<td>30</td>
</tr>
<tr>
<td>1987</td>
<td>G. Tahora</td>
<td>–</td>
<td>76</td>
</tr>
<tr>
<td>1988</td>
<td>Olwen$^2$</td>
<td>36</td>
<td>61</td>
</tr>
<tr>
<td>1989</td>
<td>Merwi</td>
<td>38</td>
<td>21</td>
</tr>
<tr>
<td>1989</td>
<td>G. Pitau</td>
<td>–</td>
<td>45</td>
</tr>
</tbody>
</table>

1 applied at 1 kg a.i./ha  
2 no increase recorded

**Table 3:** Effect of paclobutrazol on inflorescence number/m².$^3$

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Treatment</th>
<th>Year</th>
<th>Year</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>G. Pitau$^5$</td>
<td>Nil</td>
<td>1987</td>
<td>1988</td>
<td>1989</td>
</tr>
<tr>
<td></td>
<td>Paclobutrazol</td>
<td>210</td>
<td>551</td>
<td>750</td>
</tr>
<tr>
<td>Olwen$^6$</td>
<td>Nil</td>
<td>1984</td>
<td>1987</td>
<td>1988</td>
</tr>
<tr>
<td></td>
<td>Paclobutrazol</td>
<td>810</td>
<td>703</td>
<td>829</td>
</tr>
</tbody>
</table>

1 Hampton (1991); 2 Budhianto (1992); 3 Marshall and Hides (1986); 4 Marshall and Hides (1991b); 5 data recorded at peak flowering; 6 harvestable inflorescences.

Application has been generally timed for two crop developmental stages – during peak reproductive initiation, or when the reproductive buds/early flowers first become visible (i.e. a time frame of approximately one month between applications). Seed yield responses to application time have varied significantly between seasons at the same site (Marshall & Hides 1991b), among cultivars in the same seasons at the same site (Hampton 1991), or have produced no significant
differences between application times in the same
cultivar over two seasons at the same site (Budhianto
et al. 1994b).

Soil type
Paclobutrazol is relatively immobile in the soil, being
bound mainly by organic matter (Lever 1986). It is
possible that soil type may affect the
paclobutrazol response, particularly as the
chemical is primarily dependant on root
uptake (Shearing & Batch 1982). While
soil type may influence the amount of
paclobutrazol immediately available for
plant uptake, and hence alter the plant
response, this does not explain why
contrasting results can be obtained at the
same site in different seasons (Marshall
& Hides 1991b).

Cultivar
Marshall and Hides (1991b) considered
that cultivars responded similarly to
paclobutrazol application, although
Hampton (1991) did record differing
responses among four New Zealand
cultivars (e.g. seeds per inflorescence
were significantly increased in three
cultivars following paclobutrazol application at the first
visible bud stage, but not in a fourth cultivar). The
available data suggest greater variability within a cultivar
over different seasons than between or among cultivars.

Environment
The environment always has a significant effect on the
success of white clover seed production, but has also
been suggested as an explanation for variable
paclobutrazol responses, because the chemical requires
rainfall during the month after application to enable
plant uptake (Hampton & Hebblethwaite 1984). Marshall
and Hides (1991b) related the variability in response to
paclobutrazol in two consecutive seasons to the rainfall
received in the month after application, but Budhianto
et al. (1994b) found different responses in two
consecutive seasons when rainfall after application was
similar in each season.

Time of harvest
Wiltshire and Hebblethwaite (1990) reported significant
growth regulator x harvest date interactions for seed
yield in Lolium perenne, and Budhianto et al. (1995)
explored the hypothesis that paclobutrazol may alter
the rate of white clover seed development and therefore
the optimum harvest date as compared to the control.
However, while paclobutrazol increased inflorescence
number at peak flowering, despite large percentage
differences, neither ripe inflorescences or seed yield
were significantly increased (Table 4). There was also
no evidence to suggest that paclobutrazol altered seed
development, and paclobutrazol therefore had no effect
on optimum harvest time (Budhianto et al. 1995).

Table 4: Effect of paclobutrazol and time of harvest on ripe inflorescence number
and seed yield in white clover cv. G. Pitau. 1

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Harvest time (days after peak flowering)</th>
<th>Treatment Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ripe inflorescences (no./m²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>control</td>
<td>181</td>
<td>153</td>
</tr>
<tr>
<td>paclobutrazol</td>
<td>317</td>
<td>212</td>
</tr>
<tr>
<td>Harvest means</td>
<td>249</td>
<td>183</td>
</tr>
<tr>
<td>LSD P&lt;0.05 : treatment means = NS; harvest means = 63.3; treatment x harvest = NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C.V. main plots = 24%; subplots = 29%</td>
<td></td>
</tr>
<tr>
<td>Seed yield (g/m²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>control</td>
<td>25.5</td>
<td>20.8</td>
</tr>
<tr>
<td>paclobutrazol</td>
<td>37.3</td>
<td>28.8</td>
</tr>
<tr>
<td>Harvest means</td>
<td>31.3</td>
<td>24.8</td>
</tr>
<tr>
<td>LSD P&lt;0.05 : treatment means = NS; harvest means = 10.0; treatment x harvest = NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C.V. main plots = 44%; subplots = 38%</td>
<td></td>
</tr>
</tbody>
</table>

1 adapted from Budhianto et al. (1995).

Genotypic effects
As illustrated in Table 4, large percentage differences in
seed yield have not always been statistically significant.
The high variation recorded (e.g. coefficients of 30% to
75%, Budhianto 1992; Budhianto et al. 1995) may be
attributable to plot size and sample size being too small
to allow for the diversity to be found in an outcrossing
species such as white clover (although Budhianto (1992)
found that increasing plot size, sample size and replicate
number did not necessarily reduce the variation
recorded). However, it may also be possible that
responses to a plant growth regulator may differ with
genotype, and that inconsistencies in response to
paclobutrazol application may at least in part have been
explained by genotypic differences.

Budhianto (1992) examined the effect of paclo-
butrazol in three genotypes from within cv. G. Pitau.
Inflorescence production per plant averaged 320, 400
and 30 for genotypes I, II and III respectively, but
paclobutrazol significantly increased inflorescence
number (+ 32%) for genotype II only. Total mean seed
yield per plant was 74, 57 and 4g for genotypes I, II and
III respectively, but again, the only significant yield
increase following paclobutrazol application was for
genotype II (+ 25%). Thus while one genotype responded
to paclobutrazol application, two other genotypes did
not. However although the seed yield of genotype II
was increased by paclobutrazol, it was not greater than that produced by the untreated control for genotype I.

These results highlight the importance of genetic factors in determining white clover seed yield. Whether variable responses to paclobutrazol can be explained by differing genotypic responses remains to be determined.

Conclusion

Although available in New Zealand for horticultural use, paclobutrazol was not released for agriculture, a decision based mostly on concerns about the strong soil residual properties of the chemical and effects on succeeding crops. For white clover this may not be a factor, as Budhianto (1992) reported no effects on vegetative or reproductive growth in plots in year two which had received paclobutrazol at 1.0 kg ai/ha in year one. While Boelt and Nordestgaard (1993) for example, concluded that plant growth regulators had no place in white clover seed production because of inconsistency of results, the collective evidence suggests otherwise. Certainly an improved understanding of how antigibberellins such as paclobutrazol affect white clover vegetative and reproductive growth is required. However, at the present cost of the chemical ($1280/ha for a 1 kg ai/ha application rate), it is not economic. At this price, a grower would need a guaranteed seed yield increase of 320 kg/ha (at $4/kg seed) and 640 kg/ha (at $2/kg seed) just to recoup the chemical costs. This price is that for the horticultural use of paclobutrazol, and presumably if the chemical was to be released for agricultural use, its cost would decrease commensurately. For the present, paclobutrazol in white clover seed production seems destined to remain a non-fulfilled potential.

Acknowledgement

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References


