The results of our studies show that seed germination of L. terrestris populations differed with salinity and that populations could be classified in different categories based on their salt tolerance and recovery. The emergence of seedlings was not affected by type of soil. In further studies, whether population selection for tolerance to salinity in NaCl solutions is related to the capacity for growth and reproduction in soils of plant community "D" should be investigated.

ACKNOWLEDGEMENTS

We thank Lydia Ciner for critical reading of the text and the staff of the nematological laboratory and Fernanda Buckely for their assistance. The research was supported by funds from the National University of Mar del Plata-National Institute of Agricultural Technology.

REFERENCES


INTRODUCTION

Seeds yields in tropical forage legumes such as white clover (Trifolium repens L. Clifford, 1987) and red clover (T. pratense L.; Hampson, Robinson and Rowlaws, 1998), balsamroot trefoil (Lotus brachycalyx L.; Li and Hill, 1999), and Caucasian clover (T. ambiguum Bieb.; Fu, 1998) are highly dependent on the number of inflorescences produced. Caucasian clover inflorescence production has been related to plant size (Mihel, 1998) and the number and size of the secondary crown population (Cowbell, Hill and Ehrlich, 1994; Fu, 1998).

Goy (1986) recorded a 65% increase in seed yield from a seeding rate of 2 kg ha−1 in 65 cm rows c. 6 kg ha−1. However, there is no evidence to determine whether this genotypic seed yield response was due to plant density. The second objective of this study was to determine whether this genotypic seed yield response was due to plant density.

MATERIALS AND METHODS

The 4.5 m radial design (Nelder, 1962) was used for the two experiments. For each full circle (Nelder 1962; Breckel, 1967) was either sown (c. cv. Monaro) or planted (× genotype). Each circle contained 60 radials and 25 concentric rings, with each representing one plant density. The two outermost and four innermost rings were excluded as borders, so that 35 plant densities ranging from 3 to 45 plants m−2 were selected for detailed study.

Monaro. The site was the Pasture Research Unit at Massey University, the soil type was an Okakara silt loam (Cowle, 1974). The land was ploughed in mid March 1994, and power harrowed twice before sowing on 26 April. Seeds of cv. Monaro were inoculated in the laboratory (Nizshag Leugme Inoculation Coated Seed Ltd., Christchurch) following the manufacturer’s instructions and hand sown into two heaves, planting 3 seeds per hole at each specified distance along the radii. (Breckel, 1967; Fu, 1998). At the three leaf stage, emerged plants were thinned to one plant per position (Nelder, 1962). The trial was cut to 2 cm above ground on 5 October 1995 and the cut material removed. Resident seeds were covered with gypophosphate ammonium (3 litre produce ha−1) after first covering Caucasian clover plants with vertically cut plastic piping to protect them from herbicide. Further weed control was by hand in early November and December, Nipponbussia (N.P.R.: 12:10:10:2) was applied at 200 kg ha−1 on 25 November.

At harvest on 25 February 1996 nine plants were selected from random of each from the five selected densities, and the number of mature inflorescences per plant counted and collected. The inflorescences from each plant were air-dried.

Effects of Plant Density on Seed Yield in Caucasian Clover (Trifolium ambiguum Bieb.) cv. Monaro

S.M. Feu* and J.H. Hampson† and M.J. Hill‡

ABSTRACT

A radial trial design was used to determine the effect of plant density on seed yield of Caucasian clover (Trifolium ambiguum Bieb.) cv. Monaro, and the seed yield response of twelve genotypes selected from within cv. Monaro. The five densities ranged from 3 to 45 plants m−2 and seed yield m−2 was greatest at the 11 plants m−2 density, although differences from the 6 plants m−2 density were not always significant. Inflorescence number per plant was the only seed yield component affected by plant density, numbers decreasing as plant density increased. The individual genotype seed yield response to increasing plant density was similar to that for the cultivar as a whole, except that some genotypes flowered only at low densities, whereas the mean genotypic responsiveness to plant density. White root plant growth means that the seed yields recorded were low compared with other trial data for the same cultivars, the results do support the suggestion that for seed production, Caucasian clover should be sown at a rate of 2 kg ha−1 and that sowing at higher rates will reduce inflorescence number and therefore seed yield.

Additional index words: inflorescences, genotype, radial trial.

NOTES

*National Institute for Research, Massey University, Palmerston North, New Zealand
†New Zealand Soil and Technology Institute, P.O. Box 87, Lincoln, Canterbury, New Zealand
‡Appointed for publication 13 September 1993.
Table 1. Effect of plant density on Caucasian clover seed yield and yield components.

<table>
<thead>
<tr>
<th>Plants m⁻¹</th>
<th>Inflorescences</th>
<th>Florets per inflorescence</th>
<th>Seeds per plant</th>
<th>TSW</th>
<th>Seed yield (g) per plant m⁻²</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>12.0</td>
<td>37.2</td>
<td>121</td>
<td>66</td>
<td>2.26</td>
</tr>
<tr>
<td>6</td>
<td>8.3</td>
<td>48.1</td>
<td>116</td>
<td>83</td>
<td>2.26</td>
</tr>
<tr>
<td>11</td>
<td>5.7</td>
<td>61.6</td>
<td>98</td>
<td>69</td>
<td>2.06</td>
</tr>
<tr>
<td>20</td>
<td>1.0</td>
<td>20.3</td>
<td>111</td>
<td>70</td>
<td>2.22</td>
</tr>
<tr>
<td>38</td>
<td>0.3</td>
<td>11.5</td>
<td>108</td>
<td>65</td>
<td>2.12</td>
</tr>
<tr>
<td>LSD P&lt;0.05</td>
<td>3.35</td>
<td>NS</td>
<td>NS</td>
<td>0.02</td>
<td>0.47</td>
</tr>
</tbody>
</table>

*1 assessed at the final harvest on 25 February.*

Figure 1. Relationship between inflorescence number and a) seed yield per plant and b) seed yield m⁻² in Caucasian clover cv. Monoar.

RESULTS

Cv. Monoaro

Inflorescence number per plant decreased significantly as plant density increased. Twelve inflorescences per plant were produced at the lowest plant density and less than one inflorescence per plant was produced at the highest plant density (Table 1). However, on a per unit area basis inflorescence number was greatest at the 11 plants m⁻² density and had decreased by almost two thirds at the 29 plants m⁻² density (Table 1).

Plant density did not influence either florets or seeds per inflorescence, but thousand seed weight was significantly heavier at the two lowest plant densities (Table 1). Neither germination (range 96-98%) or hard seed (range 83-80%) differed with plant density (data not presented).

Seed yield per plant fell significantly as plant density increased (Table 1), although the yield at 38 plants m⁻² did not differ from that at 20 plants m⁻². Seed yield per plant was strongly associated with the number of inflorescences per plant and per m⁻² (Fig. 1). The greatest seed yield m⁻² was produced from the 11 plants m⁻² density, but this yield did not differ...
Table 1. Effect of plant density on Caucasian clover seed yield and yield components.

<table>
<thead>
<tr>
<th>Plants m⁻¹</th>
<th>Inflorescences</th>
<th>Florets per inflorescence</th>
<th>Seeds per inflorescence (g)</th>
<th>TSW</th>
<th>Seed yield (g) per plant m⁻²</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>12.0</td>
<td>37.2</td>
<td>121</td>
<td>66</td>
<td>2.26</td>
</tr>
<tr>
<td>6</td>
<td>8.3</td>
<td>48.1</td>
<td>116</td>
<td>83</td>
<td>2.26</td>
</tr>
<tr>
<td>11</td>
<td>5.7</td>
<td>61.6</td>
<td>98</td>
<td>69</td>
<td>2.06</td>
</tr>
<tr>
<td>20</td>
<td>1.0</td>
<td>20.3</td>
<td>111</td>
<td>70</td>
<td>2.22</td>
</tr>
<tr>
<td>38</td>
<td>0.3</td>
<td>11.5</td>
<td>108</td>
<td>65</td>
<td>2.12</td>
</tr>
<tr>
<td>LSD P&lt;0.05</td>
<td>3.35</td>
<td>NS</td>
<td>NS</td>
<td>0.02</td>
<td>0.47</td>
</tr>
</tbody>
</table>

*a* assessed at the final harvest on 25 February.

---

Figure 1. Relationship between inflorescence number and a) seed yield per plant and b) seed yield m⁻² in Caucasian clover cv. Monaro.

---

RESULTS

Cv. Monaro

Inflorescence number per plant decreased significantly as plant density increased. Twelve inflorescences per plant were produced at the lowest plant density and less than one inflorescence per plant was produced at the highest plant density (Table 1). However, on a per unit area basis inflorescence number was greatest at the 11 plants m⁻² density and had decreased by almost two-thirds at the 20 plants m⁻² density (Table 1).

Plant density did not influence either flowers or seeds per inflorescence, but thousand seed weight was significantly heavier at the two lowest plant densities (Table 1). Neither germination (range 96-98%) or hard seed (range 83-89%) differed with plant density (data not presented).

Seed yield per plant fell significantly as plant density increased (Table 1); although the yield at 38 plants m⁻² did not differ from that at 20 plants m⁻². Seed yield per plant was strongly associated with the number of inflorescences per plant and per m² (Fig. 1). The greatest seed yield m⁻² was produced from the 11 plants m⁻² density, but this yield did not differ
significantly from yields from the two lower densities (Table 1).

**Genotype**

Both infestances per plant and seed yield per plant differed significantly among the 12 genotypes at all but the highest plant density (Table 2). Those of the genotypes failed to flower irrespective of density while a further one did not flower at a density of 11 plants m$^{-2}$ or greater and another two at 20 plants m$^{-2}$ or greater. In general, infestation number per plant was reduced as plant density increased, and as a consequence seed yield per plant also declined with increasing plant density (Table 2).

**DISCUSSION**

Fu (1998) demonstrated that when individual plants of cv. Monaro were grown in a sand bed at a density of 3 plants m$^{-2}$, over 150 infestances and 25 g seed were produced per plant. Similarly Widdup, Knight and Haux (1996) recorded 162 infestances and 26 g seed per plant from a spaced plant trial. The infestances numbers and seed yields recorded from these density trials were therefore very low; the lowest density (3 plants m$^{-2}$) and therefore highest per plant production only recorded 12 infestances and 1.7 g seed per plant for the cultivar trial, and ranging from 0 to 27 infestances and 0 to 3.1 g seed per plant in the genotypic trial. There were two possible reasons for this poor performance. Firstly the size was a poor one for seed production, becoming waterlogged in the winter and baking hard in the summer, restricting plant growth. Secondly the weed control measures employed damaged new secondary crows and few of them grew strongly enough to contribute to seed production.

While the data should therefore be treated with some caution, those from both radial trials demonstrated that seed yield per unit area was greatest at a population of 11 plants m$^{-2}$, although not always significantly different from that of the 6 plants m$^{-2}$ population. Certainly increasing the population over 11 plants m$^{-2}$ decreased seed yield. These results therefore support the recommendations of Bryan (1974) and Guy (1996) that the sowing rate for Caucasian clover for seed production should not exceed 2 kg ha$^{-1}$. Daly, Gurrung and Lucas (1993) recommended an even lower sowing rate as they considered that a population of 20,000 plants ha$^{-1}$ was sufficient to produce a high seed yield potential in the year after establishment, but this population would have to depend heavily on the uninhibited production of secondary crows (Fu, 1998).

Seed yield depended almost entirely on infestation number, as the number of florets and seeds per infestation did not change with density, and the small differences in thousand seed weight were not consistent for density changes. Management of the crop must allow maximum floret expression (Guy, 1996) and it is now evident that a 2 kg ha$^{-1}$ sowing rate (Guy, 1996) and wide (40-45 cm) row spacing (Steiner and Snelling, 1994; Guy, 1996) encourage greater flowering than high sowing rates and narrow row spacings. Irrespective of plant density, seed set was low (average of 0.65 seeds per floret). Whether this reflects a problem with pollination, fertilisation or abortion is not known and requires closer research.

The twelve genotypes varied significantly in their ability to flower, with those remaining entirely vegetative despite an environment which allowed floral induction and expression. As plant density increased, genotypes with low numbers of infestances at low density ceased to produce infestances. The reason for the genotypic responses is not known (Fu et al., 1999), but the density response may be explained by the effect of competition on plant growth, and particularly root development. Coolbear et al. (1996) noted that root growth were likely to be the source of assimulates for driving reproductive development in this species, and Fu (1998) demonstrated a significant relationship ($R^2 = 0.852$) between root dry matter and infestation number. Although root dry matter was not recorded from the density trials, it is probable that individual plant root development was reduced as plant density increased, and as a result reproductive development was impeded.

**ACKNOWLEDGEMENTS**

Craig McGill, Robert Southward, Puyanan Lian, Zhongnan Liu and Guangli Li for technical assistance; Fu Shimin who housed the New Zealand Ministry of External Relations and Trade, the Miss E.C. Helloh Indigenous Grasslands Research Trust, and Maney University for financial support.

**REFERENCES**

significantly from those of the two lower densities (Table 1).

Genotype

Both inflorescences per plant and seed yield per plant differed significantly among the 12 genotypes at all but the highest plant density (Table 2). There were no significant differences in yield due to genotype at densities of 10 or 20 plants m⁻². However, there were differences in yield due to genotype at densities of 50 and 100 plants m⁻², with some genotypes producing significantly higher yields than others.

**DISCUSSION**

Fu (1998) demonstrated that when individual plants of cv. Monaro were grown in a seed bed at a density of 3 plants m⁻², over 150 inflorescences and 25 g seed were produced per plant. Similarly, Widdup, Knight and Hunt (1996) recorded 162 inflorescences and 26 g seed per plant from a spaced plant trial. The inflorescences and seed yields recorded from these density trials were therefore very low, the lowest density (3 plants m⁻²) and one per plant produced only 12 inflorescences and 1.7 g seed per plant for the cultivar trials, and ranging from 0 to 27 inflorescences and 0 to 3.1 g seed per plant in the genotypic trial. There were two possible reasons for this poor performance: firstly, the size was a poor one for seed production, becoming waterlogged in the winter and baking hard in the summer, restricting plant growth. Secondly, the weed control measures employed damaged new secondary crowns and few of them grew strongly enough to contribute to seed production.

The data should therefore be treated with some caution, those from both trials which demonstrated that seed yield increased significantly at a population of 1 plants m⁻², although not always significantly different from that of the 6 plants m⁻² population. Increasing the population over 11 plants m⁻² decreased seed yield. This result therefore supports the recommendations of Bryant (1974) and Guy (1996) that the sowing rate for Caucasian clover for seed production should not exceed 2 kg ha⁻¹. Daly, Gurung and Lucas (1993) recommended an even lower sowing rate as they considered that a population of 20,000 plants ha⁻¹ was sufficient to produce a high seed yield potential in the year after establishment, but this population would have to depend heavily on the un inhibited production of secondary crowns (Fu, 1998).

Seed yield depended almost entirely on inflorescence number, as the number of flowers and seeds per inflorescence did not change with density, and the small differences in thousand seed weight were not consistent for density changes. Management of the crop must allow maximum florescence exposure (Guy, 1996) and it is now evident that a 2 kg ha⁻¹ sowing rate (Guy, 1996) and wide (40-45 cm) row spacing (Steiner and Snedding, 1994; Guy, 1996) encourage greater flowering than high sowing rates and narrow row spacings irrespective of plant density. Seed set was low (average of 0.65 seeds per floret). Whether this reflects a problem with pollination, fertilization or abortion is not known and requires closer research.

The twelve genotypes varied significantly in their ability to flower, those remaining entirely vegetative despite an environment which allowed floral induction and expression. As plant density increased, genotypes with fewer seeds produced more inflorescences. The reason for the genotype response is not known (Fu aal., 1999), but the density response may be explained by the effect of competition on plant growth, and particularly root development. Coulthert et al. (1994) noted that root systems were likely to be the source of assimilates for driving reproductive development in this species, and Fu (1998) demonstrated a significant relationship (R² = 0.825) between root dry matter and inflorescence number. Although root dry matter was not recorded from the density trials, it is probable that individual plant root development was maintained as plant density increased, and as a result reproductive development was impeded.

**ACKNOWLEDGEMENTS**

Craig McGill, Robert Southward, Puying Lia, Zhaognan Nie and Guangli Li for technical assistance; Fu Shimin also thanks the New Zealand Ministry of External Relations and Trade, the M.E.C. Hettley Indigenous Grasslands Research Trust, and Maney University for financial support.

**REFERENCES**