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

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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 studied were 3, 6, 11, 20 and 28 plants m^{-2}. 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, while three remained vegetative irrespective of plant density. While poor plant growth meant that the seed yields recorded were low compared with other trial data for the same cultivar, 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.

INTRODUCTION

Seed yields in temperate forage legumes such as white clover (*Trifolium repens* L; Clifford, 1987) red clover (*T. pratense* L.; Hampton, Rolston and Rowarth, 1998), birdsfoot trefoil (*Lotus corniculatus* L.; Li and Hill, 1989), 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 (Hill, 1998) and the number and size of the secondary crown population (Coolbear, Hill and Efendi, 1994; Fu, 1998).

Guy (1986) recorded a 65% increase in seed yield from a sowing rate of 2 kg ha^{-1} in 45 cm rows c.f. 6 kg ha^{-1}, and concluded that Caucasian clover appears to require space to fully develop branches and flowers for maximum seed yield. With a thousand seed weight of approximately 2.2 g and depending on the success of emergence and establishment, a sowing rate of 2 kg ha^{-1} for Caucasian clover would produce a population of between 60-75,000 plants ha^{-1} . However the optimum plant density to maximise seed production in this species is unknown. The first objective of this study was therefore to determine the effects of plant density on seed yield and its components in Caucasian clover cv. Monaro.

Fu, Hampton and Hill (1999) demonstrated that individual plants (genotypes) selected at random from within cv. Monaro differed significantly in their ability to flower and hence produce seed. The second objective of this study was to determine whether this genotypic seed yield response was affected by plant density.

MATERIALS AND METHODS

The 4.5° radial design (Nelder, 1962) was used for the two experiments. For each a full circle (Nelder 1962; Bleasdale, 1967) was either sown (= cv. Monaro) or planted (= genotype). Each circle contained 80 radii and 25 concentric arcs, with each arc representing one plant density. The two outer-most and four inner-most arcs were used as borders, so that 19 plant densities ranging from 3 to 45 plants m^{-2} were available. From these five (3, 6,11,20,38 plants m^{-2}) were selected for detailed study.

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The site was the Pasture Research Unit at Massey University; the soil type was an Ohakea silt loam (Cowie, 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 (Nitrobug Legume Inoculant, Coated Seed Ltd., Christchurch) following the manufacturer's instructions and hand sown within two hours, placing three seeds per hole at each specified distance along the radius (Bleasdale, 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 3 October 1995 and the cut material removed. Resident weeds were controlled with glyphosate ammonium (5 litre product ha^{-1}) after first covering Caucasian clover plants with vertically cut plastic piping to protect them from the herbicide. Further weed control was by hand in early November and December. Nitrophoska (N:P:K:S = 12:10:10:2) was applied at 200 kg ha^{-1} on 25 November.

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

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Table 1. Effect of plant density on Caucasion clover seed yield and yield components.

Plants m^{-2}	Inflorescences per plant[1]	m^{-2}	Florets per inflorescence	Seeds per inflorescence	TSW (g)	Seed yield (g) per plant	m^{-2}
3	12.0	37.2	121	66	2.26	1.72	5.33
6	8.3	48.1	116	83	2.26	1.22	7.04
11	5.7	61.6	98	69	2.06	0.73	7.85
20	1.0	20.3	111	70	2.22	0.16	3.18
38	0.3	11.5	108	65	2.12	0.05	1.91
LSD P<0.05	3.35		NS	NS	0.02	0.47	4.29

[1] assessed at the final harvest on 25 February.

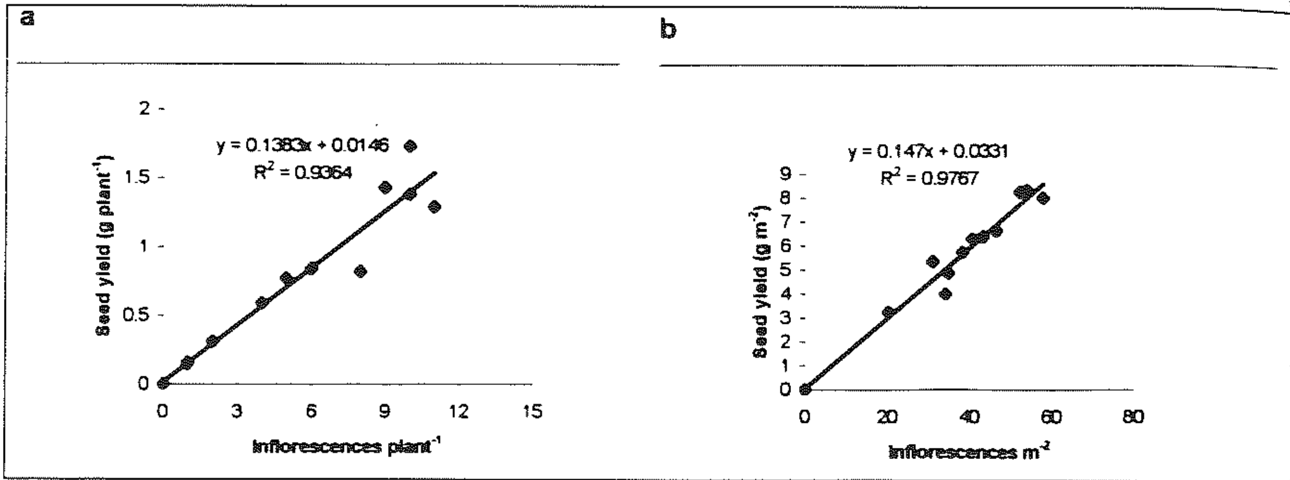

Figure 1. Relationship between inflorescence number and a) seed yield per plant and b) seed yield m^{-2} in Caucasian clover cv. Monaro.

dried at room temperature (ca. 24°C) for three months before florets per inflorescence were recorded. Seed number per inflorescence was recorded from five inflorescences taken at random from the total. Seeds were harvested by rubbing florets on a stippled rubber pad, sieving to remove trash, and pure seed obtained using an air column blower. Germination and thousand seed weight were determined using internationally agreed methodology (ISTA, 1996). By using individual plants from within each density as replicates (Bleasdale, 1967), data were processed using analysis of variance and Fisher's LSD test at P<0.05 (SAS Institute Inc., 1990).

Genotype

Secondary crown segments were cut from rhizomes arising from the primary crown of 12 genotypes from within cv. Monaro (Fu *et al.*, 1999) and potted up (Fu, 1998). Ten weeks later (15 November 1995) plants were transplanted into the radial trial with six rows per genotype along the radius. Management was as described for the seed sown radial and inflorescence and seed yield data were collected from nine plants per genotype from the same five densities.

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 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 83-89%) 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 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 2. Effect of plant density on Caucasian clover inflorescence number and seed yield per plant.

	Plants m^{-2}	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G12	G13	LSD(P<0.05) Genotype
	3	26.7	23.7	2.7	13.0	5.3	24.0	10.0	0	0	10.7	13.0	0	9.19
Inflorescences	6	15.3	12.7	1.3	8.0	7.3	8.7	5.7	0	0	4.7	7.5	0	8.43
per	11	7.0	7.0	1.7	5.7	0	3.7	1.7	0	0	1.3	4.0	0	4.02
plant	20	1.7	1.3	0.7	1.3	0	2.0	0	0	0	0	1.5	0	1.94
	38	1.0	0.7	0.7	1.0	0	0	0	0	0	0	1.0	0	NS
LSD P<0.05		5.3	3.6	NS	4.2	NS	8.8	6.1	-	-	8.8	3.5	-	
	3	1.53	1.88	0.16	0.98	0.67	1.49	1.00	0	0	0.44	0.45	0	1.00
Seed	6	1.39	1.11	0.15	0.62	0.64	0.47	0.49	0	0	0.35	0.75	0	0.74
yield	11	0.89	0.58	0.09	0.55	0	0.44	0.10	0	0	0.09	0.23	0	0.39
(g)	20	0.16	0.17	0.07	0.19	0	0.24	0	0	0	0	0.07	0	0.23
per plant	38	0.13	0.08	0.06	0.06	0	0	0	0	0	0	0.05	0	NS
LSD P<0.05		0.51	0.71	NS	0.80	NS	0.93	0.66	-	-	NS	0.20	-	NS

significantly from yields from 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). Three 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, inflorescence 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 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 inflorescence 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 performance producing only 12 inflorescences and 1.7 g seed per plant for the cultivar trial, and ranging from 0 to 27 inflorescences and 0 to 3.1 g seed per plant in the genotype trial. There were two possible reasons for this poor performance. Firstly the site was a poor one for seed production, becoming water logged 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.

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 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 uninhibited production of secondary crowns (Fu, 1998).

Seed yield depended almost entirely on inflorescence number, as the number of florets 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 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 three remaining entirely vegetative despite an environment which allowed floral induction and expression. As plant density increased, genotypes with poor numbers of inflorescences at low density ceased to produce inflorescences. The reason for the genotype 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.* (1994) noted that root reserves were likely to be the source of assimilates for driving reproductive development in this species, and Fu (1998) demonstrated a significant relationship (R^2 = 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 restricted as plant density increased, and as a result reproductive development was impeded.

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