The effect of plant density on seed yield of two cool tolerant soybean cultivars in Canterbury

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Abstract

The effects of plant density on seed yield of two cool tolerant soybean cultivars were examined in two consecutive seasons at the same site at Lincoln University, Canterbury. In the first season (2000/2001) 25 plant densities ranging from 2 to 84 plants/m^2 were established using a systematic (radial) trial design, while in the second season (2001/2002) 5 plant densities (from 20 to 80 plants/m^2) were established in replicated plots using a randomised complete block design. Soybean seed yield increased in both seasons as plant density increased to 40 plants/m^2, but did not differ among plant densities ranging from 40 to 77 plants/m^2. Seed yields ranged from 214 to 395 g/m^2 in 2000/2001 and from 221 to 276 g/m^2 in 2001/2002 depending on density. Cultivar March out yielded cv. Northern Conquest in the first season, but the reverse occurred in the second season. There was no cultivar x plant density interaction for seed yield in either season. At this site, plant populations higher than 40 plants/m^2 did not result in further increases in seed yield because pod number per plant and individual seed weight decreased.

Additional key words: *Glycine max*, radial trial design, pod number, seed weight

Introduction

Soybean (*Glycine max* [L.] Merrill.) is now being grown commercially in cool temperate environments such as those of Sweden and the United Kingdom following the release of cool-tolerant cultivars (Turff and Luers, 1999). In New Zealand, previous attempts at commercial soybean production were largely unsuccessful because the cultivars available lacked cold tolerance, could not be sown before late November and did not reach harvest maturity in the field (McCormick, 1974; McCormick and Anderson, 1981).

In the 1999/2000 season, the seed yield potential of four cool tolerant soybean cultivars, Northern Conquest, Maypole, Alta and March, was examined at five New Zealand locations (Rahman *et al.*, 2002). Seed yields, which ranged from 1.4 to 3.7 tonnes/ha depending on cultivar and location, compared favourably with international soybean yields (Tompkins and Snipe, 1997). A target plant population for these trials had been 50 plants/m^2, but actual populations ranged from 19 to 46 plants/m^2 (Rahman *et al.*, 2002). In a series of sowing date trials in the 1999/2000 and 2000/2001 seasons at Lincoln, seed yields for these same cultivars ranged from 0.8 to 2.6

t/ha (Rahman, 2002), but once again, plant populations were only between 30 – 35/m^2. While this range of populations was similar to that reported from the USA (Egli, 1988; Wells, 1991), the optimum plant population for cv. Northern Conquest and other 'Northern Soya' breeding material in the UK is 60 – 70 plants/m^2 (Turff and Luers, 1991).

For maximum yield, the optimum soybean plant density is dependent on the environment in which the plants are grown (Johnson *et al.*, 1982; Wells, 1993). The objective of this research was to determine the effect of plant density on the seed production of two cool tolerant soybean cultivars in the Canterbury environment.

Materials and Methods

Two experiments in consecutive seasons in adjacent paddocks were conducted at the Horticulture Research Area of Lincoln University, Canterbury (Lat. 43° 38'S, Long. 172° 30'E). The soil was a Wakanui silt loam (Hewitt, 1972), ex wheat in 2000 and pasture in 2001. Phosphorus and potassium levels (microgram/g soil) were 22 and 11 in 2000 (Rahman, 2002) and 17 and 10 in 2001 (Mwakangwale, 2003). The pH was 5.7 for both sites. Two cool tolerant soybean cultivars, Northern Conquest and March were used in both seasons.

2000/2001 Season

Twenty-five plant densities ranging from 2 to 84 plants/m^2 were established using the systematic (radial) design (type 1A) of Nelder (1962). This design provides an almost rectangular (square) plant arrangement (so that the shape of the area occupied by each plant remains constant but the area available per plant increases systematically with distance from the centre of the circle). The position of each plant is fixed by the intersection of the radius and arc of the concentric circle. The dimensions for the design were calculated following Bleasdale (1967). Two complete circles were used to accommodate the experiment. Each of these was divided into quarters (20 radii each), which provided eight quarter-circles in which the two cultivars were assigned randomly, thus providing four replicates per cultivar and plant density.

The intersection of the radius and the arcs was indicated using a pre-marked rod, and two seeds were hand sown at each marked position. After the first radius was sown, the marked rod was rotated by 4½° (i.e. moved 70.8 cm around the circumference of the outmost arc) and the next radius was sown. This process continued until all radii had been sown.

The site had previously been ploughed, harrowed and rolled to produce a seed bed and the pre-plant herbicide Treflan (trifluralin 400 g/litre) was incorporated at 1.5 litres product/ha one week before sowing, which took place on 12 November 2000. Lasso (alachlor 480 g/litre) at 6 litres product in 300 litres water/ha was applied one day after sowing. Seedlings were hand thinned to one per position at 35 days after sowing. No fertiliser, fungicide or insecticide was applied. Any weeds which subsequently appeared were removed by hand.

It was not possible to intensively sample from all 25 plant densities, and six (6.7, 10.8, 17.3, 27.8, 44.7, 71.6 plants/m^2) were chosen to represent a plant density range. When >95 % of the pods per plant had become brown (Egli, 1998), five plants from each replicate of these six selected plant densities were cut by hand at ground level, bagged and ambient air dried for six weeks under cover. Plant height (m) and number of main stem nodes were then recorded before the plants were divided into three (branches, main stem below [nodes 0 – 8] and main stem above [above node 8]). From each section the number of flower sites (comprising abscission scars, empty and filled pods), number of pods (those with at least one seed ≥4.00 mm), and number of seeds (≥4.00 mm) per pod were recorded. Pods were then hand shelled and seed weight (4 replicates of

20 seeds) and seed yield recorded. Seed weights presented are at the ambient seed moisture content of 12.5 % (Rahman, 2002). The percentage reproductive abortion was calculated from the number of flower sites per plant that failed to develop into mature pods.

In addition, seed yield only was recorded from all densities except the three lowest and two highest using the method described above.

2001/2002 Season

For this experiment a conventional plot (4 x 1.8 m) design (two way randomised block) was used with the two cultivars and five plant densities (20, 35, 50, 65 and 80 plants/m^2), and with four replicates of each treatment. Following seed bed preparation and the same pre-plant herbicide treatment as the previous year, seeds were hand sown on 31 October 2001 at the sowing rates and inter-row spacings required for the target plant densities (Mwakangwale, 2003). Final plant densities achieved are presented in Table 4. As in the previous season, no fertiliser, fungicide or insecticides were used, and weeds were hand removed when required.

When >95 % of the pods per plant had become brown, all plants from two metres of the middle two rows of each plot were hand cut at ground level, tied in bundles, and hung on hooks in a shed to ambient air dry to around 13 % seed moisture content. Five plants per plot were selected at random from the bundles and the number of pods per plant and seeds per pod counted. All pods were then threshed by placing them in a plastic bag and gently but repeatedly beating them with a soft broom until all seeds had been removed from the pods. Seeds were sieved to remove pod material and weighed. Seed weight was recorded using four replicates of 50 seeds per plot. All seed weights are expressed at 12.5 % seed moisture content.

Statistical Analysis

2000/2001

In a radial trial, the treatments (density) are not randomly assigned. Consequently, the error term may be biased. It was assumed that there was no environmental variation around the arcs which could cause differences in results. Since samples were not taken from adjacent arcs, each sampled area was regarded as being independent. For statistical analysis of data a split-plot design was selected where cultivar was the main plot and plant density the sub-plot, replicated four times (R. Sedcole, Mathematics and Statistics Group, Lincoln University, pers.comm.). Analysis of variance was done using a Genstat statistical package (Lawes Agricultural Trust, 1997), while curves were fitted using the Minitab statistical package and Sigma Plot graphics programmes (Rahman, 2002).

2001/2002

Analysis of variance for all parameters was done using the Genstat Sixth Edition statistical package.

Results

2000/2001

In 2000/2001 plants of cv. March were taller and had more main stem nodes and more branches than those of cv. Northern Conquest, but there were no differences in the number of flower sites or reproductive abortion (Table 1). There were no significant cultivar/plant density interactions for any of these characters. However plant density had a significant effect on all five of these characters (Table 1), as both plant height and percentage reproductive abortion increased as plant density increased, while main stem node number, branches per plant and flower sites all decreased. No significant differences were recorded for any of these characters at either the two highest or two lowest plant densities (Table 1).

Table 1. Effect of plant density and cultivar on soybean morphological and reproductive characters, 2000/2001.

Cultivar	Plant height (m)	No. of nodes on the main stem	No. of branches per plant	No. of flower sites per plant	Reproductive abortion (%)
Northern Conquest	0.38	13.0	3.2	72.6	45
March	0.46	15.0	3.6	74.4	44
LSD (P<0.05)	0.03	0.32	0.35	ns	ns
% CV	3.3	1.0	4.6	10.6	2.2
Plant Density (plants/m^2)					
6.7	0.37	14.8	4.6	119.2	32
10.8	0.38	14.8	4.9	100.2	38
17.4	0.42	14.3	4.0	77.2	46
27.8	0.45	14.0	3.3	61.7	49
44.7	0.47	13.2	2.1	44.0	51
71.6	0.45	12.7	1.7	38.8	53
LSD (P<0.05)	0.04	0.81	0.73	10.91	3.7
% CV	10.7	5.7	20.9	14.5	8.3
Significant interaction	nil	nil	nil	nil	nil

The cultivars did not differ in the number of pods per plant or seeds per pod, but seeds of cv. March were significantly heavier than those of cv. Northern Conquest, and cv. March significantly out-yielded cv. Northern Conquest (Table 2).

Pod number per plant decreased as plant population decreased, and only at the two highest plant densities were these differences not significant. However seed number per pod did not differ among the plant densities (Table 2). On a per plant basis, seed number decreased with increasing plant density (Figure 1a), but increased on a per unit area basis (Figure 1b). Individual seed weight decreased as plant density increased (Figure 1c) but did not differ at the two highest plant densities (Table 2).

Seed yield per plant decreased significantly with each successive increase in plant density up to and including 44.7 plants/m^2, but there was no difference between the two highest plant populations. Per unit area there was again no significant difference in seed yield between the two highest plant populations (Table 2), although seed yield did increase with increasing plant population (Figure 1d). When all seed yield data for both cultivars were plotted against the corresponding 21 plant densities (Figure 2), seed yield appeared to reach a plateau at 52.3 plants/m^2. At this plant population the seed yields for cv. Northern Conquest and cv. March were 330 g/m^2 and 437 g/m^2 respectively. Seed yields for the two cultivars did not differ among the four highest plant densities (i.e. from 44.7 to 71.3 plants/m^2).

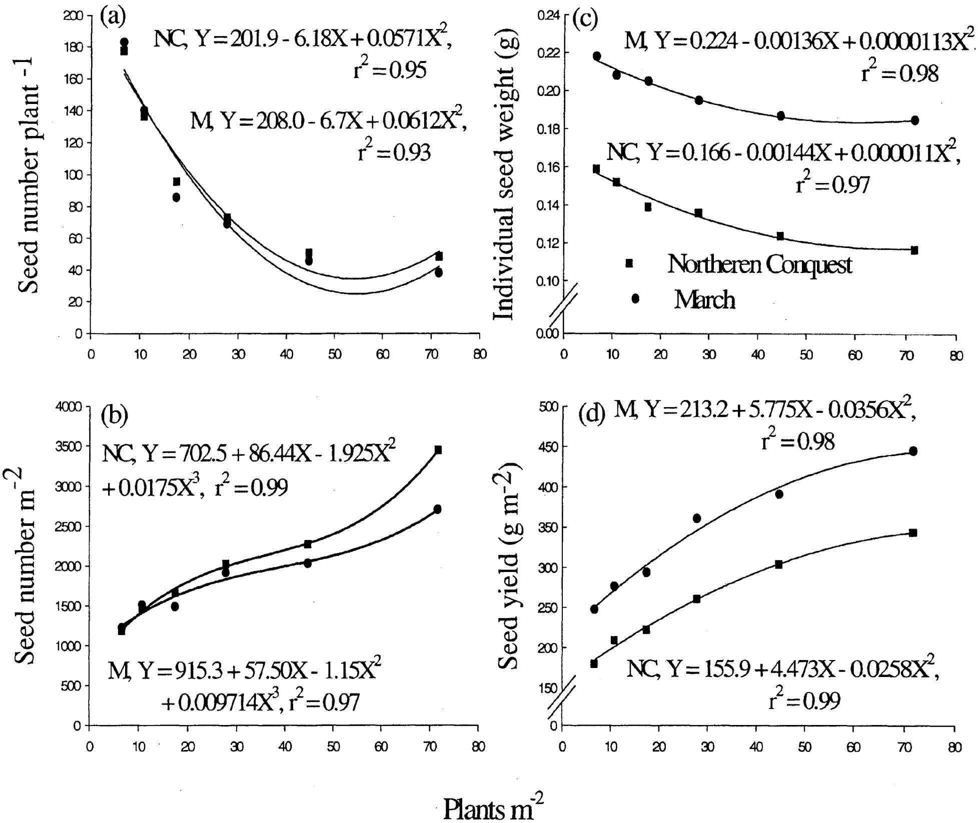

Figure 1. Relationship between plant density and (a) seed number/plant, (b) seed number/m^2, (c) individual seed weight and (d) seed yield in two soybean cultivars (NC – cv. Northern Conquest; M = cv. March) in 2000/2001.

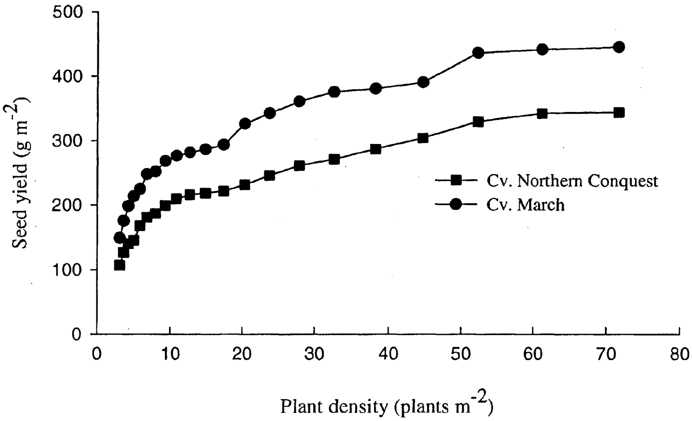

Figure 2. Effect of plant density on seed yield of two soybean cultivars in 2000/2001.

Table 2. Effect of plant density and cultivar on soybean seed yield and its components, 2000/2001.

Cultivar	Pods per plant	Seeds per pod	Seed weight (g)	Seed yield	
				g/plant	g/m²
Northern Conquest	42.1	2.30	0.138	13.3	253.4
March	44.0	2.12	0.200	17.9	335.8
LSD (P<0.05)	ns	ns	0.008	3.6	81.9
% CV	9.7	11.3	2.2	10.3	12.4
Plant Density (plants/m²)					
6.7	81.7	2.20	0.188	31.9	213.8
10.8	62.9	2.19	0.180	22.5	242.8
17.4	42.0	2.15	0.172	14.8	257.8
27.8	31.8	2.22	0.165	11.2	310.8
44.7	21.5	2.24	0.155	7.8	357.5
71.6	17.4	2.18	0.151	5.5	394.8
LSD (P<0.05)	8.6	ns	0.007	3.2	44.3
% CV	19.6	18.4	4.4	20.1	14.8
Significant interaction	nil	nil	nil	nil	nil

The effects of plant density and cultivar on plant architecture and therefore contribution to seed yield are demonstrated in Table 3 where at the lowest plant density some 60 % of the seeds were produced on the branches, compared with only around 25 % at the highest plant density. The two cultivars differed only in terms of the contribution of seed yield from the top and bottom sections of the main stem, as cv. March had around 10 % more seeds produced on the top section of the main stem, irrespective of plant density (Table 3).

Table 3. Contribution to seed yield from the branches and below and above the 8th node on the main stem of soybean c.v Northern Conquest and March grown at six plant densities 2000/2001.

	Contribution to seed yield (%)					
Plant density (plants/m²)	cv. Northern Conquest			cv. March		
	Branch	Below[1]	Above[2]	Branch	Below	Above
6.7	60	31	9	65	23	12
10.8	57	38	5	58	27	15
17.4	49	43	8	50	32	18
27.8	45	43	12	40	39	21
44.7	31	55	14	25	52	25
71.6	25	67	8	22	60	18

[1] from pods 8th node and below
[2] from pods above the 8th node

2001/2002

In the second season, significant cultivar differences were recorded for pods per plant, seed weight and seed yield but not seeds per pod (Table 4), but in contrast to the first season, cv. Northern Conquest had more pods and a higher seed yield than cv. March.

Pod number per plant decreased significantly as plant density increased up to 60 plants/m^2, but there was no difference between the two highest plant densities (Table 4). There was a significant interaction between cultivar and density for pod number per plant (Table 4) because for cv. March pod number decreases for each increase in plant density were all significant, whereas in cv. Northern Conquest, pod number per plant did not differ at the two highest plant densities (data not presented). Seed number per pod did not differ among the densities, while seed weight decreased as plant density increased, but differences among plant densities were not always significant. Seed yield per plant and per unit area did not differ among the three highest plant densities but the latter was lowest at the two lowest plant densities (Table 4).

Table 4. Effect of plant density and cultivar on soybean seed yield and its components, 2001/2002.

Cultivar	Pods per plant	Seeds per pod	Seed weight (g)	Seed yield	
				g/plant	g/m^2
Northern Conquest	24.7	2.34	0.142	8.7	294.0
March	19.4	2.32	0.153	7.2	238.2
LSD (P<0.05)	1.2	ns	0.058	1.4	31.8
% CV	8.3	1.3	3.1	10.4	14.6
Plant Density ($plants/m^2$)					
17	38.4	2.45	0.161	16.2	221.0
29	25.7	2.35	0.152	10.8	241.4
40	20.2	2.30	0.148	7.1	270.5
60	13.7	2.29	0.144	4.9	272.8
74	12.2	2.28	0.136	3.9	275.5
LSD (P<0.05)	1.9	0.18	0.009	4.1	22.9
% CV	9.0	1.6	6.0	21.4	12.8
Significant interaction	**	nil	nil	nil	nil

Discussion

Increasing plant density changed soybean plant architecture by increasing plant height and decreasing branch numbers. Plant height increased with increasing plant density because of shading which usually results in stem elongation (Dominguez and Hume, 1978). However the number of nodes on the main stem decreased, suggesting internode elongation was responsible for the height increases (Chanprasert, 1988). Morphological changes in plants are induced when plant density is increased mainly because of competition for light when soil fertility and moisture are not limited (Herbert and Litchfield, 1984). Greater branching at low plant density is considered a response to the increased amount of far-red light available during vegetative development (Kasperbauer, 1987; Board, 2000).

Both the number of flower sites and pods per plant decreased with increasing plant density, while reproductive abortion increased. Flower sites were reduced because there was a reduction in the number of nodes, but also because fewer flowers were produced (Rahman, 2002), a result also reported by Dominguez and Hume (1978). In soybean, reproductive abortion can range from 40 to 80 % depending on cultivar and environmental conditions (Heitholt *et al.*, 1986). Up to 70 % of this loss is attributed to a loss of flowers (van Schaik and Probst, 1958), and the rest due to the abortion of small (≤ 2 cm long) pods (Weibold *et al.*, 1981). Reproductive abortion is usually greater on the branches, the lower part of the main stem, and at the top nodes of the main stem (Weibold *et al.*, 1981; Heindl and Brun, 1984). In the present study reproductive abortion was greatest at the top nodes, followed by the branches, and lowest at the bottom nodes (Rahman, 2002).

Chanprasert (1988) concluded that at low plant density reproductive abortion was mainly due to intra-plant competition, whereas at high plant density, inter-plant competition was responsible. Many authors (e.g. Weibold *et al.*, 1981; Brun and Betts, 1984; Raper and Kramer, 1987) have explained reproductive abortion as resulting from a shortage of available photoassimilates, but others (e.g. Carlson *et al.*, 1987; Kokuban and Honda, 2000) consider that intra-plant competition for growth hormones may also be involved. This has yet to be resolved.

Soybean seed yield did not differ in either year among plant densities ranging from 40 to 77 plant/m^2, and thus at least at this site, there was no yield advantage in achieving a plant density of 60 – 70 plants/m^2 as recommended for cool tolerant cultivars in the UK (Turff and Luers, 1999). The seed yield response to increasing plant density reaches a phase where there is no further change to seed yield (Duncan, 1986), and these results suggest that at Lincoln, this population is between 40 and 50 plants/m^2. A population of 50 plants/m^2 is considered optimum in Brazil and Indonesia (Pearson *et al.*, 1981) and for many cultivars in the USA (Egli, 1988; Wells, 1991). Provided that the plant density achieved is sufficient to allow the crop to develop a canopy able to intercept >95% of incoming photosynthetically active radiation by the time of early reproductive growth (Johnson *et al.*, 1982), time of sowing is likely to have a greater potential impact on seed yield than plant density (Lawn *et al.*, 1977; Wells, 1993; Rahman, 2002). Alternatively, if poor growing conditions restrict soybean plant growth (Wells, 1993) then higher plant densities (60 – 70 plants/m^2) may be required to allow the crop to achieve full canopy cover, as previously reported in Canterbury by Kuman (1981).

Plots in these trials were hand harvested, but for machine harvesting, plant density may have an effect on the ease of harvesting and harvesting losses. At the lower densities, over 50 % of the seed yield was contributed by the branches, which were mostly found at nodes 1 to 3 (Rahman, 2002), whereas at the higher densities, the contribution from the main stem below the 8th node primarily from nodes 4 to 8 (Rahman 2002) increased as fewer branches were produced. Dominguez and Hume (1978), Chanprasert (1988) and Rahman (2002) have all reported that the height above the ground of the lowest pod increases with increasing plant density, which presumably would increase the ease of harvesting. However, whether pod position at a density of 40 versus 70 plants/m^2 has any effect on machine harvest efficacy and efficiency has yet to be determined.

Cv. March produced heavier seeds than cv. Northern Conquest in both seasons irrespective of plant density. Rahman (2002) found that both cultivars had similar seed growth rates, but that cv. March had a longer seed filling duration. In the 2000/2001 season this increased seed size explained the higher seed yield in cv. March, as the other seed yield components did not differ between the two cultivars. However in the following season, despite having smaller seeds than cv. March, cv. Northern Conquest out-yielded cv. March because it had five more pods per plant. Why this occurred is not known, as node number and reproductive abortion were not determined in the 2001/2002 season.

Conclusion

Seed yield in soybean is strongly dependent on the total dry matter accumulated by the beginning of seed development (Board *et al.*, 1996); in both seasons the relationship between total dry matter at this time and seed yield was highly significant (r^2 = 0.94, Rahman (2002); r^2 = 0.90, Mwakangwale (2003)). Dry matter production is also related to plant density, but at plant densities greater than 40 plants/m^2, dry matter at the beginning of seed development did not differ significantly (Rahman, 2002; Mwakangwale, 2003). As Egli (1988) has demonstrated that plant density does not influence the partioning coefficient (i.e. reproductive mass/total biomass) in soybean, seed yield increases with further increases in plant population (i.e. >40 plants/m^2) would not therefore be expected, and did not occur. Therefore at this site, 40 plants/m^2 was optimum for these two cultivars.

Acknowledgements

This work was undertaken while M.M. Rahman and M.B. Mwakangwale were postgraduate students at the New Zealand Seed Technology Institute, Lincoln University, with the support of a NZODA Scholarship for the former and a DANIDA Scholarship for the latter. The authors thank Canterbury Seed Co. Ltd and the New Zealand Institute for Crop and Food Research Ltd for the supply of seed lots, and Mr Don Heffer and Mr Dave Jack for technical assistance.

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