Response of pea seed yield to water deficit

R.J. Martin, D.R. Wilson, M.U. Riddle and R.N. Gillespie
New Zealand Institute for Crop & Food Research, Private Bag 4704, Christchurch

Abstract

The effect of water deficit on pea seed yield was determined by subjecting a crop of cv 'Crusader' to eight irrigation treatments in a field experiment at Lincoln. A mobile shelter excluded all rainfall by covering the crop automatically whenever rain occurred, but otherwise left it exposed to prevailing weather. The two extreme treatments were one that was fully irrigated (FULL) and another that received no water after crop emergence (NIL). The six intermediate treatments imposed maximum potential soil moisture deficits (MPSMD) at various times during crop development. Total water use ranged from 98 to 404 mm in the NIL and FULL treatments, respectively. Seed yield decreased linearly with increasing MPSMD, from 5.3 t/ha in FULL to 3.3 t/ha in NIL. The decrease was mainly due to reduced pod number per plant. In contrast, the number of peas per pod increased with increasing MPSMD. Seed weight was unaffected by the irrigation treatments. The seed yield response was similar to one found for cv 'Rovar' in previous experiments at Lincoln, but the effect of water deficit on the yield components differed between the cultivars.

***Additional keywords*:** Pisum sativum L, peas, irrigation, yield, leaf area.

Introduction

Peas are very sensitive to drought stress (Salter, 1962, Stoker, 1973). The response of pea yield to drought stress has been quantified (Wilson *et al*., 1985, Martin and Jamieson, 1996) using the Potential Soil Moisture Deficit deficit model of Penman (1971). They showed a reduction in pea yield of 9 kg/ha for every mm of PSMD over 49 mm. As part of a programme to develop a computer simulation model to predict the growth of peas, we needed to know not only how the yield responded to PSMD, but also how the yield components developed and responded to drought stress. To do this, an experiment was carried out in the Crop & Food Research rainshelter at Lincoln.

Materials and Methods

The rainshelter at Lincoln, Canterbury, New Zealand, is a mobile 55 m x 12 m greenhouse which automatically covers the experimental crop during rainfall, but is otherwise positioned some 50 m away (Martin *et al*., 1990). The soil is a deep (>1.6 m) Templeton sandy loam (*Udic Ustochrept*, USDA Soil Taxonomy) (New Zealand Soil Bureau, 1968) with an available water holding capacity of c. 190 mm/m of depth. The experimental site was in pasture for the previous two years, with a clover trial prior to that. Quicktest soil test results prior to any cultivation were pH 6.4, Olsen P 11, K 9, Ca 10, Mg 13, Na 12, and S 5. The pasture was sprayed off and ploughed on 24 June 2004, and cultivated with power harrows and Cambridge rolled prior to sowing.

`Crusader' peas (221 mg seed weight) were sown in rows 13 cm apart with an Amazone drill on 28 October 2004 at a seeding rate of 300 kg/ha, which achieved a plant population of 70 plants/m^2. The crop area was sprayed with Gardoprim at 2.0 L/ha and Karate at 40 ml/ha in 300 L water/ha to prevent any insect damage. Temporary sprinkler irrigation and bird netting were set up to assist even establishment. The plots were watered regularly through germination until they were established. Emergence counts were taken daily through this period.

Eight irrigation treatments were established in a randomised complete block design with three replicates. The treatments were designed to subject the crops to drought of varying duration at different times during growth:

FULL Full irrigation to replace actual soil moisture deficit weekly

NIL No irrigation after the pea crop was fully established

N3:I9 As 2 for 3 weeks (to 12 node stage), then same amount of water as 1 for 9 weeks

N6:I6 As 2 for 6 weeks (to full flower), then same amount of water as 1 for 6 weeks

N9:I3 As 2 for 9 weeks (to pod fill), then same amount of water as 1 for 3 weeks

I3:N9 As 1 for 3 weeks (to 12 node stage), then no water for 9 weeks

I6:N6 As 1 for 6 weeks (to full flower), then no water for 6 weeks

I9:N3 As 1 for 9 weeks (to pod fill), then no water for 3 weeks

Treatments were applied when the trickle irrigation system was operational. This was on 29 November, when the soil moisture deficit to 1.6 m was 30 mm. Each plot had its own trickle irrigation supply, with emitters spaced 300 mm x 450 mm apart, and was watered weekly. All treatments scheduled for irrigation received the same amount of water, equal to the water use of the no drought (fully irrigated) treatment during the previous week. This was measured to 1.6 m by neutron probe and time domain reflectometry. The PSMD was calculated for each treatment by adding the maximum weekly Penman evapotranspiration from the no drought treatment to the irrigation deficit (the difference between the amount of water applied to the treatment and to the no drought control). Penman evapotranspiration was calculated from data collected from the Lincoln weather station 300 m away.

Fungicide applications to prevent foliar diseases were made on 23 December (Bravo at 2.0 L/ha and Cereous at 250 ml/ha in 300L water) and 21 January (Folicur at 150 ml/ha Ridomil 72MZ at 2.5 kg/ha in 400L water/ha).

Biomass harvests were taken on 13 December (start of flowering), 4 January (early pod stage), 24 – 27 January (mid pod fill) and 8-23 February (maturity). For the first three harvests, the plants in two 0.5 m^2 quadrats were counted and removed to a laboratory for further analysis. In the laboratory the number of branches on all the plants were counted, then a 10 plant subsample taken for node counts; leaf and stipule senescence scores, area and dry weights; stem and branch weights; and pea and empty pod numbers and weights. On the remainder of the sample, vegetative dry weights and pea and pod numbers and weights were measured

The final harvest date of each treatment varied as plants in more drought stressed plots matured earlier (Table 1). Similar measurements were taken as for the previous harvests, except that separate leaf, stem and stipule measurements were not taken.

From the final harvest a 1,000 pea sub-sample was retained for quality tests. A visual colour test scored peas for stains and bleaches. Size distributions were measured by shaking peas successively through 7.14 mm, 6.75 and 5.95 mm sieves, and weighing those left on each sieve. An overnight soaking test was used to check the proportion of 100 g of seed that softened and swelled. Germination tests were carried out on two samples of 100 seeds at 20^{o}C, with counts done on day five and day ten. The results were analysed with analysis of variance using the GenStat statistical package (GenStat Committee, 2003).

Results

From 6 November (mean 50% emergence in each plot) to 17 November (over 95% emergence) 16 mm water was applied through the sprinkler system to prevent capping of the soil. Trickle irrigation commenced on 29 November and 25 to 58 mm was applied weekly depending on the actual water used by the fully irrigated treatments. The total water application to the fully irrigated plots was 437 mm, compared to Penman PET of 476mm, and water use of 404 mm. In contrast, the nil irrigated treatment used 98 mm from soil moisture reserves, extracting water to a depth of 1m (Figure 1). The MPSMD experienced by treatments ranged from 91 (FULL) to 391 mm (NIL)

Table 1. Water applied, water use, and maximum potential soil moisture deficit (MPSMD) (mm), date when MPSMD occurred and harvest date for each treatment.

Treatment	Full	Nil	N3:I9*	N6:I6	N9:I3	I3:N9	I6:N6	I9:N3
Sprinkler**	16	16	16	16	16	16	16	16
29 Nov	30	0	0	0	0	30	30	30
6 Dec	25	0	0	0	0	25	25	25
13 Dec (H1)	30	0	0	0	0	30	30	30
20 Dec	30	0	30	0	0	0	30	30
28 Dec	34	0	34	0	0	0	34	34
3 Jan (H2)	34	0	34	0	0	0	34	34
10 Jan	26	0	26	26	0	0	0	26
17 Jan	58	0	58	58	0	0	0	58
24 Jan (H3)	51	0	51	51	0	0	0	51
31 Jan	37	0	37	37	37	0	0	0
7 Feb	38	0	38	38	38	0	0	0
14 Feb	28	0	28	28	28	0	0	0
Total applied	437	16	352	254	119	101	199	333
Water Use	404	98	333	224	133	200	288	377
MPSMD	91	391	171	262	362	316	249	133
Date of MPSMD	12 Dec	7 Feb	27 Dec	16 Jan	30 Jan	9 Feb	17 Feb	21 Feb
Harvest Date	23 Feb	8 Feb	21 Feb	16 Feb	9 Feb	10 Feb	18 Feb	22 Feb

* No water for 3 weeks, Irrigated for 9 weeks

** 16 mm applied at c. 2 mm per day for eight days after emergence

At first flower and early pod stage there was no significant (P<0.05) effect of irrigation treatment on LAI or total dry weight. However, by mid pod fill, the LAI of the stressed treatments Nil and, N9I3 (mean 0.75) was only a third of FULL, N3I9 and I9N3 and I3N9 (mean 2.26), with the other treatments between (mean 1.4). Total dry weights were much less affected by drought stress (Table 2), there being only a 30% reduction from unstressed to stressed treatments. However, by maturity, there was a two fold difference in total biomass, with Full, N3I9, I6N6 and I9N3 averaging 10 t/ha, I3N9 7.5 t/ha and the other three treatments 6 t/ha.

The irrigation treatments had no effect on node numbers (12.0) at early flower, and no effect on the number of vegetative (15.3) nodes at early pod stage. Treatments not irrigated by early pod stage had significantly more nodes with pods than irrigated treatments, but irrigated treatments had more nodes with flowers on them, so the total number of nodes (18.4) did not differ between treatments (Table 3).

Flowering had finished by mid pod fill. At this harvest there was no significant effect of irrigation treatment on the number of vegetative nodes (17), but the low stress treatment to this stage, i.e. Full, N6I6, N9I3 and I3N9 1378 averaged 6.5 nodes with pods on them, compared to 3.1 nodes for the other treatments, resulting in 23.9 total nodes for the low stress treatments and 19.7 nodes for the

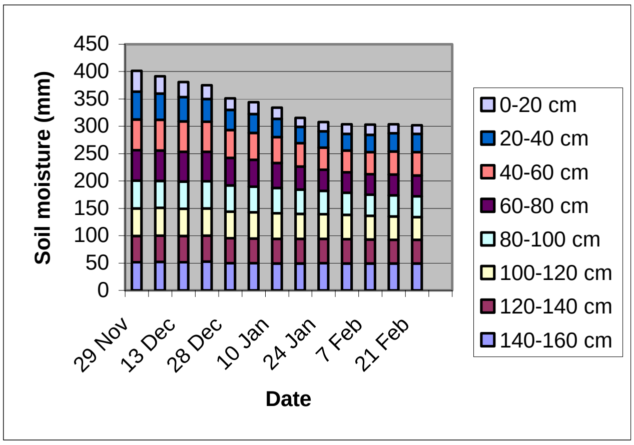

Figure 1. Soil moisture profiles for the nil treatment from 29 November to 21 February

Table 2. Crop growth at early flower (13 December), early pod (4 January), mid pod fill (24-27 January) and at maturity

Treatment	LAI at early flower	Total DWT at early pod	LAI at early pod	Total DWT at early pod	LAI at mid pod	total dwt at mid pod	Maturity total dry weight (t/ha)
Full	0.92	89.6	3.73	407	2.67	891	10.98
Nil	0.70	87.2	2.06	336	0.82	660	5.77
N3:I9*	0.75	88.1	1.92	320	2.15	936	9.88
N6:I6	0.77	91.0	1.60	309	1.33	625	6.22
N9:I3	0.84	101.7	1.75	358	0.68	642	5.94
I3:N9	0.66	71.9	2.50	330	1.41	696	7.49
I6:N6	0.90	90.3	2.75	312	1.47	874	9.66
I9:N3	0.94	109.0	2.70	382	2.01	859	10.61
LSD (5%)**	0.301	30.84	1.226	113.3	0.603	207.9	2.006

* No water for 3 weeks, Irrigated for 9 weeks)

** Least significant difference at the 5% level (14 degrees of freedom

Table 3. Crop Development at early flower (13 December), early pod (4 January) and mid pod fill (24-27 January)

Treatment	Early flower node no	Early pod total node no	Early pod vegetative nodes	Early pod podded nodes	Early pod flowering nodes***	Mid pod total nodes	Mid pod veg nodes	Mid pod podded nodes	Mid pod wt/pea
Full	12.3	17.9	15.4	0.1	2.4	23.2	17.1	6.1	0.043
Nil	11.7	18.5	15.0	2.0	1.4	18.8	16.5	2.4	0.167
N3:I9*	12.3	18.0	14.9	0.9	2.3	23.5	17.1	6.3	0.07
N6:I6	12.3	18.1	14.8	1.3	2.1	20.3	16.6	3.6	0.143
N9:I3	11.7	18.6	15.7	1.4	1.5	19.6	17	2.6	0.167
I3:N9	12.3	18.4	15.4	0.3	2.7	20.0	16.5	3.6	0.066
I6:N6	11.3	18.9	15.9	0.1	2.9	24.4	17.8	6.5	0.043
I9:N3	12.0	19.1	15.3	0.5	3.3	24.5	17.3	7.2	0.040
LSD (5%)**	0.87	2.04	1.84	0.77	0.90	1.01	1.32	0.86	0.0200

* No water for 3 weeks, Irrigated for 9 weeks)
** Least significant difference at the 5% level (14 degrees of freedom)
*** H2 repro and veg nodes NS

Table 4. Pea yield, at 12 % moisture content, and major yield components for each treatment at maturity.

Treatment	Pea seed yield (t/ha)	Plant no/m^2	Pods/ plant	Initiated peas/pod	Aborted peas/pd	Formed peas/pod	DWT/ pea (g)	Harvest Index
Full	5.27	75.3	9.2	6.1	2.9	3.2	0.21	43.0
Nil	3.32	77.0	4.1	7.3	2.9	4.4	0.20	45.3
N3:I9*	5.37	71.3	10.4	7.2	3.6	3.6	0.21	49.3
N6:I6	3.72	71.3	4.6	7.1	2.5	4.5	0.23	53.3
N9:I3	3.14	64.0	4.7	7.7	2.9	4.8	0.21	45.6
I3:N9	3.85	64.0	6.6	7.2	3.2	4.0	0.21	46.0
I6:N6	4.51	66.3	9.1	6.8	3.3	3.5	0.21	42.7
I9:N3	5.23	70.7	9.8	6.8	3.0	3.8	0.21	45.0
LSD (5%)**	1.050	20.23	3.52	0.58	0.41	0.57	0.024	3.43

* No water for 3 weeks, Irrigated for 9 weeks)
** Least significant difference at the 5% level (14 degrees of freedom)

high stress treatments. At mid pod fill the developing peas were significantly heavier in the heavily stressed treatment Nil, N6I6 and N9I3 (0.16g) than in the other treatments (Table 3).

Compared to the fully irrigated treatment, pea yields were reduced by a third when no water was applied after establishment (Table 4). There was no significant difference in pea yields between Full, N3I9, I6N6, and I9N3 (average 5.1 t/ha) and these were significantly higher than the other four treatments (average 3.5 t/ha).

The irrigation treatments had no significant effect on plant numbers or on wt/pea (Table 4).

The major factor affecting pea yield was the number of pods/plant. The treatments that were not stressed for six weeks after emergence, i.e. Full, N3I9, I6N6 and I9N3, had double the number of pods/plant (9.6 compared to 4.5 pods/plant), but, in contrast, had 20% less formed peas/pod (3.5) than the other treatments (4.4 peas/pod) (Table 4). There was no consistent trend in the number of initiated peas that aborted with increasing water deficits. The Full treatment had less peas initiated per pod (6.1 peas/pod) compared to an average of 7.2 peas/pod for the other seven treatments
(Table 4).

Seed yields decreased linearly with increasing MPSMD (Figure 2). Droughts less than three weeks, either early or late in the growth of the crop, i.e. N3I9 and I9N3, had little effect on seed yield. For droughts longer than three weeks (N6I6, N9I3< I3N9, I6N6), the reduction in seed yield was slightly, but not significantly greater, with early drought than with late drought at similar MPSMD's, as the reduction in pod numbers with early drought slightly outweighed the increase in pea numbers per pod (Table 4).

The number of peas per pod increased with increasing drought stress (Table 4). This was a result of significantly more peas being initiated in each pod. This indicates that the well-watered 'Crusader' plants produced more pods than they could fill, and so aborted peas, so that the remaining peas could be filled. This resulted in there being no significant difference in weight per pea between treatments (Table 4). There was little or no effect of drought stress on seed quality.

Discussion

The relationship between pea seed yield and MPSMD's experienced by this crop (90-400mm), for each additional 1 mm of deficit, around 9 kg/ha of field pea seed yield was lost, irrespective of the timing if the drought (Figure 2). This result was very similar to that obtained in previous rainshelter (Martin and Jamieson, 1996) and field (Wilson *et al.*, 1985) trials with Rovar field peas (Figure 3).

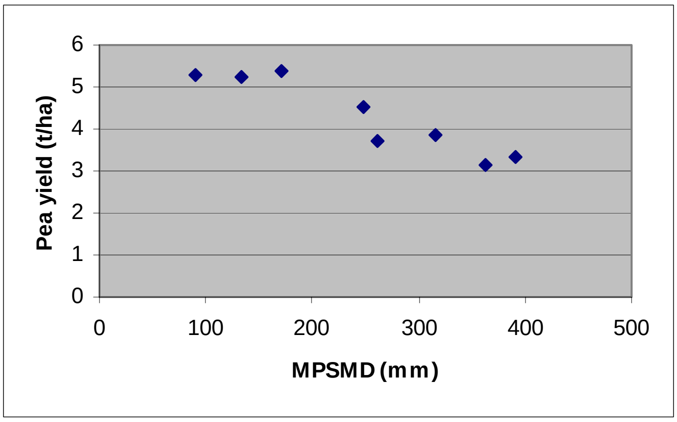

Figure 2. Effect of maximum potential soil moisture deficit (MPSMD) on pea seed yield for each treatment.

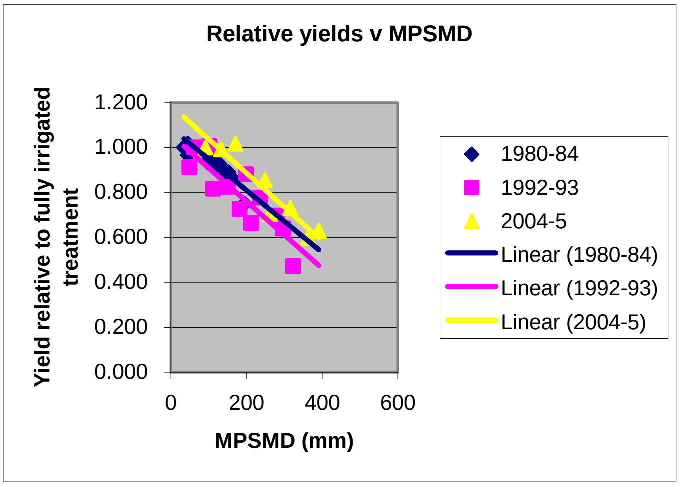

Figure 3. Effect of maximum potential soil moisture deficit (MPSMD) on pea seed yield for each treatment relative to the fully irrigated treatment yield. Data from 1980-84 (Wilson *et al*., 1985), 1992-3, (Martin & Jamieson, 1996) and 2004-5 (this paper)

However, the trend line for Crusader is to the right of those for Rovar (Wilson *et al.*, 1985; Martin and Jamieson, 1996), suggesting that Crusader may be more drought tolerant.

The results of this trial reinforce the recommendations of Martin & Jamieson, (1996) that peas should be irrigated to prevent a deficit of no greater than 90-100 mm to develop (about two weeks of dry weather in a typical Canterbury summer), and water should be then applied to match the deficit being experienced by the crop. If less water than this is applied, then the return interval will be shorter, or else yield will be reduced as described above.

One difference between this trial and previous trials (Wilson *et al*., 1985, Martin and Jamieson, 1996) is that drought had no effect on pea seed size in ‘Crusader’. In previous trials with ‘Rovar’ field peas, irrigation increased pea size, but had no effect on peas/pod. ‘Crusader’ produced more pods than ‘Rovar’, but pea seed size was much smaller. In previous trials, all three yield components have either increased or decreased with drought stress, but pod number per plant was still the most affected (Salter, 1962, 1963; Stoker, 1973; Martin & Tabley, 1981).

Irrigation treatment had no effect on the number of vegetative nodes, but the more stressed treatments produced fewer flowering nodes and pods, but produced podded nodes earlier. This carried through to heavier seed at mid pod fill, but, by maturity, there was no difference in seed weight, although the more stressed treatments matured earlier. More stressed treatments produced fewer pods, but more formed peas/pod, in contrast to Rovar, where drought stress had no effect on peas/pod, but increased pea weight (Martin & Jamieson, 1996)

Overall the relationship between pea seed yield and MPSMD of Crusader peas was very similar to that of Rovar peas, but the two cultivars differed in the components of that seed yield, and this needs to be taken into account in pea growth models.

Acknowledgements

This trial was funded by FRST and FAR. We thank Shane Maley, Michelle Weavers, David, Emma for assistance with the sampling of the trial

References

French, B. K.; Legg, B. J. 1979: Rothamsted irrigation 1964-1976. *Journal of Agricultural Science, Cambridge* **92**: 15-37.

GenStat Committee. 2003. Release 7.1 Reference Manual, Parts 1-3. VSN International, Hemel Hempstead, Hertfordshire, UK.

Martin, R. J.; Tabley, F. J. 1981: Effects of irrigation, time of sowing, and cultivar on yield of vining peas. *New Zealand Journal ofExperimentalAagriculture* **9**: 291-297.

Martin, R. J.; Jamieson, P. D.; Wilson, D. R.; Francis, G. S. 1990: The use of a rainshelter to determine yield responses of Russet Burbank potatoes to soil water deficit. *Proceedings of the Agronomy Society of New Zealand* **20**: 99-101.

Martin, R.J.; Jamieson, P.D. 1996. The effect of timing and intensity of drought on the growth and yield of field peas. *New Zealand Journal of Crop and Horticultural Science* **24**: 167-174.

New Zealand Soil Bureau 1968: General Survey of the soils of the South Island, New Zealand. *Soil Bureau Bulletin* **27**: 404 p.

Penman, H. L. 1971: Irrigation at Woburn. VII. Pp.147-170 *in*: Report Rothamsted Experimental Station for 1970, Part 2.

Salter, P. J. 1962: Some responses of peas to irrigation at different growth stages. *Journal of Horticultural Science* **37**: 141-149.

Salter, P. J. 1963: The effect of wet or dry soil conditions at different growth stages on the components of yield of a pea crop. *Journal of Horticultural Science* **38**: 321-334.

Stoker, R. 1973: Response of viner peas to water during different phases of growth. *New Zealand Journal of Experimental Agriculture* **9**: 73-76.

Wilson, D. R.; Jamieson, P. D.; Jermyn, W. A.; Hanson, R. 1985: Models of growth and water use of field peas (*Pisum sativum* L.). Pp.139-151 *in*: The Pea Crop: a Basis for Improvement. Hebblethwaite, P. D.; Heath, M. C.; Dawkins, T. C. K. *ed*. London, Butterworth.