IRRIGATION OF FIELD PEAS ON A SOIL WITH IMPEDED DRAINAGE

P.B. Greenwood and R.M. McNamara
Research Division, Ministry of Agriculture & Fisheries, Oamaru

ABSTRACT

The response of field peas cv. Rovar to irrigation and waterlogging was investigated during the 1982/83 season in the Lower Waitaki Valley on a typically compact yellow-grey earth with impeded drainage. The aim of the experiment was to assess the effects of waterlogging, a common occurrence in the area with over-irrigation and when rainfall occurs soon after irrigation. Sprinkler applications of 25-160 mm water were made at each irrigation.

Fully restoring plant available water (PAW) at each irrigation, scheduled at 45 mm deficit (62% depletion), increased seed yield by 35% to 5200 kg/ha but short periods of waterlogging induced by applying a further 20-110 mm water at each irrigation reduced yield by 15-30% (670-1530 kg/ha). Two irrigations applying 20 mm water more than required to fully restore PAW reduced seed yield by 800 kg/ha (15%) mainly through a reduction in the number of pods/plant.

Because peas appear sensitive to small amounts of excess water the duration of waterlogging is of more practical importance than the intensity of waterlogging. Irrigating at 50% depletion of total PAW with 10-15 mm water less than required to fully restore PAW is recommended to reduce the risk of waterlogging.

Additional Key Words: waterlogging, over-irrigation, yellow-grey earth.

INTRODUCTION

Irrigation gives large increases in yield of pasture, lucerne and arable crops in the drier areas of North and Central Otago. Many of the yellow-grey and brown-grey earths there contain compact subsoil zones and/or fragipans which reduce permeability, restricting the downward movement of water (Orbell, 1974; Wilson *et al.*, 1985). These compact subsoils can cause these soils to become temporarily waterlogged following over-irrigation or when rainfall occurs soon after irrigation. In the Lower Waitaki Valley of North Otago the rainfall pattern is characterised by a summer maximum. Heavy summer rainfalls, particularly in December, are common. Consequently waterlogging of irrigated crops frequently occurs.

There has been considerable research conducted overseas on the effects of waterlogging and it is known that it leads to a reduction in soil oxygen concentration and increases the concentrations of carbon dioxide and ethylene (Jackson, 1979; Trought and Drew 1980a; Hunt *et al.*, 1981). Waterlogging also increases the rate of denitrification and reduces plant uptake of N, P, K and some trace elements (Belford *et al.*, 1980; Trought and Drew, 1980b; Pulford and Duncan, 1981). These effects of waterlogging often lead to reductions in crop growth and survival causing reductions in seed size and yield (Cannell *et al.*, 1979; Jackson, 1979; Belford *et al.*, 1980). Yield reductions have been reported in wheat, barley and peas of 2-50%, 30-40% and 6-40% respectively with waterlogging (Watson *et al.*, 1976, Belford *et al.*, 1980, Cannell *et al.*, 1980, 1984). However most of the latter were pot studies and examined only severe waterlogging.

Although there are large areas of poorly drained soils in North and Central Otago there is no information on the amount of water required to reduce crop yield through waterlogging or on the magnitude of any such yield depression. Work by Cossens (1982) in Central Otago on a clay alluvial Linnburn soil showed that increasing the depth of irrigation water by 80% reduced annual pasture production by 14%. Similar work on a compact North Otago soil reduced lucerne dry matter yield by about 10% by irrigating with 20 mm water per irrigation more than was required to fully restore plant available water (Greenwood unpub.).

This experiment was conducted to investigate the effects of a range of irrigation water applications on the production of field peas grown on a typical, poorly drained North Otago cropping soil. The principal objective of the study was to provide information to assist farmers to avoid crop waterlogging and to achieve optimum seed yield.

MATERIALS AND METHODS

Site

The experiment was conducted 15 km N.E. of Oamaru on the downland margin of the Lower Waitaki Valley. The soil was a Hilderthorpe mottled silt loam (YGE) typical of most of the poorly drained arable soils in the Lower Waitaki Valley Irrigation Scheme. The physical characteristics of this soil are given in Table 1. The site had previously grown 3 consecutive cereal crops and prior to sowing had the following MAF soil test values (0-20 cm); pH 6.3, Ca 13, K 4, P 15, Mg 24, SO_4-S 22, % C 2.4, % N 0.22.

Design and Treatments

The 16 m x 16 m plots were arranged in a completely randomised design with 4 replicates. There were 9 irrigation treatments which covered a range of water applications at each irrigation (Table 2). Treatment 1 (FC) was chosen to represent the quantity of water typically applied to a crop at each spray irrigation (approx. 40 mm). Treatments 4-7 represented either excessive irrigation or different amounts

TABLE 1: Soil physical characteristics.

Soil depth (cm) (horizon)	Moisture (vol %) at F.C.	15 bars	Available water capacity (mm)	Dry bulk density (g/cc)	Macroporosity %
0-10 (Ap)	32.0	10.3	21.7	1.03	28
10-20 (Ap)	37.6	12.1	25.5	1.22	16
21-26 (AB)	40.4	12.8	13.8	1.47	4
27-50 (Bwg)	35.3	12.3	52.8	1.52	8
51-65 (Bwg_2)	35.0	11.3	33.3	1.59	6
66-89 (C)	32.0	10.7	48.9	1.69	6

TABLE 2: Treatments and irrigation details.

Treatment		Irrigation dates (and numbers)		Water applied/irrigation Target	Achieved (b)
1	Irrigated at 38% AWC to FC	1,21/12	(2)	44	50
2	.5FC	1,8,21/12; 11/1	(4)	22	23
3	.75FC	1,21/12; 11/1	(3)	33	39
4	1.5FC	1,21/12	(2)	66	70
5	2FC	1/12	(1)	88	93
6	3FC	1/12	(1)	132	139
7	4FC	1/12	(1)	176	161
8	I2FC(a)	1,8,14/12	(3)	97,28,28	97,28,28
9	Dryland	-			

(a) Irrigated to 2FC as in treatment 5 but followed by 2 further irrigations with 28 mm after 7 and 14 days.
(b) Mean of all irrigations

of rain falling soon after irrigation. Treatment 8 (I2FC) was designed to assess the effects of a prolonged period of rain after irrigation. Treatments 2(.5FC) and 3(.75FC) represented light irrigations which may be conducted to avoid the possibility of waterlogging with rain falling soon after irrigation. Treatment 9 was unirrigated.

As pea roots did not extend below 30 cm, trigger soil moistures at which irrigation commenced and calculations of irrigation water to be applied were based on the 0-30 cm soil zone. Irrigation was conducted when the 0-20 and 20-30 cm soil moisture levels (determined gravimetrically at weekly intervals), reached the trigger level of 38% available water capacity (AWC). This corresponded to soil water contents of 20.1% and 22.4% (volumetric) for the 2 depths respectively. The quantity of water applied to each irrigation treatment was based on the amount of water required to restore the 0-30 cm soil zone to field capacity (FC) in treatment 1. For example treatment 5 (2FC) received twice the quantity of water determined for treatment 1. Numbers and dates of irrigations together with target and actual water applications are included in Table 2. Except for treatment 7 (4FC) the actual quantities of water applied closely matched the target quantities. Irrigation of 4FC ceased at 161 mm as surface run-off began to occur.

Plots were irrigated individually with one sprinkler located in the centre of each at an application rate of 6.5 mm/hr. This rate was lower than the infiltration rate into the A horizon of the soil but significantly higher than the rates for the deeper soil horizons.

Rovar field peas were sown at 15 cm row spacings on September 29, 1982 with 190 kg/ha of a 12:10:10 (N:P:K) fertiliser. Established plant densities ranged from 96 to 103 plants/m^2. In mid November the crop was sprayed with cyanazine (1.5 kg ai/ha) and MCPB (0.6 ai/ha) for weed control and throughout the experiment was free of pests and diseases.

Measurements

Soil moisture levels were measured thermogravimetrically at the 0-20 and 20-30 cm soil depths at weekly intervals, and after each irrigation at the 0-20, 20-30, 30-45, 45-60 cm soil depths at daily intervals for 4 days. At each sampling, soil cores were bulked into treatments from 2 of the 4 replicates of each treatment.

All soil and crop sampling was from the plot area between 3 m and 6.5 m radius from the sprinkler (105 m^2/plot). This area received an even rate of water application and gave a buffer area between adjacent plots of approximately 5 m. Soil moisture measurements in these buffer zones showed there was no lateral movement of water between plots.

The effects of the treatments on crop performance were assessed with various yield and component measurements. Herbage yield was measured from a 0.54 m^2 area/plot on 6 occasions and vine length and node numbers/plant from 4 plants/plot on 4 occasions. Immediately prior to harvest, 20 plants/plot were removed for pods/plant and seeds/pod determinations. Seed yield was measured by harvesting an area of 27 m^2/plot from the

TABLE 3: Climatic data for 1982/83 and 13 year mean.

	Rainfall (mm)		Mean temp. (°C)		Potential evapotranspiration (mm)	
	Mean	1982/83	Mean	1982/83	Mean	1982/83
Oct.	40	49	10.3	9.8	84	N.A.
Nov.	40	22	12.0	13.3	103	N.A.
Dec.	66	74	13.9	12.9	131	142
Jan.	40	30	15.1	14.4	132	131
Feb.	27	25	15.0	13.5	104	96

dryland plots on February 17 and from the remainder of the plots on February 22. Individual seed weights were measured on subsamples from this harvest. Plant nutrient concentrations were determined using plant material from the herbage cuts.

Climate

Rainfall in 1982/83 was similar to the mean although November was drier than normal (Table 3). Mean temperatures were slightly lower. Evapotranspiration records were only available for December-February but showed a close match with the mean. During flowering (November 29-December 27) available water was below the trigger for irrigation approximately 60% of the time and during pod swelling (December 27-January 24) for approximately 70% of the time (Figure 1). There was a very dry period in late flowering (4% AWC) and another in mid pod swelling (16% AWC). Plant available water did not fall below the trigger level during vegetative growth.

RESULTS

Seed yield

The highest yield was attained by irrigating to FC (2 irrigations) and to .75FC (3 irrigations) (Table 4). The yields were 35% and 31% higher than the dryland yield and close to the North Otago district average. Irrigating with small quantities of water (.5FC, 4 irrigations) gave an intermediate seed yield. All treatments irrigated to above FC gave significant ($P < 0.01$) yield reductions. Treatments 1.5FC and 2FC reduced seed yield by approximately 730 kg/ha and treatments 3FC and 4FC by 1100 kg/ha.

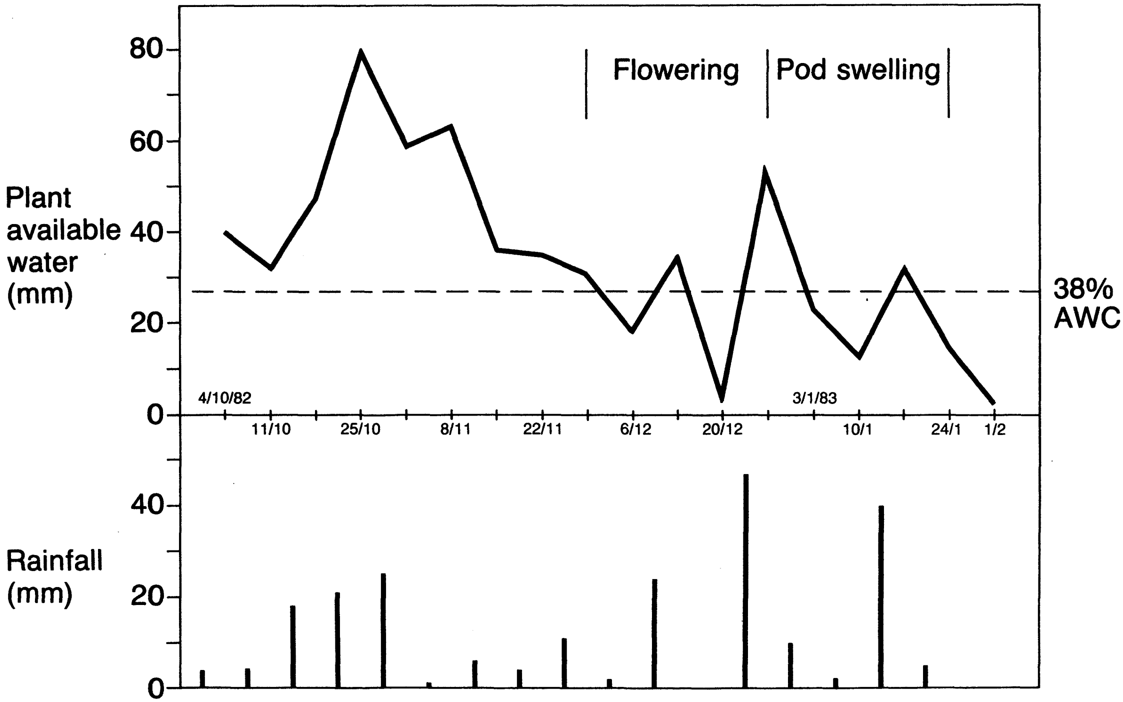

Figure 1: Weekly rainfall and weekly levels of available water in the dryland plots from October 4 until February 1.

TABLE 4: Seed yield and water use efficiency.

Treatment	Seed yield (kg/ha at 14% moisture)	Irrigation water use efficiency (kg/mm) (1)
FC	5190	13.3
.5FC	4460	6.5
.75FC	5050	10.2
1.5FC	4400	3.9
2FC	4520	7.1
3FC	4170	2.2
4FC	4020	1.0
I2FC	3660	−1.3
Dryland	3860	
SE$\bar{x}$	80	

(1) Expressed as irrigated-dryland seed yield/mm irrigation water applied.

Intermittent irrigation (I2FC) produced a yield slightly lower than that of dryland and significantly ($P < 0.01$) lower than all other irrigation treatments. Although 2FC might have been expected to give a lower seed yield than 1.5FC which received 22 mm water less per irrigation, the latter received one extra irrigation and therefore may have been subjected to waterlogging similar to 2FC.

TABLE 5: Relationship between % maximum seed yield and waterlogging intensity.

% total plant available water (1)	% maximum pea seed yield
70	86
84	97
100	100
107	87
111	85
118	80
133	77
SE$\bar{x}$	2

(1) measured 16 hours after irrigation.

Table 5 shows the relationship between % maximum seed yield and % total PAW (0-30 cm) measured approximately 16 hours after irrigation. The latter was taken as a measure of waterlogging intensity.

Yield components

Just before start of pod swelling total herbage yield was highest at .75FC and at FC (Table 6). Irrigating to 1.5FC, 2FC and 3FC reduced total yield slightly but the greatest reduction (20%) occurred in the heavily irrigated treatments 4FC and I2FC, and in the dryland and minimal irrigation (.5FC) treatments.

Vine lengths and nodes/plant are other measures of vegetative growth and measurements made at mid pod swelling are included in Table 6. Similar treatment responses as for herbage yield were apparent but the differences between FC and 0.5FC, 0.75FC, 1.5FC, 2FC, 3FC were minimal.

Significant treatment effects on seed yields were reflected mainly in the number of pods/plant (Table 6) and a close linear relationship existed with this component (Grain yield = −234.8 + 1062.7 x pods/plant $P < 0.001$). Although similar trends were evident in seeds/pod and seed weight (Table 6) differences were considerably smaller.

Concentrations of N, P, K and S in whole-plant samples from FC, 1.5Fc, 2FC, 3FC and 4FC treatments taken at the start of pod swelling are given in Table 7 which shows reduced concentrations mainly of N, P and K in the waterlogging treatments.

Irrigation water use efficiency

Measures of irrigation water use efficiency expressed as seed yield above the dryland yield per mm of water

TABLE 7: Plant nutrient concentrations.

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Sulphur (%)
FC	3.59	.27	1.75	.28
1.5FC	3.49	.27	1.86	.29
2FC	2.70	.22	1.49	.29
3FC	2.69	.23	1.29	.26
4FC	2.39	.22	1.27	.25
SE$\bar{x}$	.20	.02	.14	.01

TABLE 6: Plant measurements and components of yield.

Treatment	Total herbage (kg DM/ha)	Vine length (mm)	Nodes/ plant	Pods/ plant	Seeds/ pod	Seed weight (mg)
FC	5360	381	17.5	5.1	4.2	25.5
.5FC	4590	363	18.0	4.3	4.1	26.6
.75FC	5680	366	17.8	5.1	4.1	26.8
1.5FC	4970	376	17.3	4.2	3.9	25.1
2FC	5050	372	17.5	4.3	4.0	25.5
3FC	4940	383	17.2	4.0	3.9	25.5
4FC	4530	315	15.8	4.1	3.8	25.1
I2FC	4550	327	15.2	3.9	3.7	24.4
Dryland	4710	311	16.5	4.0	3.5	24.6
SE$\bar{x}$	220	19	0.5	0.2	0.2	0.6

applied ranged from −1.3 kg/mm (I2FC) to 13.3 kg/mm (FC) (Table 4).

DISCUSSION

Irrigation response

Rovar field peas irrigated to .75FC and FC during flowering yielded 31% and 35% more seed than dryland peas and returned approximately 13 kg seed per mm irrigation water applied. On soils with similar available water capacities in Canterbury, irrigation responses from Rovar peas of 40%, 55-106% and 12% were recorded in 1980/81, 1981/82 and 1983/84 respectively (Wilson *et al.*, 1981, 1984; Zain *et al.*, 1983). In the 1981/82 season in Canterbury the moisture deficit for December-February was significantly higher than in the present experiment (379 mm vs 238 mm) and the low response in 1983/84 reflected a wet season. In the 1980/81 experiment which gave an irrigation response similar to the present work, the return per mm of irrigation water was approximately 10 kg seed/mm.

Irrigation was not required during vegetative growth, and all irrigations were conducted during flowering and pod swelling, increasing mainly pods/plant (28%) and seeds/pod (20%) with seed weight showing only a slight response (4%). Nevertheless increases in herbage yield and vine length were recorded. Similarly, in previous work garden and field peas gave increases in yield mainly to irrigation during flowering and pod swelling Salter and Goode, 1967). Consequently irrigation is normally recommended during these supposed moisture sensitive periods, even though there is no conclusive evidence for their existence (Husain *et al.*, 1983; Zain *et al.*, 1983).

Although irrigating to 0.5 of field capacity (22 mm) required 2 more irrigations than irrigating to field capacity, the same total quantity of water was applied. Seed yield was 14% lower than irrigated to FC mainly through a reduction in the number of pods/plant. As a result the yield per mm of irrigation water was halved. As the level of PAW in this treatment, in common with all other irrigation treatments, did not fall below the irrigation trigger level of 38% PAW, the observed yield depression indicates a significant reduction in growth at levels of PAW above 38%. Guidelines for irrigation during flowering and pod swell vary, with 25% and 50% PAW both being currently recommended (Muir, 1978; Stoker, 1979). Weekly soil moisture determinations showed that PAW in the .5FC treatment was frequently between 38% and 50% especially during early flowering whereas under all other irrigation treatments it was generally above 50%. Irrigation when soil moisture falls to 50% PAW would seem a sensible recommendation and in this experiment it may have given higher yields from the .5FC, .75FC and FC treatments and thus a greater irrigation response.

Waterlogging

There is little doubt that peas are susceptible to waterlogging. Both green and seed pea yields have been reduced by controlled, waterlogging in controlled environments (Cannell *et al.*, 1979; Jackson, 1979; Bedford *et al.*, 1980). Under field conditions it is difficult to control and assess the intensity of waterlogging and few attempts have been made. The present experiment showed that peas are very sensitive to short periods of waterlogging in the field.

Although a marked yellowing of leaves was apparent for 3 weeks after waterlogging, because all waterlogging occurred during flowering, vegetative growth as assessed by total vine length was little affected. No leaf senescence was observed after the yellowing so the 6-15% depression in herbage yield was most likely the result of differences in numbers and size of developing pods.

As found by Cannell *et al.* (1979) and Jackson (1979) the yield reduction of 13 to 30% which resulted from waterlogging was mainly due to a similar reduction in the number of pods/plant. However, as waterlogging during flowering did not reduce total node number, the reduction in pod number must have resulted from a reduction in the number of fertile flowering nodes. Only small reductions in the numbers of seeds/pod were observed.

Apart from the 1.5FC vs 2FC treatments, seed yield decreased and seed per mm of irrigation water applied decreased with increased quantities of irrigation water applied. The anomaly at 1.5FC and 2FC was most likely caused by an interaction between intensity and duration of waterlogging. Treatment 1.5FC, although irrigated with less water, received one extra irrigation suggesting that a small quantity of water in excess of FC can affect seed yield and that duration of waterlogging is of considerable importance. This is also supported by the results of the intermittent waterlogging treatment. At the first irrigation, I2FC received the same quantity of water as 2FC but then was further irrigated twice at 7 day intervals with an extra 25 mm above FC. The total quantity of water applied was similar to that applied to the 4FC treatment at one irrigation but the seed yield was significantly lower. Cannell *et al.* (1979) reported that waterlogging for 24 hours gave large reductions in field pea yield but also showed duration of waterlogging to be important as a further 24 hours waterlogging reduced seed yield by an additional 17%. The effect of varied intensity of waterlogging has not been previously investigated. In the present experiment soil water content was measured daily for 4 days after each irrigation however sampling was not sufficiently frequent or precise to accurately assess the intensity of waterlogging in each treatment. Nonetheless sampling approximately 16 hours after irrigation gave some assessment of waterlogging intensity in the root zone and there was a significant relationship between waterlogging intensity and reduced seed yield.

Work investigating the effect of waterlogging at different growth stages has shown that waterlogging just before flowering is most damaging (Cannell *et al.*, 1979). Waterlogging during and after flowering has less effect and during vegetative growth is of least importance. Reasons for this are unclear but root growth appears most severely affected by waterlogging at or near flowering (Cannell *et al.*, 1979) which may limit nutrient uptake. Whole-plant chemical analysis at pod swell showed a reduced uptake of N, P, K and to a lesser extent S.

As waterlogging through either excessive irrigation or rainfall soon after irrigation is most likely in North Otago during flowering and pod swelling the results from this experiment are likely to be typical for most seasons but probably underestimate the results of waterlogging during the preflowering period.

CONCLUSIONS

Although irrigation significantly increases seed yield of field peas in the Lower Waitaki Valley, short periods of waterlogging through over-irrigation or rain soon after irrigation lead to considerable reductions in yield. As peas appear sensitive to small amounts of water above FC the duration of waterlogging is of more practical importance than intensity. Irrigating at 50% AWC with 10-15 mm less water than required to fully restore PAW is recommended as an insurance against rain falling soon after irrigation. In most years this would require only one or two additional irrigations and in the Lower Waitaki Valley Irrigation Scheme the additional cost far outweighs the penalty of short periods of waterlogging.

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