EFFECTS OF POLYACRYLAMIDE (PAM) AND GYPSUM ON IRRIGATED AND DRYLAND POTATOES (*Solanum tuberosum* L.).

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A.Mills

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ABSTRACT

An experiment was conducted at Lincoln University to investigate the effects of irrigation, micronised polyacrylamide (PAM) and gypsum on the growth and yield of 'Ilam Hardy' potatoes in 2001-2002.

At the final harvest, tuber yields were similar (59 500 kg ha^{-1}). Environmental factors dominated results, particularly January rainfall, which was 150% of the 16-year average. Economic yield (tubers >113g) was not affected by any treatment and was >80% of total tuber yield. Premium size tubers (>170g) were 65% of total tuber yields and no treatment affected tuber size distribution. The maximum crop growth rate was higher from irrigated (189 kg DM ha^{-1} d^{-1}) than dryland plots (174 kg DM ha^{-1} d^{-1}). This reflected differences in leaf area index at two times during the later growth period. Mean crop growth rate, as a result, was also lower (118 kg DM ha^{-1} d^{-1}) compared to irrigated plots (130 kg DM ha^{-1} d^{-1}). The duration of growth was similar (125 days) for all treatments.

There was no effect of any treatment on soil adherence to tubers. Aggregate stability was increased 24% by gypsum application. However, poor initial soil structure caused by years of intensive cultivation meant this only increased to 2.4% and was unlikely to have had any affect on crop growth and yield.

Keywords: aggregate stability, duration, growth rates, gypsum, irrigation, PAM, Polyacrylamide, potato, soil adherence, *Solanum tuberosum*, tuber size distribution, yield.

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LIST OF ABBREVIATIONS

AWC	available water holding capacity
CGR_{max}	maximum crop growth rate
DAE	day after emergence
DAS	days after sowing
D_L	critical limiting deficit
DM	dry matter
D_{pmax}	potential soil moisture deficit
DUR	duration of growth
E_T	evapotranspiration
FWT	fresh weight
GLM	general linear model
HI	harvest index
k	extinction coefficient
LAI	leaf area index
LAI_{crit}	critical LAI
LSD	least significant difference
MW	molecular weight
OM	organic matter
P	turgor pressure
PAM	polyacrylamide
PAR	photosynthetically active radiation
P_g	gross photosynthesis
PG	phosphogypsum
P_n	net photosynthesis
RUE	radiation use efficiency
WMAGR	weighted mean absolute growth rate
WUE	water use efficiency
Ψ	leaf water potential

CHAPTER ONE

INTRODUCTION

Potato yields in New Zealand were reported as 43 000 and 50 000 kg ha^{-1} in 2000 and 2001 respectively (FAO Stats, 2002). However, yields of up to 100 000 kg ha^{-1} have been achieved. Potential yields have not been realised due to poor management and environmental factors including water stress. Water stress affects cell expansion directly, and cell division indirectly, though reduced turgor pressure but as stress develops partial or full stomatal closure causes transpiration and photosynthesis to decline before severe stress directly affects carboxylation processes and membrane degradation and plant death occurs (Hsaio, 1973; Brown, 1995).

Jamieson (1985) reported the yield response of potato to be 45 to 50 kg tubers ha^{-1} mm^{-1} of water applied, provided that the water was required. Yield losses were found to be a linear function of the maximum potential deficit. Tuber yield from irrigated plots was about 65% greater than that of unirrigated plots. Vos and Groenwold (1989) reported a 50% increase in total dry matter of irrigated compared to unirrigated potato. In contrast, Penman (1971) reported irrigation reduced tuber yields by about 5% in a wet year with sufficient rainfall to meet crop requirements. Yield effects are generally a reflection of water stress on cell expansion and division rather than stomatal control (Jefferies and MacKerron, 1993).

Polyacrylamide (PAM) has been advocated as a synthetic soil conditioner, which may stabilise aggregate stability resulting in increased infiltration rates. The product used in this experiment is a newly developed micronised product, and there is no data in the literature directly comparable to results gathered during the course of the experiment. Efficacy is believed to be improved by gypsum application as PAM only maintains the original soil structure. The addition of calcium, in the form of gypsum, prior to PAM application enhances soil particle flocculation leading to an increase in aggregate stability (Shainberg *et al.*, 1990), which is then further stabilised by PAM application.

The objectives of the experiment were:

- To determine the effects of irrigation, micronised polyacrylamide and gypsum on leaf area development, light interception and yield of potato.

- To investigate the effect of gypsum application on the efficacy of micronised polyacrylamide relating to aggregate stability.

- To determine treatment effects on soil adherence to tubers based on processor requirements.

CHAPTER TWO

REVIEW OF THE LITERATURE

2.1 Introduction

Potato production in New Zealand, in the year to 31/12/2000, occupied 12 000 ha^{-1} and total production was in the vicinity of 500 000 t resulting in average production of 45 300 kg tubers ha^{-1}. This increased to 50 000 kg ha^{-1} in 2001. However, the production area has now decreased by about 15% (FAO, 2002). Some growers have produced tuber yields exceeding 100 000 kg ha^{-1}. Reasons for this variation between average and maximum yield potential include poor management and environmental conditions that cause water stress and increase pest and disease prevalence.

2.2 Potato Growth and Development

The potato is an annual herbaceous plant most commonly propagated clonally from seed tubers. Apical buds on seed tubers are protected by scale leaves in the eye of the tuber and the number of eyes on a tuber depends on tuber weight and tuber shape. When bud dormancy is broken, sprouts grow from the previously dormant apically dominant buds to form mainstems (haulms) (Vos, 1999).

Figure 2.1 is a schematic representation of a potato plant with one mainstem. However, three to seven mainstems per seed tuber is typical. Ewing and Struik (1992) showed mainstem numbers increase with physiological age of the seed tuber due to weakened apical dominance. Flower initiation occurs before tuber initiation only a few weeks after emergence and in this sense the potato is a determinant plant. However, the plant is indeterminate in the sense that there is no fixed point at which branching ceases and this is influenced by environmental conditions (Vos, 1999).

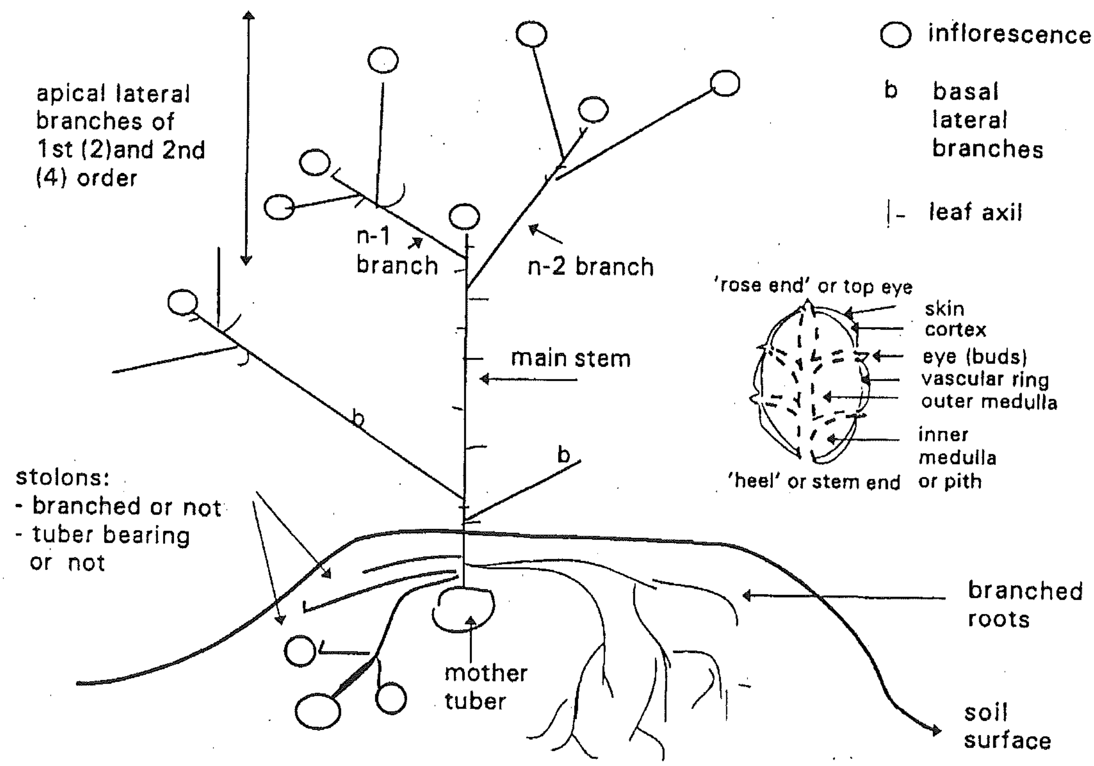

Figure 2.1. Schematic representation of a potato plant, with one mainstem, indicating component parts (Vos, 1999).

2.2.1 Tuber formation

Tuber formation is reliant on a sequence of events including stolon induction, stolon initiation, elongation and branching of the stolons, tuber induction and tuber initiation. Tuber re-absorption can also occur after tuber initiation and is influenced by resource availability (Ewing and Struik, 1992). These events occur in chronological order but do not occur simultaneously at each node. Stolon initiation begins at the nodes closest to the mother tuber and progresses acropetally. As a result there is generally a two-week overlap in the periods of stolon and tuber formation. The rate of tuber bulking is sigmodial not linear and relates to canopy development and the quantity of light intercepted (Allen and Scott, 1980; Vos, 1999).

2.2.2 Crop Growth Rate

A linear relationship exists between light interception and total DM accumulation, and the slope of this relationship is defined as radiation use efficiency (RUE) (Monteith, 1977) (Figure 2.2). Sale (1974) showed shade reduced the growth rate of potato proportionally to the quantity of light the crop intercepted. Tubers are initiated early in the growth of the crop and assimilate is partitioned to the developing tubers from initiation to senescence or harvest. Therefore, there is a linear relationship between tuber yield and intercepted photosynthetically active radiation (PAR) (Allen and Scott, 1980). However, temperature and water stress can modify the response. Leaf area determines the quantity of light a crop intercepts. Any factor that reduces leaf area below that required for 95% interception will reduce yield (Biscoe and Gallagher, 1977; Monteith, 1977; Sinclair and Muchow, 1999).

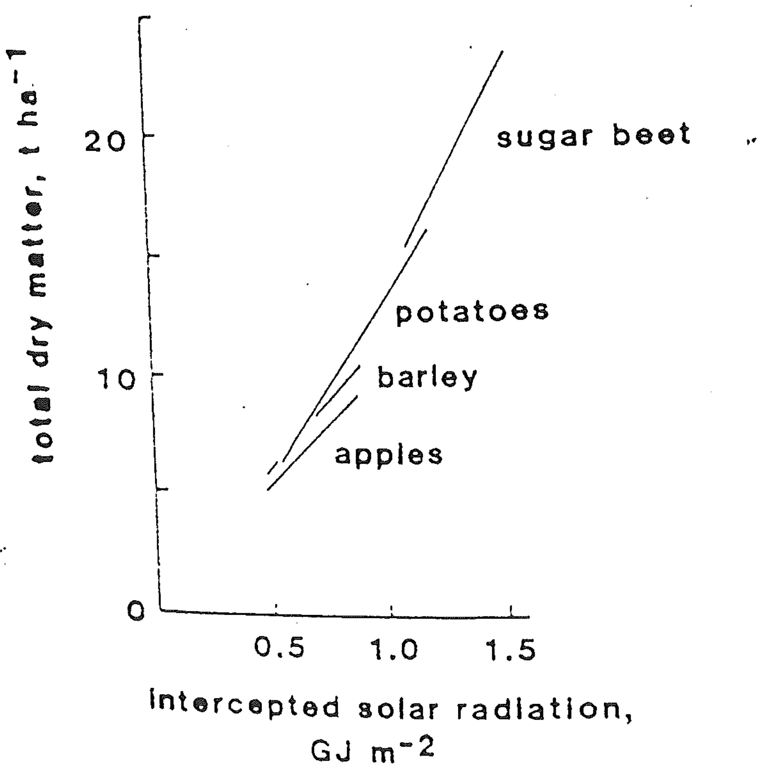

Figure 2.2. Relationship between total dry matter at harvest and radiation intercepted by foliage throughout the growing season (Monteith, 1977).

2.3 Leaf Area Development

The development of the potato leaf canopy consists largely of the expansion of already initiated leaves and new leaves are produced for most of the life of the crop (Allen and Scott, 1980). Following initiation, leaf growth is dominated by cell division, which continues up to leaf unfolding. The exponential increase in leaf area during lamina expansion is caused primarily by cell expansion. In a rapidly growing crop, senescence normally begins shortly after the leaf reaches full size. This is associated with a reduction in photosynthetic activity and re-mobilisation of organic N to developing leaves. Leaf shading, nutrient deficiency, drought, frost, humidity, herbivory and disease can also affect senescence rates (Allan and Scott, 1980; Hay and Walker, 1989; Vos, 1999).

Early in the season the rate of leaf area expansion is limited by low temperature. Later in the season, high temperatures and high soil moisture deficits may increase the rate of senescence and consequently reduce interception. The photosynthetic rate also declines in older leaves. Leaf area development is generally more sensitive to water deficits than leaf senescence or leaf photosynthesis. Jefferies (1989) showed leaf growth declined rapidly when the potential soil moisture deficit (D_{pmax}) exceeded 16mm on a sandy loam soil and at a D_{pmax} of 77mm growth ceased (Jefferies, 1989; Jefferies and MacKerron, 1989). However, this may limit the level of response to subsequent rainfall due to a reduction in the amount of PAR intercepted (Biscoe and Gallagher, 1977).

2.3.1 Leaf Area Index

Jefferies and MacKerron (1993) explained potato yield differences in relation to light interception and tuber dry matter (DM) content. The leaf area index (LAI) of 'Maris Piper' was decreased 57% under drought compared to irrigated plots. The duration of leaf growth was reduced and DM accumulation declined in response ($r = 0.70$). Tuber DM differed between genotype but it was noted that these were only small differences.

Jefferies and MacKerron (1989) showed differences in growth were related to differences in interception and RUE. Drought caused total DM and shoot size to be affected before reductions in tuber DM production were observed. Treatments were similar until 40 days after emergence (DAE) but towards the end of the season differences diminished and final harvests were similar. Total tuber yield was reduced in the drought treatment in both years and yields from the droughted treatments were 44 and 37% of the irrigated treatments in 1986 and 1987 respectively. Tuber DM content increased over time and was consistently higher in the droughted treatment indicating a proportionally greater affect on tuber moisture content than on DM accumulation. Tuber moisture contents were only 39 and 31% of the irrigated treatments while tuber DM production was 62 and 56% of the irrigated treatments. Drought reduced tuber populations as fewer tubers were initiated.

Generally, water stress affects potato DM production through changes in canopy growth and development. This affects the amount of radiation intercepted rather than RUE (Allen and Scott, 1980; 1992; Jefferies, 1989; 1993). Jefferies (1989) showed the rate of leaf extension was directly proportional to turgor pressure (P) and leaf water potential (Ψ) and leaf growth was reduced by drought when P and Ψ were less than 0.5MPa and –0.28 respectively.

Turgor pressure drives cell expansion and thus leaf growth therefore leaf growth rate should reflect changes in leaf water status. Leaf growth is very sensitive to changes in D_{pmax} and the rate of leaf extension rate declined rapidly when the D_{pmax} exceeded 16mm on a sandy loam soil (Jefferies, 1989). This is substantially lower than the limiting deficit proposed by Penman (1971) of 25mm. However, the critical limiting deficit differs depending on soil depth and texture, (which affect the plant available water), and environment or genotype also affect the point at which yield reductions occur.

Jefferies (1993) examined the responses of 19 potato genotypes for differences in the rate of leaf expansion and osmotic adjustment. Water stressed crops had slower and reduced canopy development and leaf area duration was reduced compared to irrigated crops. However, although reductions in final leaf size were due to reductions in the rate of leaf expansion, leaf area duration was unaffected by drought.

Drought reduced potato LAI from 2.3 and 3.0 compared to 4.0 and 5.2 when irrigated (Jefferies and MacKerron, 1989). As a result interception was reduced by 29 and 19% respectively, which caused a reduction in DM accumulation. Canopy development under drought resulted in reduced leaf growth and branching was restricted. Light interception was further reduced by wilting of leaves and premature senescence (Jefferies and MacKerron, 1993).

2.3.2 Rate of Leaf Appearance

The rate of leaf appearance is temperature dependent based on thermal time to determine the phyllochron. Under drought conditions, potatoes had a faster rate of leaf appearance (26.5 °C d^{-1} $leaf^{-1}$) than was observed in irrigated crops (28.3 °C d^{-1} $leaf^{-1}$) for leaves five to nine but this altered to 23.5 °C d^{-1} $leaf^{-1}$ and 41.2 °C d^{-1} $leaf^{-1}$ respectively for leaves 5 to 14. Reductions in the phyllochron may be a result of increases in tissue temperature when transpiration is insufficient to meet evaporative demand. Increases in tissue temperature will depend on the soil water status and the evaporative demand. In the irrigated treatments the phyllochron, duration of leaf growth and the maximum leaf length differed between years indicating the influence of environmental factors other than soil moisture status (Jefferies, 1989).

2.3.3 Radiation Use Efficiency

Radiation use efficiency is the efficiency of radiation conversion into DM. This depends on factors including the photosynthesis/ respiration balance and associated energy costs to the crop. There are further relationships between population density, N fertiliser, canopy development and crop yield (Hay and Walker, 1989). Under non- limiting conditions there is a linear relationship between DM production and absorbed PAR that is defined as RUE. However, growth rate and RUE are not independent. Leaf area index and canopy structure determine light interception and the efficiency of absorption that is achieved (Ludlow, 1978; Goyne *et al.*, 1993; Gimenez *et al.*, 1994).

Changes in the RUE of potato reflected reductions in photosynthesis initially because of stomatal closure increasing diffuse resistance to CO_2 followed by under severe stress direct effects on carboxylation processes. Water stress initially increased DM partitioning to tubers so harvest index (HI) was higher in droughted treatments mid season than in irrigated treatments. Changes in partitioning may result from direct effects of water stress or may reflect changes in N nutrition due to water supply limiting nutrient uptake (Jefferies and MacKerron, 1993).

Potato RUE ranges from 2 to 3 g MJ^{-1} PAR absorbed for plants grown under non-limiting conditions. This is high for a C3 species and is related to the energy required to form the final product. Carbohydrate synthesis requires a conversion factor of $\geq$ 0.83 g photosynthate g carbohydrate compared to a conversion factor of 0.71 for protein synthesis. However, conversion efficiency generally declines once the optimum temperature is exceeded (Monteith, 1972; 1977; Sinclair and Muchow, 1999).

2.4 Irrigation and Yield Relationships

Penman (1971) proposed yield reductions would be proportional to the amount by which the maximum deficit exceeds a threshold deficit (critical limiting deficit). However, when the maximum deficit is below the threshold value relative yield is not affected. The critical limiting deficit (D_L) varies between species but is related to the available water holding capacity (AWC) of the soil within the root extraction zone.

Irrigation reduces the maximum deficit therefore the maximum deficit of an irrigated plot will always be less the maximum deficit of a water stressed dryland or droughted treatment. Penman (1971) calculated the critical limiting deficit for potatoes to be 25mm. The largest response to irrigation occurred in 1955, a dry year, but in years with sufficient water (non-limiting to growth), irrigation caused negative yield responses. Yield responses ranged from 450 – 500 kg tubers ha^{-1} cm^{-1} water applied, which was similar to pasture responses to irrigation. In 1954, a wet year, irrigation decreased yield by an average of 2 100 kg tubers ha^{-1} compared to dryland treatments which produced a mean yield of 39 250 kg ha^{-1}. In contrast, in a dry year (1955) where the dryland yield was 22 250 kg tubers ha^{-1} compared to about 45 000 kg tubers ha^{-1} from irrigated treatments of the cultivar Majestic. Jamieson (1985) also reported yield responses of 45-50 kg tubers ha^{-1} mm^{-1} beyond a soil moisture deficit of 40 mm and yield responses to irrigation were linear in the absence of rain.

Potato is generally thought to be sensitive to water stress because of a shallow root system. Opena and Porter (1999) reported 85% of potato roots were concentrated in the top 30cm of soil. However, contributions of roots outside this zone to plant water requirements were not determined. Obviously, this would depend on the AWC of the soil related to crop water requirement and the frequency of irrigation.

Symptoms of water stress include reduced plant size, fewer leaves, reduced leaf area duration and a decline in specific leaf weight compared with non-stressed plants. Daily tuber and top growth rates were increased by irrigation, ranging from 2.62 to 17.63 g m^2 and -0.90 (an apparent negative value) to 10.01 g m^2, for dryland and irrigated plots respectively. Assimilate partitioning to tubers decreased with increased irrigation.

Increasing irrigation applications beyond 100% evapotranspiration (E_T) did not increase yields (Hang and Miller, 1986).

2.5 Drought and Economic Yield

Martin (1979) reported no response to irrigation prior to flowering in 1976 even though the season was drier than average. Irrigation after flowering increased yields by 30% and table yields by 72% but tuber DM was reduced from 23.7% in dryland treatments compared to 22.1% DM when irrigated after flowering. Table yields were increased from 16 100 kg ha^{-1} to 27 300 kg ha^{-1} when irrigated after flowering and total tuber yields increased from 30 000 to 38 800 kg ha^{-1} for 'Ilam Hardy' potatoes. In 1978, irrigation increased total yield by 31% and table yields by 42% and in 1977, irrigation increased total yields by an average of 44% and table yields by 50%. 'Ilam Hardy' gave the highest yield of cultivars grown (47 300 kg ha^{-1}) and highest table yield (37 800 kg ha^{-1}) but tuber DM was lower (21.9%) than that of 'Wha' (23.1%) or 'Whitu' (24.1%) (Table 2.1).

Table 2.1. Yields, and tuber dry matter content of four potato cultivars sown in Canterbury, New Zealand in 1977. Values followed by the same letter do not differ at $p<0.05$ (Martin, 1979).

Cultivar	Total Yield ($kg\ ha^{-1}$)	Table Yield ($kg\ ha^{-1}$)	Tuber Dry Matter (%)
'Ilam Hardy'	$47\ 300_a$	$37\ 800_a$	21.9_c
'Kennebec'	$39\ 200_c$	$33\ 700_b$	22.3_c
'Wha'	$42\ 800_b$	$31\ 500_c$	23.1_b
'Whitu'	$39\ 300_c$	$29\ 000_c$	24.1_a

Martin *et al.* (1992) irrigated 'Russet Burbank' potatoes and showed process grade tuber yield from drought stressed treatments was highest (58 000 kg ha^{-1}) when drought was imposed during tuber initiation. This produced fewer but larger tubers. Drought during late tuber bulking reduced process grade yields by 20%, with both tuber size and tuber number being reduced by up to 20%. This was similar to the results of Lynch and Tai (1989) although there were cultivar differences in timing and sensitivity to drought. Dryland treatments had low yields and small tubers because the seasonal rainfall was 50% less than the mean average rainfall. However, the levels of water deficit imposed had no effect on tuber processing quality (Martin *et al.*, 1992).

2.6 Processing Requirements

Processors require tubers meeting certain requirements for processing. Admiraal (1988) summarised these as a tuber DM of 20% or greater with a sugar content less than 0.1% and tuber size must exceed 50mm with a tuber weight of > 113g. In addition, for a crop to be accepted by a processor, tubers must have <2% soil adherence and less than 1% physiological damage. Mechanical damage from harvest should be <4% and no diseased crop is accepted (Hughes and Shepard, 1983). Therefore, any factor, which affects the proportion of tubers within the saleable size distribution, may reduce economic yield.

2.7 Water Use Efficiency (WUE)

Crop yields vary with environmental conditions, but generally DM production is reduced in proportion to the reduction in transpiration caused by the water deficit (Allen and Scott, 1980; Tanner and Sinclair, 1983). The relationship between crop production per unit of water used during growth is defined as water use efficiency. Conversely, this relationship can be used to determine yield reductions caused by developing soil moisture deficits (Jamieson, 1985). Plants limit transpiration losses by increasing stomatal resistance reducing water loss to the atmosphere and thus prevent dehydration of plant tissue. Vapour flow modification, because of partial or full stomatal closure, is another mechanism available to limit water loss and the balance between these mechanisms is species dependant (Hsiao, 1973; Brown, 1995).

Stomatal closure or an increase in the photosynthetic efficiency decreases the partial pressure of CO_2 in the stomatal cavity this increases the transpiration efficiency. Thus, water stressed plants often have better WUEs than unstressed crops. However, increased internal resistance to CO_2 uptake may prevent such an increase in response to water stress (Turner, 1986).

Differences in the transpiration efficiencies of different crop species can be attributed to differences in the carboxylation pathways used and the energy requirements required to produce different products. Canopy structure and population density can modify the evaporation: transpiration ratio and can therefore alter E_T efficiency. Nitrogen promotes increased leaf area production and thus increases in E_T efficiency can be achieved by employing improved management strategies but transpiration efficiency is unlikely to be affected (Tanner and Sinclair, 1983; Allen and Scott, 1980; 1992). However, high transpiration efficiency is not always a benefit due to the trade off between transpiration efficiency and potential productivity (Turner and Begg, 1981). However, E_T can be manipulated by increasing infiltration rates, reducing soil evaporative losses and increasing time to canopy closure at which point transpiration dominates E_T efficiency (Tanner and Sinclair, 1983).

Tanner and Sinclair (1983) stated that increasing water use efficiency in crops could be achieved by

- Decreasing losses from the soil profile in drainage,
- Reducing surface runoff to increase the volume of water available for crop growth and
- Reducing evaporative losses from the soil

The experiment reported investigates the use of micronised polyacrylamide (PAM) on potato growth and yield. Non-micronised PAM is widely used in cropping systems in the USA and Australia, to reduce erosion and increase infiltration rates. However, there is very little information relating to the effects of polyacrylamide on plant growth and yield (Ben-Hur, 2001) and because of its recent development no reliable literature regarding the use of micronised PAM is available. It has also been hypothesised that gypsum application could increase the efficacy of PAM.

2.7.1 Polyacrylamide (PAM)

PAM ($CH_2CHCONH_2$) is a white, solid, water-soluble high molecular weight polymer, which is derived from the polymerisation of acrylamide with N, N^1-methylene bisacrylamide. Water-soluble polyacrylamides are available in cationic, non-ionic and anionic forms. These are widely used in wastewater clarification, food processing, papermaking and petroleum recovery (Morris, 1992; Lewis, 1993). In contrast, water insoluble crosslinked PAMs have been used in the horticulture industry. Chng (2000) investigated the use of insoluble crosslinked PAM as a transplant aid and concluded water content of transplant media was not increased by PAM.

As the soil dries following application, the polymer becomes bonded to the soil in a manner, which is largely irreversible. Aggregate stability was increased and it was shown that only minimal desorption occurred if the soil was kept moist. As anionic PAMs do not penetrate the aggregates, if the aggregate is broken up by cultivation or raindrop impact the interior of the aggregate is exposed and susceptible to erosion or dispersion (Letey, 1994).

The anionic micronised PAM used in the experiment at Lincoln was of high molecular weight (MW) (15-20 million g mol^{-1}) and is extremely viscous at concentrations above 1-2% in solution. However the addition of a salt (ammonium sulphate) added to the formulation reduces the viscosity allowing the formula to be applied by a spray unit (Barvenik, 1994).

2.7.2 Erosion and Infiltration Rate Enhancement by PAM

Shainberg and Levy (1994) reported an optimum rate of 20kg ha^{-1} of high MW anionic PAM was required to reduce surface crust formation, compared to 80 kg ha^{-1} when the PAM had a medium MW. Phosphogypsum (PG) application was found to have a greater effect on infiltration rates compared to PAM when applied alone but PG applied in addition to PAM increased infiltration rates from 2.5mm h^{-1} in the PAM only treatment to 35mm h^{-1} after 80 mm cumulative rainfall occurred. This was thought to be due to an enhancement of polymer efficacy with the addition of electrolytes (PG). However, PAM application at rates below 0.7 kg ha^{-1} had an inconsistent effect on sediment losses, following flood irrigation, but soil losses decreased by an average of 94% at PAM rates above 0.7 kg ha^{-1}. Effects on net infiltration ranged from –8.0 to a 48% increase over the controls with PAM application rates up to 1.8kg ha^{-1} (Lentz and Sojka, 1994). This could be of particular importance as Ben-Hur (1994) reported runoff following irrigation of potato was higher than that measured for cotton, corn and peanut crops as a result of ridging angles of 20% compared to crops which were not ridged.

Increased water availability from PAM application is generally accepted to be a result of improved infiltration resulting from reductions in runoff rather than due to increased in the available water holding capacity of the soil. However, Agafonov (1983) reported evaporation losses from the soil decreased by approximately 60% when PAM was applied to the upper soil layer at a rate of 0.1 %.

Ben-Hur (2001) used a synthetic low MW non-ionic polymer to study the effects on seal formation, infiltration rate, runoff and erosion in potato (cv. Chloster) yield. Under simulated rain, polymer applications of 0 (control), 5, 10, 25 and 50 kg^{-1} ha^{-1} resulted in final infiltration rates of 17, 19, 27, 28 and 31 mm ha^{-1} respectively. Erosion rates reduced from 6.1 t ha^{-1} in the control to 3.5, 1.9, 0.9 and 0.9 t ha^{-1} as rates increased.

2.7.3 Aggregate Stability

Increased infiltration rates due to PAM application were investigated by Mitchell (1986). The objective was to examine if PAM stabilised the soil surface from dispersion, slaking and surface sealing. Rates applied were 0, 6.6, 13.3 and 32.2 kg ha^{-1} in solution and 42 kg ha^{-1} PAM applied dry (not in solution). Aggregate stability increased from 9.0% in the control to 45.2% and infiltration increased from 30 to 57% during the first 4 hours of irrigation when 32.2 kg ha^{-1} PAM was applied in solution on shrink and swell clay soil containing 50% clay of which 45% was montmorillonite. This is similar to the results presented by Terry and Nelson (1986) who showed aggregate stability was increased by PAM application (Table 1).

Table 2.2. Effect of irrigation method and PAM application (650 kg ha^{-1}) on aggregate stability (%) in the surface 0-5cm of a Timpanogos clay loam (Terry and Nelson, 1986).

Conditioner treatment	Irrigation Method	Sampling Date 12/07	5/08	9/08	19/08	26/08	30/08
Nil	Flood	21.1_b	15.1_b	11.4_b	17.6_b	17.5_b	15.2_b
PAM	Flood	82.0_a	57.2_a	48.0_a	47.7_a	60.0_a	53.4_a
None	Sprinkle	17.1_b	13.5_b	9.3_b	15.9_b	20.4_b	16.8_b

Water stable aggregate percentages followed by the same letter are not significantly different at $p<0.05$ using the Duncans multiple range test.

Wallace and Wallace (1986a) applied non-micronised PAM at rates equivalent to 8.6, 16.6, 37, 66, 132, 330 and 1980 kg ha^{-1}. The experiment conducted at Lincoln used a newly developed micronised PAM applied at 25 and 50 ppm as the company supplying the PAM suggest application at very low rates. The rates of 25 and 50ppm were suggested as the optimum rates for application and these resulted in rates equivalent to 50 and 100g ha^{-1} respectively.

2.7.4 PAM and Plant Growth and Yield

Some short-term studies have shown that PAM application can result in increased plant dry weights. For example, Wallace and Wallace (1986a) harvested lettuce and cotton seedlings only 16 DAE and concluded PAM increased plant DM production. In addition, many of the experiments have been conducted in glasshouses rather than field trials and rates of PAM application have been much greater than the rates applied in the current investigation into the effects of micronised PAM and gypsum on irrigated and dryland potato.

Wallace and Wallace (1986a) showed that soil physical characteristics, particularly aggregation, were highly correlated with crop yields in corn and onion, and was related to PAM application. However, PAM was applied with a polysaccharide and there was no PAM only control. Wallace and Wallace (1986b) investigated the effects of soil conditioners on tomato seedling emergence. Although the anionic polymer increased the time to emergence by 2 days, only 10 seeds were planted per pot and no mention was made regarding replication. In addition, plant height at day 10 was not measured but scored as small, medium or tall. As such the results within this paper are subject to misinterpretation.

Cook and Nelson (1986) reported improved crop emergence using PAM but effects varied month to month. No environmental data was presented but the optimum rate for emergence was 67 kg ha^{-1} in June. Rates of 22, 45, 67 and 90 kg ha^{-1} all resulted in greater emergence over the control in July. In contrast, it was stated that the August trial provided no effect of PAM due to rainfall following treatment application. Over the three months which trials were conducted it can be concluded that no consistent results were found. Wallace and Wallace (1986c) reported that tomato seedling emergence differed between soil types, but PAM application had no effect on plant dry weight.

2.7.5 Gypsum

Calcium promotes rapid flocculation of colloidal soil particles due to the divalent charge the ion possesses. In addition, Ca^{2+} promotes soil organism activity responsible for soil structure formation and aggregate stability. Intensive cultivation can breakdown aggregates and reduce soil organic matter content necessary for promoting aggregation. Degradation of soil structure can result in weak structure, which is prone to formation of surface crusts following rainfall events, which may reduce seedling emergence. Soils with poor structure have a reduction in the amount of pores which reduces both the infiltration rate and hydraulic conductivity of the soil (McLaren and Cameron, 1996).

Polyacrylamide maintains soil structure rather than improving it so application to a soil with degraded soil structure will stabilise the original degraded structure (Cook and Nelson, 1986; Lentz and Sojka, 1994). It is hypothesised that gypsum ($CaSO_4.2H_2O$) application will increase the calcium content of the soil and enhance soil flocculation. Polyacrylamide application following gypsum application may result in improved soil structure and stabilisation of that improvement in structure by PAM. Increased infiltration rates may increase water availability within the profile however this is probably due to reduced losses as runoff. However, Wallace *et al.* (1986) stated that PAM application in solution might not be suitable for frequently irrigated soils as water penetration may be reduced, thus increasing runoff.

2.8 Conclusions

- Potato growth and yield is linearly related to PAR interception under non-limiting conditions.

- Canopy development consists of the expansion of already initiated leaves.

- Water stress has the greatest effect on canopy development and reduces leaf area.

- Drought can decrease the phyllochron and increase the rate of development.

- Irrigation increased tuber yields in dry years but negative yield responses can occur when irrigation is not required.

- There is very little reliable information on the effects of PAM on crop yields even though it was developed more than 40 years ago.

- Micronised PAM has only been developed recently and therefore there is no information regarding its effects on crop growth and yield. Furthermore recommended application rates are very low.

- PAM has been shown to increase infiltration rates, decrease soil erosion and enhance aggregation.

- Gypsum enhances flocculation of soils and it is hypothesised that PAM may stabilise an improved soil structure when applied after gypsum application.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

An experiment was conducted at the Horticultural Research Area at Lincoln University, Canterbury (latitude 42° 38'S) on a Wakanui silt loam (Cox, 1978) soil (Mottled Immature Pallic) in the 2001/2002 growing season to determine the effects of micronised polyacrylamide (PAM) and gypsum on the growth and yield of irrigated and dryland potatoes (*Solanum tuberosum* L.).

3.2 Experimental Design and Treatments

The treatments were irrigation (irrigated and dryland), micronised PAM (0, 25 and 50 ppm) and gypsum (0 and 500 kg ha^{-1}). The design was a split plot with irrigation as the main plot. Plots were 11m x 4.2m and the 12 treatments (Table 3.1) were replicated three times.

3.2.1 Irrigation Scheduling

After micronised PAM and gypsum were applied (05/11/2001) 16mm of irrigation was applied to both irrigated and dryland plots. Until canopy closure, irrigation was applied when the sum of 75% of daily evapotranspiration reached 30mm. Two applications of 30mm were applied using a gun irrigator fitted with a deflector plate to prevent irrigation of dryland plots. Irrigation (30mm) was applied on the 10/12/2001 and 24/12/2001. Further applications were not required.

Table 3.1. Details of treatments and application rates.

Treatment number	Irrigation level	PAM Rate	Gypsum rate
1	Dryland	0 ppm l^{-1}	0 kg ha^{-1}
2	Dryland	0 ppm l^{-1}	500kg ha^{-1}
3	Dryland	25 ppm l^{-1}	0 kg ha^{-1}
4	Dryland	25 ppm l^{-1}	500kg ha^{-1}
5	Dryland	50 ppm l^{-1}	0 kg ha^{-1}
6	Dryland	50 ppm l^{-1}	500kg ha^{-1}
7	Irrigated	0 ppm l^{-1}	0 kg ha^{-1}
8	Irrigated	0 ppm l^{-1}	500kg ha^{-1}
9	Irrigated	25 ppm l^{-1}	0 kg ha^{-1}
10	Irrigated	25 ppm l^{-1}	500kg ha^{-1}
11	Irrigated	50 ppm l^{-1}	0 kg ha^{-1}
12	Irrigated	50 ppm l^{-1}	500kg ha^{-1}

3.2.2 Micronised Polyacrylamide (PAM)

Micronised PAM was applied at 0, 25 and 50 ppm. The PAM was dissolved in a saturated ammonium sulphate solution, which was then mixed with water. The diluted solution was then applied to the appropriate plots. The PAM was applied on the 05/11/2001 with a Solo spray unit with a single hand wand. Nozzles were tjet 11003 with an 110° spray angle (Plate 3.1).

3.3.3 Gypsum rates

Gypsum was applied at a rate of 500 kg ha^{-1} (McLenegan, pers. comm., 2001) on the 01/11/2001.

3.3 Site History

The site was sown in blue lupins (*Lupinus angustifolius*) in the 2000 growing season. In March 2001 the site was put into a short rotation Moata ryegrass (*Lolium multiflorum*) pasture.

3.4 Soil Testing

Soil tests were conducted to determine fertiliser requirements on the 20/09/2001. Soil quicktest results (Table 3.2) indicated low sulphate sulphur. As a result, all basal fertilisers applied (Table 3.3) contained sulphur to prevent confounding due to gypsum application ($CaSO_2.H_2O$). Total fertiliser nutrient inputs were equivalent to 100 kg N ha^{-1}, 42 kg K ha^{-1}, 22 kg P ha^{-1} and 153 kg S ha^{-1}.

Table 3.2. Soil pH and nutrient quicktest results for a Wakanui silt loam at Lincoln University.

pH	**P**	**Ca**	**Mg**	**K**	**Na**	**S (SO_4^-)**
5.6	20	5	16	12	4	3

Fertilisers were applied on the 23/10/2001 prior to sowing. The site was worked over with a deep grubber to a depth of 300 mm before a Vicon Veri spreader with a bout width of 6m was used to apply fertilisers. A Duncan vibratiller was used to incorporate fertilisers to a depth of 150mm.

Table 3.3. Rates and forms of basal fertilisers applied to a Wakanui silt loam at Lincoln University.

Fertiliser	Nutrient content (N, P, K, S) (%)	Rate applied (kg ha^{-1})
Ammonium sulphate	(21, 0, 0, 24)	476
Potassium sulphate	(0, 0, 42, 17)	100
Superphosphate	(0, 9, 0, 11)	200

3.5 Management

3.5.1 Sowing

Prior to sowing the site was cultivated twice (19/09/2001 and 26/09/2001) with a roto crumbler. Certified 'Ilam Hardy' seed potatoes were delivered on the 21/09/2001 and placed in a coolstore at 3°C to reduce sprouting prior to sowing. The crop was sown on the 23/10/2001 with an International Harvester twin row planter and ridged at sowing. Inter-row spacing was 800 mm with an interplant spacing of 300mm to achieve a target population of 40 000 plants ha^{-1}. Ridges were re-moulded using a Massey Ferguson 3 row potato moulder on the 04/12/2001 when plants had reached approximately 15 cm in height (Plate 3.2).

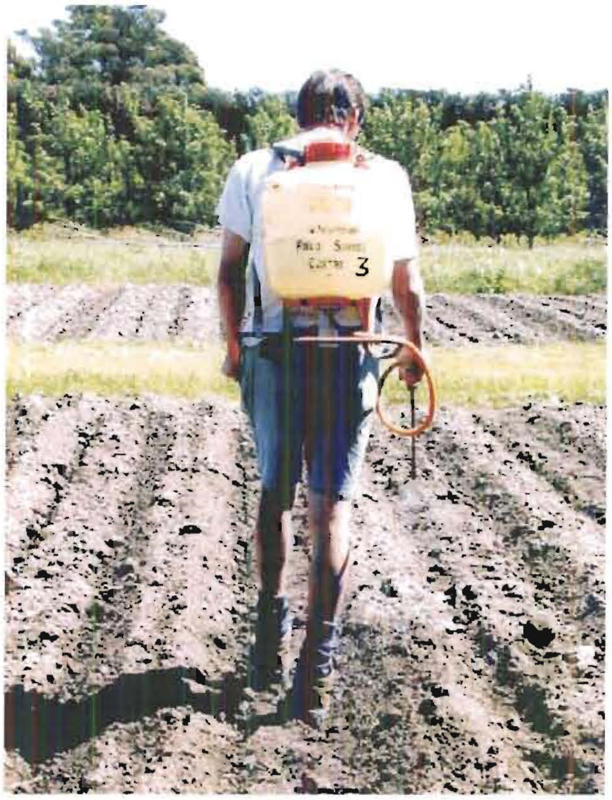

Plate 3.1. PAM application with a Solo spray unit on the 05/11/2001.

Plate 3.2. Re-ridging of potatoes on the 04/12/2001 with a Massey Ferguson 3 row potato moulder.

3.5.2 Pre Emergent Herbicides

Three pre-emergent herbicide applications were made (Table 3.4) to kill pasture and control weed species present (Wham Chemsafe, 1996). All applications were made with a wetting agent (Citowett) at 25ml per 100 l H_2O applied. Applications were made with a Croplands 12m spray rig fitted with tjet 11004 nozzles with a 110° spray angle. Travel speed was 8 km hr^{-1} with a spray pressure of 300Kpa.

Table 3.4. Pre-emergent herbicide application rates, active ingredient and dates of application.

Date	Rate	Active ingredient
14/09/2001	2 l ha^{-1}	Glyphosate (360 gai l^{-1})
13/10/2001	3 l ha^{-1}	Glyphosate (360 gai l^{-1})
06/11/2001	2 l ha^{-1}	Glyphosate (360 gai l^{-1})

3.5.3 Post Emergent Herbicides

Sencor (metribuzin at 750g kg^{-1} in the form of a water dispersible granule) was applied at a rate of 1 kg ha^{-1} on the 04/12/2002 to control major weed species present at the site (Wham Chemsafe, 1996). Application method was the same as detailed for pre-emergent applications (Section 3.5.2). Weed species included californian thistle (*Cirsium arvense*), wireweed (*Polygonum aviculare*), blue lupin (*Lupinus angustifolius*), field pansy (*Viola arvensis*), black nightshade (*Solanum nigrum*), hairy nightshade (*Solanum sarrachoides*) and fathen (*Chenopodium album*).

3.5.4 Fungicides

Potato early blight (*Alternaria solani*) (Plate 3.3) was identified (Pay, pers. comm., 2002) at the site on the 14/01/2002 and was sprayed on the 16/01/2002. Bravo, a systemic fungicide containing chlorothalonil at 500g l^{-1} (Wham Chemsafe, 1996) at a rate of 1.1 l ha^{-1} was applied using the method detailed in section 3.5.2. In an effort to control the outbreak two further applications were made on the 4/02/2002 and 18/02/2002. A visual assessment of the proportion of leaf area affected by blight was made on the 08/02/2002 and was estimated as affecting about 10% of total leaf area (McKenzie, pers. comm., 2002a). A fourth fungicide application was made using Manex, (active ingredient maneb at 480g l^{-1}) applied at a rate of 2 l ha^{-1} on 25/02/2002 (Plate 3.4).

On the 04/04/2002, two weeks prior to the final harvest, a desiccant (Reglone) was applied at a rate of 4 l ha^{-1} to reduce weed biomass at the final tuber harvest (18/04/2002). Applications details are presented in section 3.5.2.

Plate 3.3. Necrotic lesions on leaf surfaces of 'Ilam Hardy' potatoes caused by early blight (*Alternaria solani*).

Plate 3.4. Manex fungicide application (25/02/2002) with a tractor mounted boom sprayer with tjet 11004 nozzles.

3.6 Weather data

Weather data including rainfall and potential evapotranspiration was collected from the Broadfields site located 2km north of the experimental site.

3.7 Environmental Damage

On the 08/02/2002 a number of broken stems and browning of the underside of the leaves looked similar to frost damage (Plate 3.5). This was probably a result of wind chill caused by a southerly change on the 05/02/2002 and 06/02/2002. The majority of leaf damage occurred on the lower epidermis (Stewart, pers. comm., 2002).

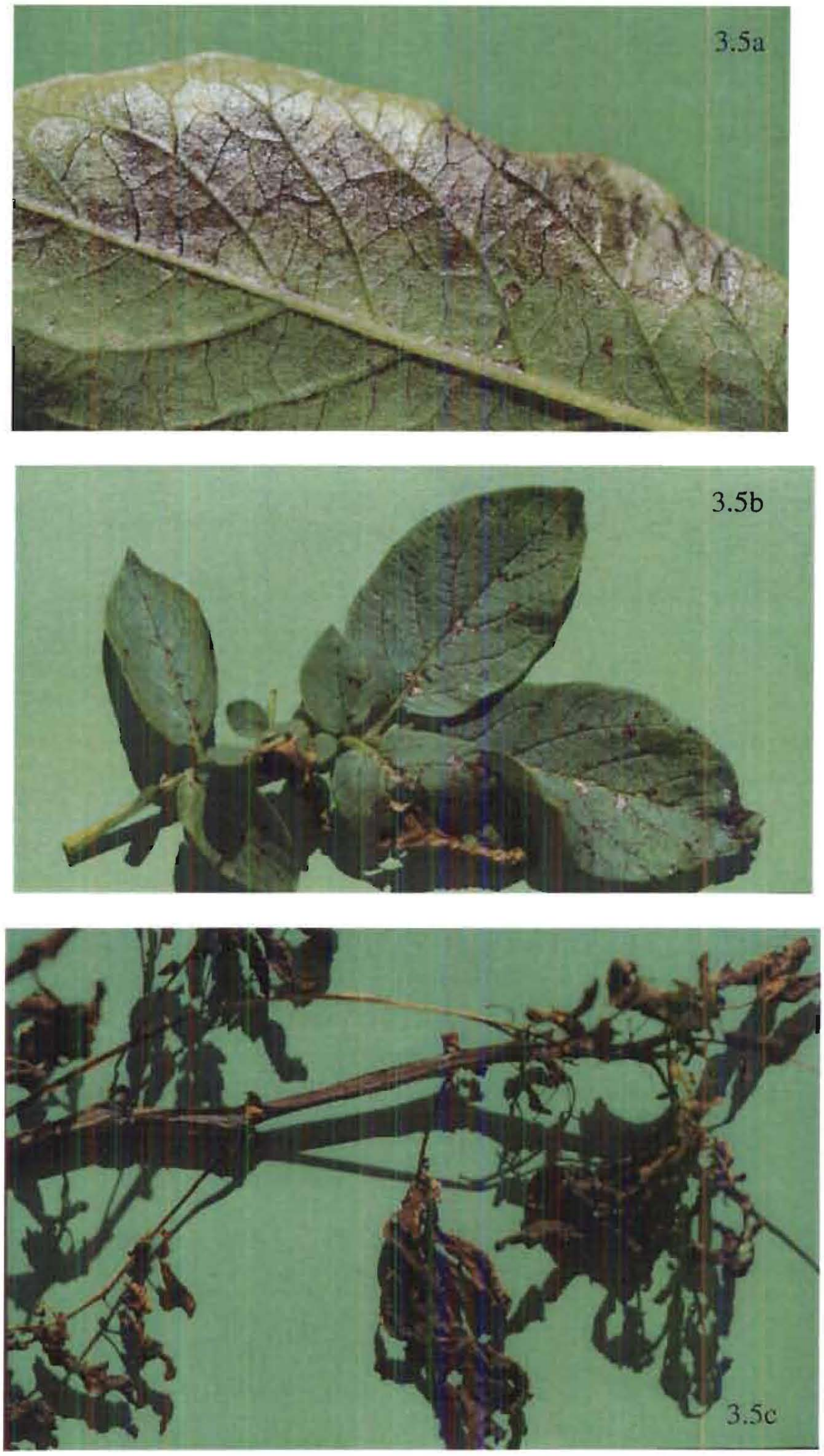

Plate 3.5. Wind damage to the lower epidermis of the leaf (3.5a) was subsequently followed by premated senescence of the leaf area (3.5b), but where mainstem had broken completely the entire haulm senesced (3.5c).

3.8 Measurements

3.8.1 Plant Population

After emergence, plant counts were made along an 11m row in each plot and interplant spacing was measured. This was used to determine the mean interplant spacing and determine if the target population (40 000 plants ha^{-1}) was achieved.

3.8.2 Leaf area Index and Light Interception

Leaf area index (LAI) and percent interception were made using a Sunscan canopy analysis system (Delta T Industries). The calibration is shown in Appendix 1. A malfunction on the 08/01/2002 resulted in all subsequent measurements being made with a Li-Cor 2000 plant canopy analyser. Measurements were taken every 7-10 days, unless conditions were unsuitable, until 12/02/2002.

3.8.3 Radiation Interception

Radiation interception was calculated from photosynthetically active radiation (PAR) calculated as 0.5 x total solar radiation receipts measured at the Broadfields meteorological station from 50% emergence of the crop (15/11/2001) until maximum LAI was achieved. Radiation use efficiency was calculated as the slope of the relationship between cumulative intercepted radiation and dry matter production from 50% emergence to the point maximum LAI was achieved.

3.8.4 Aggregate Stability

Soil samples were taken on the 2/02/2002 and stored in a cooler at 4°C until processing. On the 6/02/2002 field moist samples were sieved through 4mm and 2mm diameter sieves and soil not within the fraction required for the tests was discarded and the remaining portion of the samples were air dried at 23°C for 7 days.

Aggregate stability was determined using the wet sieving technique described by Kemper and Rosenau (1986). A 100g sample of air-dry aggregates was placed in a wet sieve for 10 minutes at 25 strokes per minute. Aggregates remaining after wet sieving were collected and oven dried overnight at 105°C. A further sample of about 10 g was oven dried overnight at 105°C to determine soil moisture content. Equation 3.1 was used to determine the amount of stable aggregates present using soil dry weight equivalents.

$$\text{Stable Aggregates (\%)} = \frac{\text{Soil weight remaining}}{\text{Initial sample weight}} * 100 \qquad \text{Equation 3.1}$$

3.8.5 Tuber Soil Adherence

At the final harvest, ten randomly selected tubers were used to determine soil adherence. Tubers were placed in paper bags and allowed to air dry for one week to reduce soil moisture content. Soil adhering to the tubers was then brushed off and weighed and dried at 105°C. Soil dry weight was then used to calculate percentage soil adherence of tuber fresh weight.

3.8.6 Destructive Harvests

Destructive harvests were initially made every 2 weeks after tuber initiation, which was defined as the point when swellings on the tips of the stolons were twice the diameter of the stolon on which it was produced (Plate 3.6). Four plants per plot were taken at the initial harvest but this was increased to 5 plants per plot for subsequent harvests. Sampling events were reduced to once every 3 weeks following the harvest on 16/02/2002.

Destructive harvests were used to calculate total, tuber and above ground dry matter (DM). Samples were washed and separated into components and then oven dried at 60°C. The final harvest for total DM was conducted on the 14/03/2002 as reglone application on the 04/04/2002 meant the subsequent harvest (18/04/2002) was for tubers only as top biomass had senesced. An area equivalent to $4.8m^2$ was sampled at the final tuber harvest (18/04/2002).

Tuber fresh weight, %DM and tuber size distribution were determined at the final harvest (18/04/2002). Tubers were separated into four grades (Table 3.5) based on processor requirements and previous work conducted by Searle (1999). Tuber DM percentage was determined from five table grade tubers.

Table 3.5. Grades and tuber weights used at the final harvest (18/04/2002) to determine tuber size distribution of 'Ilam Hardy' potatoes at Lincoln.

Grade	Weight Range (g)	
Pig	< 50	
Seed	50 – 113	Diameter < 45mm
Table	113-170	Diameter ≤ 65mm
Super	> 170	

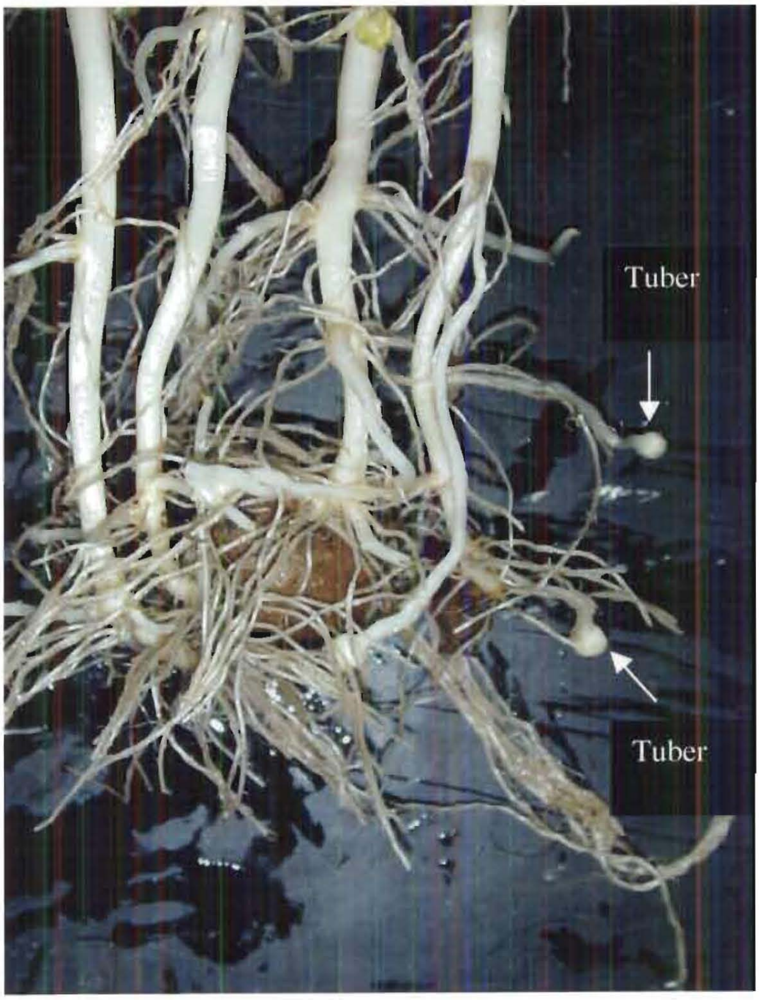

Plate 3.6. Tuber initiation was defined as the point when the swelling at the tip of the stolons was twice the diameter of the stolon.

3.9 Statistical Analysis

Statistical analysis was performed in the Systat9 statistical package using the General Linear Model (GLM). Main plot effects were analysed using the hypothesis test. Means separations were conducted using Fishers protected Least Significant Difference (LSD) (Clark, 1994). Radiation use efficiency of irrigated and dryland plots were analysed by linear regression. Slopes were separated using a two-tailed t-test.

3.10 Functional Growth Analysis

Total dry matter accumulation over time was analysed using the Maximum Likelihood Program (MLP). Sigmoidal growth curves were fitted to sequential harvest data for each plot using logistic (equation 3.2), generalised logistic (equation 3.3) or gompertz curves (equation 3.4) (Ross *et al.*, 1979; Causton and Venus, 1981). Appropriate equations were used to reduce the standard error to no more than 10% of the parameter generated.

$$Y = \frac{C}{(1 + \exp(-b(x - m)))} \quad \text{.......................Equation 3.2}$$

$$Y = \frac{C}{(1 + T\exp(-b(x - m)))^{1/T}} \quad \text{.......................Equation 3.3}$$

$$Y = C * \exp(-\exp(-b(x - m))) \quad \text{.......................Equation 3.4}$$

Where C represents the final size, T is a shape parameter and b and m are constants.

Parameters derived were used to calculate the weighted mean absolute growth rate (WMAGR), duration of growth (DUR) and maximum crop growth rate (CGR_{max}) (Appendix 2). Derivates were analysed in Systat9 using the GLM and means were separated by LSD where necessary.

CHAPTER FOUR

POTATO GROWTH AND YIELD

4.1. Environmental Conditions

A summary of weather data collected from the Broadfields meteorological station for the period from 23/10/2001 to 22/04/2002 is presented in Figure 4.1. Rainfall in October and November was above average. However, December rainfall was about 50% less than the average and irrigated plots received two applications of 30mm. In contrast, January rainfall was 1.5 times greater than the 16-year average. As a result, irrigation applications were unnecessary following the second application on the 31/12/2001. Mean total solar radiation and temperature followed seasonal patterns. In February, a southerly change (05/02/2002 and 06/02/2002) deposited 37.8mm of rain and caused wind damage (wind run on the 06/02/2002 was 956km with a minimum temperature of 7.8°C) to the crop (Plate 3.5).

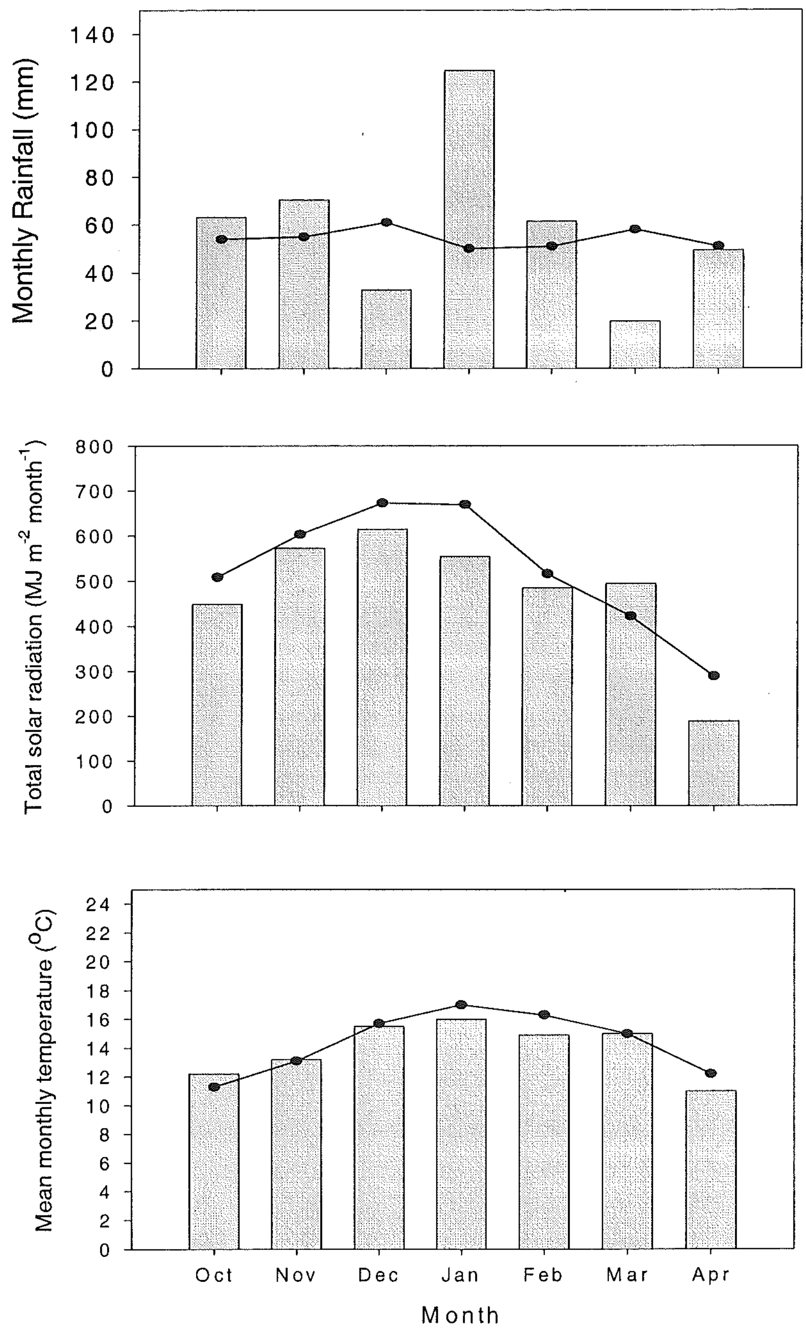

Figure 4.1. Weather data for the 2001/2002 growing season at Lincoln, New Zealand from sowing (23/10/2001) to final harvest (22/04/2002). (Data for April is only for the period until the final harvest (22/04/2002)). Monthly long-term means (●) are indicated for temperature, rainfall, and solar radiation receipts based on the period from 1975 – 1991.

4.2. Tuber Yield and Size Distribution

At the final harvest, 177 days after sowing (DAS), treatments had no effect on total tuber yield or any tuber fraction measured (Plate 4.1 and Table 4.1). Average total tuber yields (59 500 kg ha^{-1}) were similar from a mean population of 32 460 plants ha^{-1} (01/12/2001). The main component of total tuber fresh weight was super grade tubers (>170g), which made up 65% of tuber yield. Economic yield (tubers >113g) contributed 82% of the total tuber yield and was similar (48 767 kg ha^{-1}) for all treatments (data not presented). Tuber damage during harvest was also not affected by any treatment and did not exceed 1% of total tuber yield (data not presented).

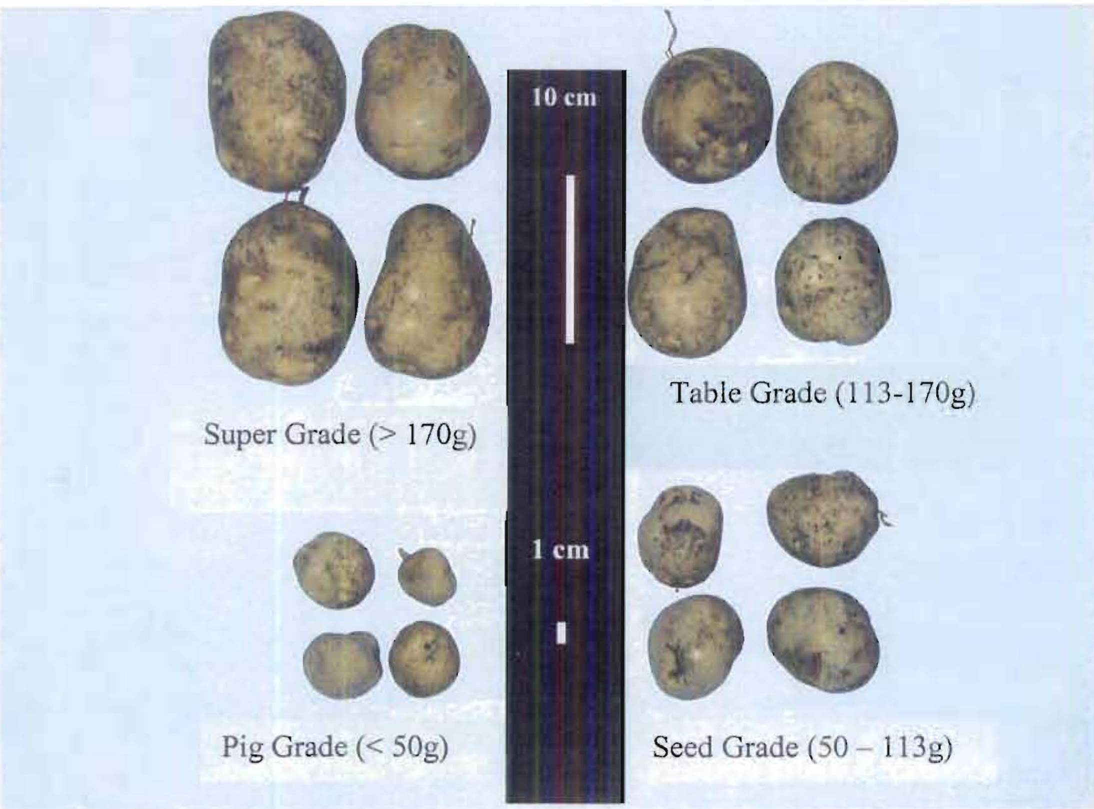

Plate 4.1. Grades used to determine the size distribution of tubers at the final harvest (177 DAS).

Table 4.1. Total tuber freshweight (FWT) yield and tuber size distribution of an Ilam Hardy potato crop sown at Lincoln in the 2001/2002 growing season.

Treatment	Total Tuber FWT Yield (kg ha^{-1})	Tuber fresh weight grades (kg ha^{-1}) Super Grade (>170g)	Table Grade (113-170g)	Seed Grade (50-113g)	Pig Grade (<50g)
Dryland	59 670	37 960	10 620	9880	700
Irrigated	59 330	39 440	9500	9410	580
Significance	ns	ns	ns	ns	ns
0 ppm PAM	59 350	37 990	10 190	10 030	660
25 ppm PAM	58 930	40 200	9490	8310	540
50 ppm PAM	60 220	37 920	10 510	10 600	730
Significance	ns	ns	ns	ns	ns
0 kg ha^{-1} Gypsum	57 870	36 770	9750	10 290	610
500 kg ha^{-1} Gypsum	61 130	40 630	10 380	9000	680
Significance	ns	ns	ns	ns	ns
Interactions					
PAM*Gypsum	ns	ns	ns	ns	ns
Irrigation*PAM	ns	ns	ns	ns	ns
Irrigation*Gypsum	ns	ns	ns	ns	ns
Irrigation*PAM*Gypsum	ns	ns	ns	ns	ns

4.3. Tuber Dry Matter Production

Total tuber dry matter at the final harvest (18/04/2002) was 14 294 kg DM ha^{-1} and treatments had no effect (Table 4.2). Tuber dry matter content was similar at 24%.

Table 4.2. Total tuber dry matter (DM) (kg ha^{-1}) and dry matter (DM) content of 'Ilam Hardy' potato tubers (%) harvested after natural senescence (18/04/2002), at Lincoln, in the 2001/2002 growing season.

Treatment		Tuber DM (kg ha^{-1})	Tuber DM (%)
Dryland		14 154	23.7
Irrigated		14 434	24.3
	Significance	ns	ns
0 ppm PAM		14 150	23.9
25 ppm PAM		14 142	23.9
50 ppm PAM		14 590	24.2
	Significance	ns	ns
0 kg ha^{-1} Gypsum		14 030	24.2
500 kg ha^{-1} Gypsum		14 558	23.8
	Significance	ns	ns
Interactions			
PAM*Gypsum		ns	ns
Irrigation*PAM		ns	ns
Irrigation*Gypsum		ns	ns
Irrigation*PAM*Gypsum		ns	ns

4.4 Total DM Production

4.4.1. Irrigation

Total dry matter (DM) production was similar until 95 DAS (Figure 4.2). At 95 DAS (26/01/2002) total DM production was greater ($p<0.01$) from irrigated treatments (8690 kg DM ha^{-1}) than from dryland treatments (6711 kg DM ha^{-1}). Total DM production at 116 DAS was greater ($p<0.01$) from irrigated plots (11 263 kg DM ha^{-1}) than from dryland plots (10 253 kg DM ha^{-1}). Dead top biomass indicated disease and environmental damage (06/02/2002) was similar across the site. No naturally senesced material was included in this fraction. On average, 4% of above ground biomass had senesced prematurely due to blight and environmental conditions (data not presented). Subsequently, at 142 DAS, irrigated plots continued to produce greater ($p<0.05$) total DM (14 909 kg DM ha^{-1}) than dryland plots (12 976 kg DM ha^{-1}). Total DM was not measured at the final harvest (18/04/2002) due to desiccant application.

4.4.2. PAM and Gypsum

Both PAM and gypsum, at no time, had any effect on total DM production of 'Ilam Hardy' potatoes. There were also no interactions.

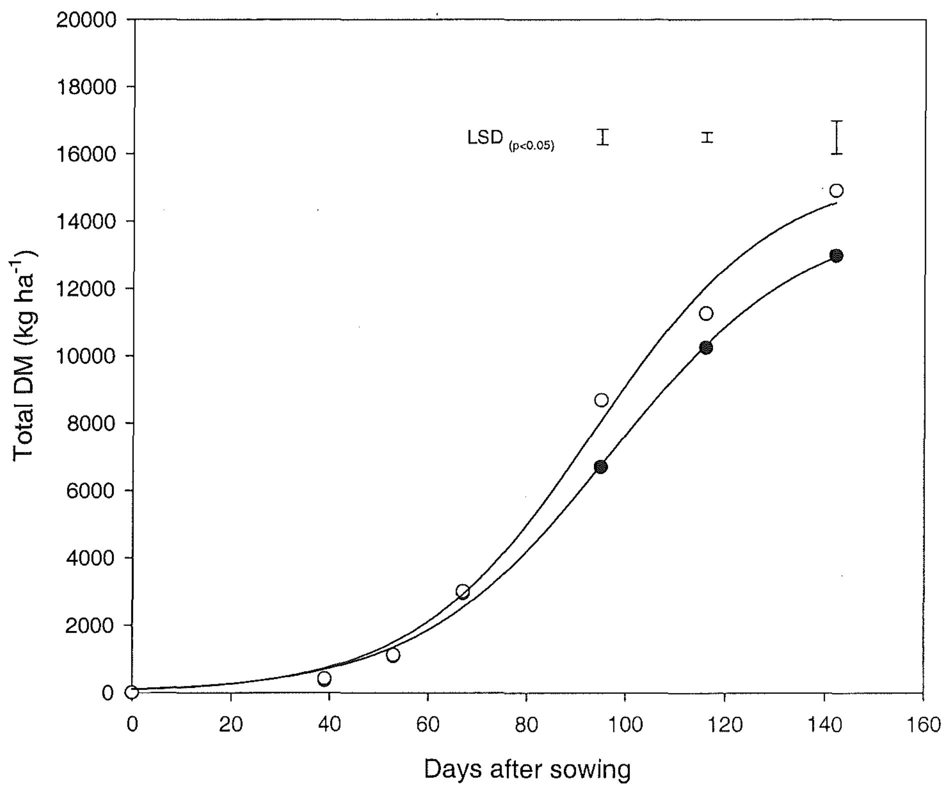

Figure 4.2. Total dry matter (kg ha^{-1}) of irrigated (○) ($r^2 = 0.994$) and dryland (●) ($r^2 = 0.998$) 'Ilam Hardy' potatoes from sowing (23/10/2001) to the final total harvest (14/03/2002) 142 days after sowing. Sigmoidal curves were fitted to data. Error bars indicate LSD at $p<0.05$ when effects were observed.

4.5. Leaf Area Development

4.5.1. Critical LAI and the Extinction Coefficient

Radiation interception was highly correlated with LAI (r^2 = 0.992) when fitted with an exponential equation (Figure 4.3). The critical LAI of 'Ilam Hardy' potato, determined at 95% interception, was 3.5. Slight deviations in the graph were caused by a change in equipment used to measure LAI. The extinction coefficient (k) was determined as –0.876 by fitting a regression between LAI and the natural log of the fraction of PAR transmitted through the canopy (Figure 4.4).

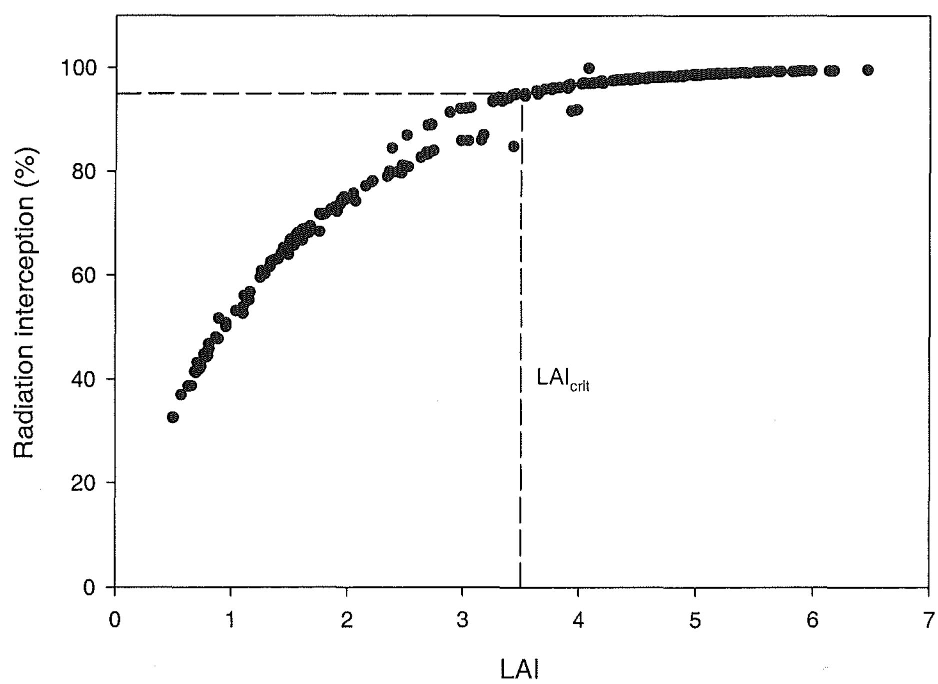

Figure 4.3. A diminishing returns relationship between LAI and intercepted incident radiation (%) in an 'Ilam Hardy' potato crop grown at Lincoln in the 2001/2002 growing season. Critical LAI (95% interception) (LAI_{crit}) occurred at a LAI of 3.5. (r^2 = 0.992). Apparent deviations occurred when equipment was changed due to mechanical failure.

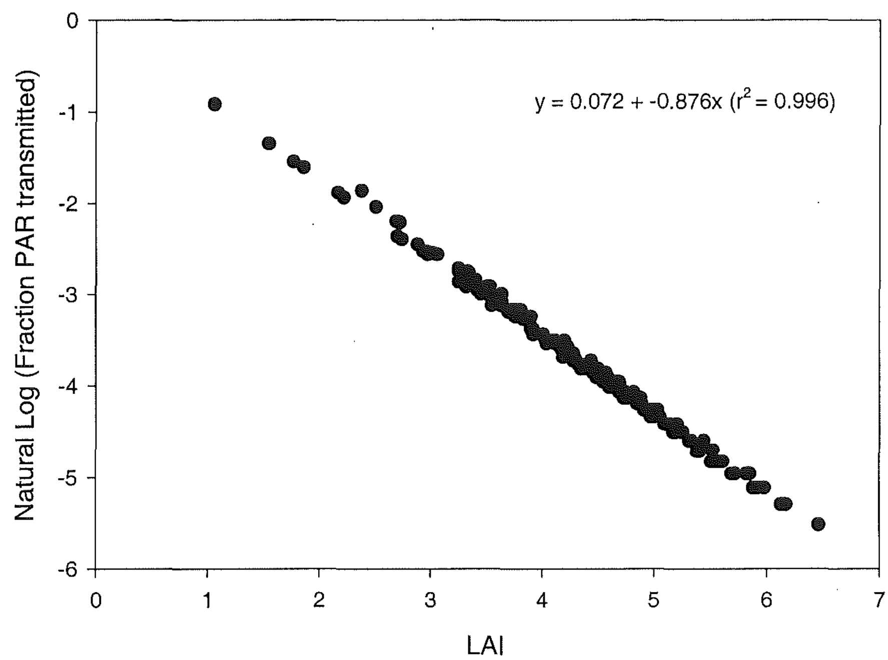

Figure 4.4. The relationship between the natural log of the fraction of PAR transmitted through the canopy and LAI. The slope of the line (-0.876) represents the extinction coefficient (k).

4.5.2 Canopy Development over Time

Canopy development was affected by irrigation at 85 and 94 DAS (Figure 4.5). At 85 DAS, the LAI of irrigated plots was 37% greater (4.8) than that of dryland plots (3.5). Subsequently at 94 DAS irrigated plots still maintained 29% greater LAI (5.3) than dryland plots (4.1). Observations at all other times were not affected by any treatment. Critical LAI was achieved at 67 and 85 DAS by irrigated and dryland plots respectively.

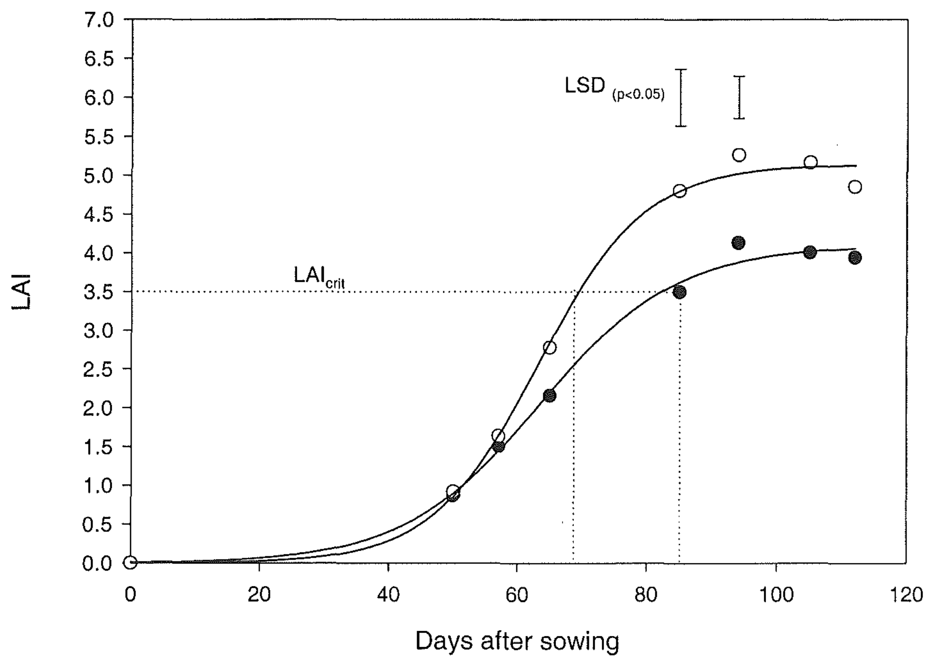

Figure 4.5. Leaf area index (LAI) from 57 to 112 days after sowing (DAS) of irrigated (○) ($r^2 = 0.995$) and dryland (●) ($r^2 = 0.995$) 'Ilam Hardy' potatoes. Sigmoidal curves were fitted to data from sowing (0 DAS). Time to reach critical LAI (LAI_{crit}) is indicated (·····) for irrigated and dryland treatments. Error bars represent LSD at $p<0.05$ when differences were observed.

4.5.3. Maximum LAI

Irrigated plots produced a higher ($p<0.05$) maximum LAI (5.3) (25/01/2002) than dryland plots (4.4) (Table 4.3). However, the LAI_{crit} value indicated all treatments intercepted 95% of incident radiation at a LAI of 3.5 (Figure 4.5).

Table 4.3. Maximum leaf area index (LAI) and intercepted incident radiation (%) of 'Ilam Hardy' potatoes measured 94 days after sowing (25/01/2002) at Lincoln.

Treatment	Maximum LAI	Maximum Interception (%)
Dryland	4.1	97
Irrigated	5.3	99
$LSD_{(p<0.05)}$	0.06	ns
CV%	11.40	
0 ppm PAM	4.6	98
25 ppm PAM	4.6	98
50 ppm PAM	4.9	98
Significance	ns	ns
0 kg ha^{-1} Gypsum	4.7	98
500 kg ha^{-1} Gypsum	4.7	98
Significance	ns	ns
Interactions		
PAM*Gypsum	ns	ns
Irrigation*PAM	ns	ns
Irrigation*Gypsum	ns	ns
Irrigation*PAM*Gypsum	ns	ns

4.6. Radiation Interception and Radiation Use Efficiency (RUE)

From emergence until maximum LAI, total intercepted PAR was about 375 MJ^{-1} PAR m^{-2} for both irrigated and dryland treatments. However, irrigated plots produced about 30% more DM (8690 kg ha^{-1}) than the dryland plots (6711 kg ha^{-1}) by 95 DAS when maximum LAI was achieved (see Figure 4.2). Radiation use efficiency was similar for irrigated (2.4 g DM MJ^{-1} PAR m^{-2}) and dryland (1.9 g DM MJ^{-1} PAR m^{-2}) treatments (Figure 4.6).

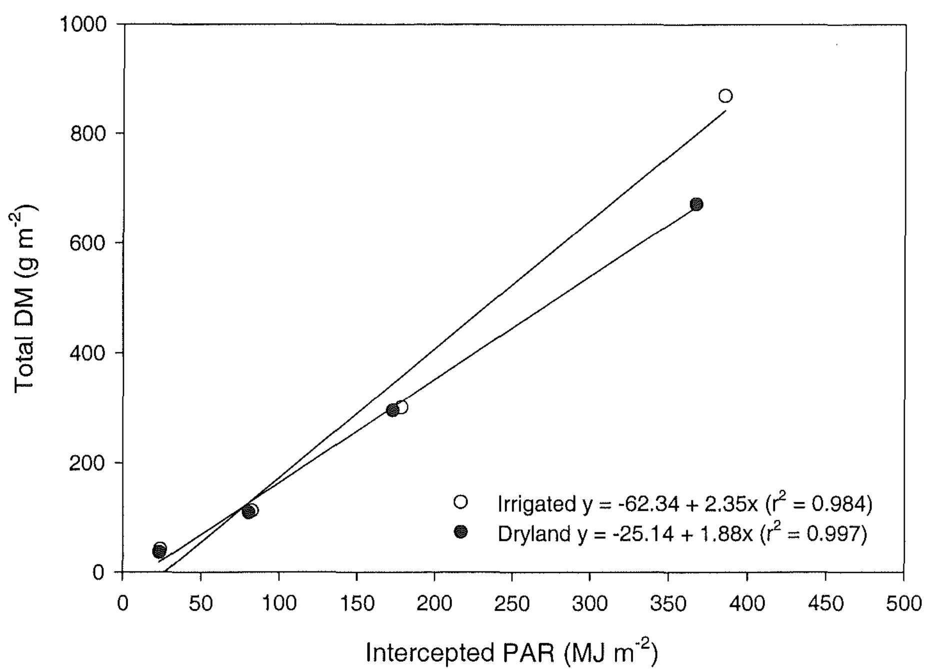

Figure 4.6. The relationship between DM production and intercepted PAR from 50% emergence (15/11/2001) to maximum LAI (25/01/2002) for irrigated (○) and dryland (●) 'Ilam Hardy' potatoes. Note: On the y-intercept 0 g m^{-2} total DM relates to 50% emergence (15/11/2001) not sowing date.

4.7. Functional Growth Analysis

Both the WMAGR and CGR_{max} were increased by irrigation (Table 4.4). Dryland plots had a lower mean growth rate ($p<0.001$) during the linear phase of growth and consequently a lower mean rate of DM accumulation during the linear growth phase. The maximum crop growth rate was lower from dryland (118 kg DM ha^{-1} d^{-1}) than irrigated plots (130 kg DM ha^{-1} d^{-1}). There was no difference in the duration of growth, which was a mean of 125 days.

Table 4.4. Weighted mean absolute growth rate (WMAGR), duration (DUR) of growth and maximum crop growth rate (CGR_{max}) at the point of inflexion of 'Ilam Hardy' potatoes.

Treatment	WMAGR (kg DM ha^{-1} d^{-1})	DUR (days)	CGR_{max} (kg DM ha^{-1} d^{-1})
Dryland	118	120	177
Irrigated	130	129	189
$LSD_{(p<0.05)}$	0.52	ns	7.85
CV%	0.64		4.27
0 ppm PAM	124	125	183
25 ppm PAM	116	130	172
50 ppm PAM	131	119	190
Significance	ns	ns	ns
0 kg ha^{-1} Gypsum	128	130	178
500 kg ha^{-1} Gypsum	120	120	184
Significance	ns	ns	ns
Interactions			
PAM*Gypsum	ns	ns	ns
Irrigation*PAM	ns	ns	ns
Irrigation*Gypsum	ns	ns	ns
Irrigation*PAM*Gypsum	ns	ns	ns

4.8. Aggregate Stability

Gypsum applied at 500 kg ha^{-1} increased ($p<0.05$) the percentage of stable aggregates by 24% (Table 4.5). At 0 kg gypsum ha^{-1} there were 1.8% stable aggregates compared to 2.3% stable aggregates in gypsum plots.

Table 4.5. Treatment effects on the percentage stable aggregates determined by the wet sieving technique of a Templeton silt loam soil at Lincoln.

Treatment	Stable Aggregates (%)
Dryland	2.38
Irrigation	1.73
Significance	ns
0 ppm PAM	2.14
25 ppm PAM	1.93
50 ppm PAM	2.09
Significance	ns
0 kg ha^{-1} Gypsum	1.84
500 kg ha^{-1} Gypsum	2.27
$LSD_{(p<0.05)}$	0.26
CV%	25.72
Interactions	
PAM*Gypsum	ns
Irrigation*PAM	ns
Irrigation*Gypsum	ns
Irrigation*PAM*Gypsum	ns

4.9. Soil Adherence

There was no difference in the amount of soil adhering to tubers at the final harvest (Table 4.6). Soil present on tuber surfaces was about 0.8% based on soil dry weight.

Table 4.6. Effects of irrigation and application rate of PAM and gypsum at high and low levels on soil adherence to tubers using soil dry weight.

Treatment	Soil Adherence (%)
Dryland	0.72
Irrigation	0.78
Significance	ns
0 PAM / 0 Gypsum	0.79
50 ppm PAM / 500kg ha^{-1} Gypsum	0.70
Significance	ns
Interaction	
Irrigation* Application Rate	ns

CHAPTER FIVE

DISCUSSION OF EXPERIMENTAL RESULTS

5.1. Environment, Irrigation and Potato Production

Final tuber yield (Table 4.1) was not affected by any treatment as environmental conditions dominated results obtained in the 2001-2002 season. Irrigation was not applied after December 2001, as January rainfall was 150% greater than the 16-year average (Figure 4.1) and disease control was necessary to maintain leaf area.

The final measurement of total DM occurred on the 14/03/2002. Three weeks later, on 04/04/2002, a desiccant (Reglone) was applied to the crop. The final tuber harvest was conducted on the 18/04/2002. Sample size was larger at the final tuber harvest (18/04/2002) (4.8 m^2 harvested per plot) compared to 5 plants per plot for sequential harvests conducted from 01/12/2001 to 14/03/2002. This three-week difference, in addition to different sampling procedures, resulted in higher tuber DM production than total DM production reported in Table 4.2 and Figure 4.2 respectively.

5.1.1 Final Tuber Yield

Total tuber yields were similar (59 500 kg tubers ha^{-1}) (Table 4.1). This is about 20% higher than the New Zealand average for 2000 and 2001 (FAO Stats, 2002). Searle (1999) reported yields ranging from 35 800 to 77 700 kg ha^{-1} for 'Ilam Hardy' potatoes grown on a Templeton silt loam and Wakanui silt loam respectively. Yields differed with treatment and between years. However, it was noted that experiment 1 (1985) did not receive full irrigation because of a blight outbreak, (not controlled), which reduced the growing season to 121 days. This was a similar situation to that of the 2001-2002 growing season. In 2001-2002 the crop was managed for control of the outbreak, which allowed the leaf area to be maintained for a similar duration. Searle (1999) reported total tuber yields that were similar (61 300 kg ha^{-1} in 1985) to those achieved in the 2001-2002 growing season (59 500 kg ha^{-1}). Population densities differed between Searles' (1999) experiment (44 330 seed tubers ha^{-1}) and those reported here (32 460 seed tubers ha^{-1}) which was equivalent to a 37% difference in sowing rates. However, this could indicate either a plastic response to increased populations or the economic benefits of disease control.

Searle (1999) reported 'Ilam Hardy' potatoes were more sensitive to water stress during early growth and less sensitive to late drought in contrast to the response of Russet Burbank potatoes reported by Martin *et al.* (1992). In addition, it was concluded that tuber number in 'Ilam Hardy' was controlled by moisture stress prior to tuber initiation. During this period the crop had sufficient moisture. Jefferies and MacKerron (1989) also reported drought reduced tuber populations as fewer tubers were initiated.

5.1.2 Tuber Size Distribution

Tuber size distributions indicated about 85% of tuber yield was within the economic fraction (>113g) of which 80% was in the super grade (>170g). Processors pay premiums for super grade tubers and do not accept tubers <113g (Hughes and Shepard, 1983; Admiraal, 1988). Searle (1999) also reported an economic yield of 80% of total tubers and the proportion of super grade tubers was 70%. This is about 13% lower than that achieved in 2001-2002. However, the plasticity of response to environmental conditions, in addition to a higher sowing rate, which reduces resources available for individual plant growth, may explain this variation.

5.1.3 Tuber DM Content

Tuber DM% was similar (24%) (Table 4.1) and all treatments exceeded the 20% DM content required for processing. These values exceed those reported by Searle (1999) for table grade tubers. As tuber water content is more affected by water stress, terminating irrigation applications to help with disease control probably caused the increase in tuber DM% (Jefferies and MacKerron, 1989). Silva *et al.*, (1991) indicated the importance of the timing of irrigation applications. Irrigation applications during tuber initiation and early bulking increases tuber DM%. Early tuber bulking corresponded with a January rainfall of 125mm. Generally, water stressed potatoes have a higher DM% than irrigated potatoes as tuber water content is more affected than DM accumulation (Jefferies and MacKerron, 1989).

5.1.4 Canopy Development

Differences in LAI (Figure 4.4) were observed 85 and 94 DAS but effects subsequently diminished. Cell division dominates leaf expansion until the leaf reaches about 30% of its final size and is indirectly affected by cell expansion due to a minimum cell size required for cell division (Hsaio, 1973; Biscoe and Gallagher, 1977). However, water stress develops gradually and with sufficient rainfall in January the deficit was relieved and leaf growth proceeded normally in both irrigated and dryland plots. Cell division is followed by rapid cell expansion, which is directly driven by turgor pressure (Hsaio, 1973). Although differences in leaf area occurred after January rainfall, cell division in young, developing leaves had probably been affected by water stress in late December and therefore leaves forming during this period were probably more limited by a lower cell number. In contrast, leaves expanding under water stressed conditions were of smaller size because of reduced leaf expansion (not measured). Jefferies (1989) reported the rate of leaf extension was directly proportional to P and Ψ, and leaf growth was reduced by drought when P and Ψ were less than 0.5MPa and –0.28 respectively. Final leaf size in dryland plots during this period was probably sink limited as when cell number is set there is no potential to increase leaf expansion as there are insufficient cells present to expand (Hsaio, 1973) as well as being limited by reduced cell expansion.

Critical LAI, determined at 95% interception, was 3.5 (Figure 4.3) and occurred at 67 and 85 DAS for irrigated and dryland treatments respectively. This was lower than the LAI_{crit} for 'Ilam Hardy' potatoes on the same soil type reported by Searle (1999) of 4.0 or an environmentally mediated alteration in canopy architecture. However, Searle (1999) did not report this parameter and therefore a direct comparison cannot be made. Alternatively, this may have been influenced by the unavoidable need to change equipment due to a mechanical failure. Wolfe *et al.* (1983) showed leaf area expansion, leaf area duration and biomass accumulation were reduced by drought. Maximum LAI ranged from 2 – 6 and varied between cultivars as a result of differences in canopy architecture and hence light penetration into the crop canopy (Hay and Walker, 1989).

Maximum LAI was greater from irrigated than dryland plots (Table 4.3). However, there is a diminishing returns relationship between LAI and light intercepted and 95% interception occurred at a LAI of 3.5, which both irrigated and dryland treatments achieved. However, dryland plots reached LAI_{crit} 18 days later than irrigated plots (Figure 4.5). This would help to account for increased total DM production in irrigated plots.

Maintenance respiration increases with increasing leaf age and relates to the amount of plant biomass to be maintained (Biscoe and Gallagher, 1977). The greater maximum LAI achieved by irrigated treatments probably, during later growth, meant that respiratory losses were greater which could have affected net photosynthesis (P_n) Photosynthetic efficiency of individual leaves declines as leaf age increases as potato plants are indeterminate and able to continue leaf production to replace senescing leaves (Pashiardis, 1988) and therefore the duration of growth rather then crop growth rate becomes more important in yield determination than in determinate species.

It was noted that dryland plots did not plateau at the same point as irrigated treatments (Figure 4.4). Two of the most logical explanations for this are a difference in plant density or a change in canopy architecture affecting light penetration into the canopy (Hay and Walker, 1989). However, this would require further quantification. It would have been beneficial to continue to monitor the decline in leaf area to quantify variations in leaf area duration between irrigated and dryland treatments. However, this would have been difficult, and very time consuming, with the degree of environmental damage and the fact that the equipment does not differentiate between green plant organs and senesced or necrotic plant material.

Radiation use efficiency (Figure 4.6) was similar for both irrigated and dryland treatments but accumulated interception was low compared to those reported elsewhere (see Shah, 1998). Measurements used for calculation of RUE were made only up to 94 DAS (71 DAE) when maximum LAI was reached because of the effects of cold wind damage, disease and senescence, which would have confounded RUE calculation if subsequent measurements had been included. However, assuming similar rates of daily interception for the two weeks following this point total accumulated PAR intercepted would have been near values reported by Shah (1998) and therefore low values on the x-axis merely reflect the short period over which RUE was calculated. Shah (1998) reported RUE values ranging from 1.97 to 2.78 g MJ^{-1} m^{-2} and RUE increased with increasing nitrogen applications. This was similar to the results presented in Figure 4.6. However, Allen and Scott (1980) reported RUEs of 3.5 – 3.7 g MJ^{-1} m^{-2}, which was similar to the results of both Jefferies and MacKerron (1989) and Burstall and Harris (1986). Reasons for low RUEs include nitrogen deficiency, water stress and disease. Photosynthesis is not as sensitive to water stress as cell expansion and division (Hsaio, 1973) but when stomata are closed to limit plant water loss, CO_2 movement into the leaf and assimilation is restricted. This decreases P_n, and therefore DM accumulation, but the quantity of light intercepted by the leaves is unchanged, unless leaf wilting or rolling occurs to reduce the heat load experienced by the plant. Shah (1998) showed as early blight infection increased in severity RUE was reduced by 17 to 28% compared to uninfected plants. In addition, RUE progressively declined in all treatments by about 20% from the first to the final harvest.

The extinction coefficient (k) of 'Ilam Hardy' potatoes was 0.88 (Figure 4.4). This was similar to the range of 0.82 to 0.86 reported for the same cultivar by Shah (1998). Canopy architecture plays a large role in the determination of LAI_{crit}. Species with erectophile canopies have higher LAI_{crit} than planophile canopies, as light penetration into the canopy differs. A k of 0.88 indicates a very horizontal leaf angle, which intercepts the majority of light in the upper layers of the canopy. Early in growth this would be a benefit in maximising light interception with a low LAI. However, as canopy development increases, and the crop canopy closes, leaves in the lower layers of the canopy contribute little to photosynthesis as there is less light transmitted through the canopy to be intercepted. In addition, leaves at the top of the canopy, which intercepted most of the incoming light, could reach the light saturation point beyond which photosynthesis cannot increase regardless of increased light interception (Monteith, 1977; Sale, 1973; Hay and Walker, 1989; Sinclair and Muchow, 1999).

5.1.5 Functional Growth Analysis

Figure 4.2 indicates the differences in total DM production, which resulted in a higher (9.5%) WMAGR from irrigated plots. When leaf area is reduced by reductions in cell expansion and division, light interception is reduced which limits gross photosynthesis (P_g) while as water stress develops partial or full stomatal closure would have reduced CO_2 movement within the leaf associated with a decrease in P_n (Biscoe and Gallagher, 1977). The maximum crop growth rate was 9% higher from irrigated than from dryland plots. This was because of the divergence of LAI (although values were similar) of irrigated and dryland treatments at the point of inflexion when the linear growth phase is entered in addition to irrigated plots reached LAI_{crit} 18 days prior to dryland plots. The higher LAI of irrigated treatments as the linear growth phase was entered resulted in the interception of more PAR, which resulted in greater DM accumulation.

During early drought cell expansion and division processes are affected both directly and indirectly. However, as water stress develops photosynthesis declines partly due to stomatal closure and partly due to increased mesophyll resistance. The reductions observed in crop growth rate associated with water stress occur due to a decrease in the free energy of cellular water, which is generally expressed in terms of the soil moisture deficit (Penman, 1971; Monteith and Scott, 1982).

Pashiardis (1988) and Monteith and Scott (1982) reported the CGR_{max}, of temperate C3 crops such as potato, to range from 150 to 200 kg DM ha^{-1} d^{-1} when grown under non-limiting conditions in Western Europe. As a result crop yields are correlated with the duration of the growth period. Monteith (1978) reported WMAGR for C3 crops to be about 130 kg DM ha^{-1} d^{-1}. Results indicate both CGR_{max} and WMAGR derived from growth curves (Ross *et al.*, 1979) were similar to values reported by Monteith and Scott (1982).

5.2 Disease

Environmental conditions resulted in an outbreak of early blight (*Alternaria solani*), which caused chlorosis and development of necrotic spots on leaf surfaces (Plate 3.3). About 10% of the leaf area was affected by 08/02/2002, resulting in reduced light interception, which reduced potential yield. Fungal spores within the crop are able to infect healthy tissue increasing disease prevalence within the crop. However, treatment with appropriate fungicides slows disease development. Reducing irrigation applications (or the intensity of applications) during cool weather and cooler parts of the growing season can also aid with disease control (Turkensteen, 1988).

Coffey *et al.* (1970) showed assimilate translocation in tomato (*Lycopersicon esculentum* Mill.) infected with *Alternaria solani* was altered in infected compared to uninfected leaves. During the early stages of infection there was increased assimilate retention in infected leaves while during the later stages, when there was extensive chlorosis and necrosis, export usually increased because necrotrophic organisms derive nutrients from dead tissue. Therefore photosynthesis is reduced in areas on the leaf with necrotic lesions and leaf area duration can be reduced (Holiday, 1992). However, the extent of the infection and plant age will affect translocation patterns (Coffey *et al.*, 1970).

Cold wind damage caused loss of leaf area due to damage to the lower epidermis, which was followed by premature senescence of leaves within the subsequent week. High wind run figures, also resulted in broken mainstem haulms (Plate 4.5). As a result phloem transfer from source (leaves) to sink (tubers) was broken and therefore DM accumulation to tubers on broken haulms ceased at this point. It is unknown how much this affected final yields as damage was distributed evenly over the site and, in order to prevent confounding, plants with severe damage were not harvested to prevent results indicating treatment effects that were in fact due to environmental damage.

5.3 Polyacrylamide and Gypsum

Micronised PAM had no effect on potato growth or development. Rates applied were extremely low compared with rates of non-micronised PAM reported elsewhere (Quastel, 1953; Martin, 1954). In addition, comparisons between new generation non-micronised PAM reported in section 2.7.1 and micronised PAM applied in the experiment are not directly comparable as the products are not identical and application rates of non-micronised PAM products have been much higher than those used here. For example, the literature reports new generation PAM application rates between 0.7 and 1980 kg ha^{-1} by Shainberg and Levy (1994) and Wallace and Wallace (1986a) respectively.

5.3.1 Aggregate Stability

Gypsum increased aggregate stability by 24%. However, in practical terms, aggregate stability of 2.4% is unlikely to have any great effect on crop production from the site. McLaren and Cameron (1996) showed stable aggregates were highest (>80%) under permanent pasture compared to heavily cultivated soils (<45%). This is about 1800 times lower than was determined in the experiment in 2001-2002 (Table 4.5). However, the site had not been in permanent pasture for at least 15 years (Jack, pers. comm., 2002), which would have resulted in decreased soil OM (not measured) and aggregate degradation by cultivation. Section 3.3 only documents the known site history for the two years prior to this experiment.

Shainberg *et al.* (1990) reported gypsum application, which enhanced flocculation of clay particles, resulted in an interaction with non-micronised PAM applications to further increase aggregate stability. However, PAM was applied at rates of 10, 20 and 40 kg ha^{-1} and cannot realistically be compared with the rates of micronised PAM applied at Lincoln. Quastel (1953) reported yield improvements after an application of 224 kg ha^{-1} of synthetic polymer and lettuce yields increased 325% after applying 4400 kg ha^{-1} of synthetic soil conditioner. It was noted that in order for PAM to be commercially feasible to a grower PAM cost would have to be less than gypsum while still gaining the same benefits of aggregation and improved soil structure.

Soil physical characteristics, particularly aggregation, were highly correlated with crop yields in corn and onion. This was related to soil aeration and resistance to emergence but PAM was applied with a polysaccharide and no treatment was a 'PAM only' control (Wallace and Wallace, 1986a).

Quastel (1953) reported the importance of soil organic matter in improving/ maintaining soil structure and therefore soil productivity and mentioned the importance of soil conditioners in areas where organic matter (OM) inputs were low due to intensive agricultural activities. Soil aggregation influences water movement, and soil aeration, which impact on crop productivity and yields. However, experiments with these earlier products were conducted in laboratories rather than under field conditions.

This led to the development of synthetic soil conditioners, which did not degrade as rapidly (Quastel, 1953). It was noted that polymer application had no effect on permanent wilting point or AWC but under field conditions benefits in increasing infiltration rates could increase water available to plants by increasing aggregate stability. At this early stage it was emphasised that soil conditioners stabilise aggregates and therefore a good structure was required at or prior to polymer application. Gardner (1952) also pointed out that many of the claims present on the market were grossly exaggerated and misleading. This is still true today. Plant dry matter increases are of little relevance to a producer if harvests are taken 16 - 44 DAE (Wallace and Wallace 1986a; 1986c).

Cook and Nelson (1986) also found results have proven difficult to repeat and a lack of consistent results tends to invalidate previous results. Sherwood and Engibous (1953) reported the main benefits of PAM applications were associated with enhancement of soil physical characteristics and effects on crop yields may not occur even when soil structure is measurably improved.

Thorough mixing of the polymer with soil is essential for structure stabilisation however surface applications were observed to prevent surface crusting and erosion. Cultivation breaks down aggregates (Quastel, 1953). Many of the reported yield increases have occurred with early generation synthetic conditioners such as hydrolysed polyacrylonitril (HPAN) or vinyl acetate-maleic acid (VAMA) (see Quastel, 1953 and Martin, 1954) and there appears to be little substantial and scientifically relevant information regarding yield increases resulting form application of the new generation of synthetic polymers. Wallace and Wallace (1986a) applied rates equivalent to 8.6, 16.6, 37, 66, 132, 330 and 1980 kg ha^{-1}. The experiment conducted at Lincoln used a newly developed micronised PAM applied at recommended rates of 25 and 50 ppm, which was equivalent to applications of 50 and 100g ha^{-1} respectively.

5.3.2 Soil Adherence

PAM had no effect on soil adherence to tubers (Table 4.6). Processors state tubers must have less than 2% soil adherence (Hughes and Shepard, 1983) and control tubers had less than half this amount of soil adherence. Therefore, even if micronised PAM had an effect, it would have been of no financial benefit to a grower.

It would be unusual for the product to affect this parameter as surface applied PAM was not in contact with the tubers or the soil surrounding them. Micronised PAM applied by this method would increase, at sufficiently high and appropriate rates, infiltration rates at the soil surface but soil physical properties within the profile below the zone of application would remain unchanged. If the product were capable of reducing soil adherence to tubers it would need to be present in the area within the ridges where the tubers formed. In addition, tests for soil adherence were conducted on ten randomly selected tubers. It would have been more appropriate to use a different methodology, which could take into account the surface area of the tubers and the depth and number of eyes.

Polyacrylamide is degraded by UV light and cultivation (Wallace *et al.*, 1986; Barvenik, 1994; Letey, 1994) and micronised PAM must be applied in solution as it is applied at low rates and application in a dry form is not feasible as particle size is low and would result in uneven distribution and loss by air movement. Polyacrylamide does not move far from the site of application but surface application prior to emergence exposed PAM coated aggregates to UV light. As PAM is degraded by cultivation, potatoes, which require re-moulding to prevent greening of the developing tubers when exposed to light, may not have been an appropriate crop for the investigation.

In this experiment, PAM had no beneficial effects on plant growth, yield or soil characteristics. There are a number of possible reasons why this was the case.

1. The rate applied was insufficient.

2. Ultraviolet light and cultivation promote degradation of PAM and the product was applied prior to emergence and therefore there was no canopy cover.

3. Silt loam soils have the greatest plant AWC of all soil types. Tanner and Sinclair (1983) stated that water use efficiency could be increased by reducing evaporative losses and decreasing drainage losses from the soil profile use of micronised PAM on sand textured soils may differ from the results gained at Lincoln on a silt loam. However, PAM interacts with the clay fraction of the soil and thus higher rates may be required and effects will vary with different clay minerals (Letey, 1990).

4. High January rainfall was sufficient to maintain crop growth in dryland plots and therefore no differences were observed at the final harvest. Any benefits to be gained would occur under water limited conditions where external factors such as

those mentioned by Tanner and Sinclair (1983) could be manipulated, as PAM has no direct influence on plant growth.

CHAPTER SIX

GENERAL DISCUSSION AND CONCLUSIONS

Environmental conditions dominated results and nullified most irrigation effects. In addition, secondary effects caused early blight infection, which has been shown to reduce yields through decreases in the photosynthetic surface available for light interception and subsequent conversion to DM (Shah, 1998). Radiation use efficiencies were similar for irrigated and dryland plots, which indicated drought was not severe enough to cause significant reductions in net photosynthesis. However, differences in canopy development over time indicated cell expansion and division were more sensitive to drought than stomatal movements and this reduced radiation interception (Hsaio, 1973).

Differences in total biomass production, through increased radiation interception due to the production of a greater leaf area in irrigated plots, were not reflected in the final tuber yields of irrigated and dryland treatments. Sampling methodology and sample size differed between the final total biomass harvest (14/03/2002) and the final tuber harvest (18/04/2002). This indicated it may have been beneficial to harvest total biomass at the final harvest (18/04/2002) to identify if differences still existed. However, this would have made the final tuber harvest more difficult and time consuming.

Results indicate that when transient drought occurs at about critical LAI 'Ilam Hardy' potatoes can recover and produce similar final yields to irrigated treatments if seasonal rainfall is sufficient to overcome soil moisture deficits. In the literature many authors show final yields are reduced by drought (Martin, 1979; Jefferies and MacKerron, 1989; Searle, 1999). However, environmental conditions during this experiment resulted in higher than average rainfall in January, which allowed canopy development in both irrigated and dryland plots to reach the critical LAI at which point 95% of incoming light is intercepted.

The literature indicates PAM can increase infiltration rates and reduce erosion at higher rates than those used at Lincoln. However, the products are not directly comparable as micronised PAM is a newly developed product, which has not been investigated previously. Quastel (1953) and Martin (1954) both indicated early generation PAM would only stabilise the original soil structure and the benefits of PAM application would only be of an economic benefit if PAM provided the same effect of gypsum but at a lower cost. In addition, many claims of increases in plant growth and yield have occurred at extremely high rates (Quastel, 1953) with early generation products. The lack of consistent, and repeatable, results is difficult to interpret and many authors report application rates as a percentage of the soil volume, which can be misleading. Methodology in many of the experiments reported is also misleading (Wallace and Wallace 1986a, 1986c).

The water soluble PAM being investigated at Lincoln had application rates determined in parts per million. This is unsuitable as a determinant of an application rate as the amount of PAM applied is directly related to the amount of water applied. The greater the amount of water the greater the amount of PAM applied. The rate recommended for application was 25ppm which would result in 6 kg PAM ha^{-1} if 25.4mm of water were applied. However, this may have confounded the results of the irrigation treatment as dryland plots receiving PAM would have gained an additional 25.4 mm of water in the application process. The current experiment applied a rate equivalent to 1mm water ha^{-1} resulting in a PAM application rate of 50g ha^{-1} for 25ppm and 100g ha^{-1} for a rate of 50ppm.

Experiments conducted with non-micronised PAM have used rates ranging from 0.7 kg ha^{-1} (Shainberg and Levy, 1994) to 4400 kg ha^{-1} (Quastel, 1953). It generally appears that the new generation PAMs tend to be applied at rates ranging from about 5 to 2000 kg ha^{-1} (Mitchell, 1986; Terry and Nelson, 1986; Wallace and Wallace 1986a; 1986b; 1986c; Ben-Hur, 2001). Therefore, it may be beneficial to investigate application of micronised PAM at rates that are closer to those reported for non-micronised PAM.

Conclusions

The environment dominated results during the experiment in 2001-2002. However, the following conclusions can be made:

- Dryland 'Ilam Hardy' potatoes can recover from mild transient drought to produce similar tuber yields to irrigated plots (59.5 t ha^{-1}).

- Tuber size distribution was unaffected by any treatment imposed.

- Total DM production of 'Ilam Hardy' was linearly related to radiation intercepted and the majority of light is intercepted at the top of the crop canopy because of the planophile nature of the canopy.

- Maximum and mean crop growth rates, over time, reflected differences in LAI between irrigated and dryland plots.

- Gypsum increased aggregate stability by 24% but this had no effect on plant growth or yield.

- No treatment affected soil adherence to tubers.

- PAM did not increase plant growth and yield in these conditions.

Recommendations for Future Research

1. A primary objective of future experiments should be to quantify rates required on a per area or per soil volume basis.

2. The depth of PAM infiltration and aggregate stabilisation should be determined from surface applications in solution.

3. Soil adherence tests require an improved methodology to account for the surface area of the tubers and number and depth of eyes.

4. A comparison of traditional granular PAM and micronised PAM could help determine if the micronised version is more useful.

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Personal Communications

Jack, D. 2002. Technician, Field Service Centre, Lincoln University. 13/06/2002.

McKenzie, B.A. 2002a. Senior Lecturer, Plant Sciences Group, Lincoln University. 08/02/2002.

McKenzie, B.A. 2002b. Senior Lecturer, Plant Sciences Group, Lincoln University. 12/06/2002.

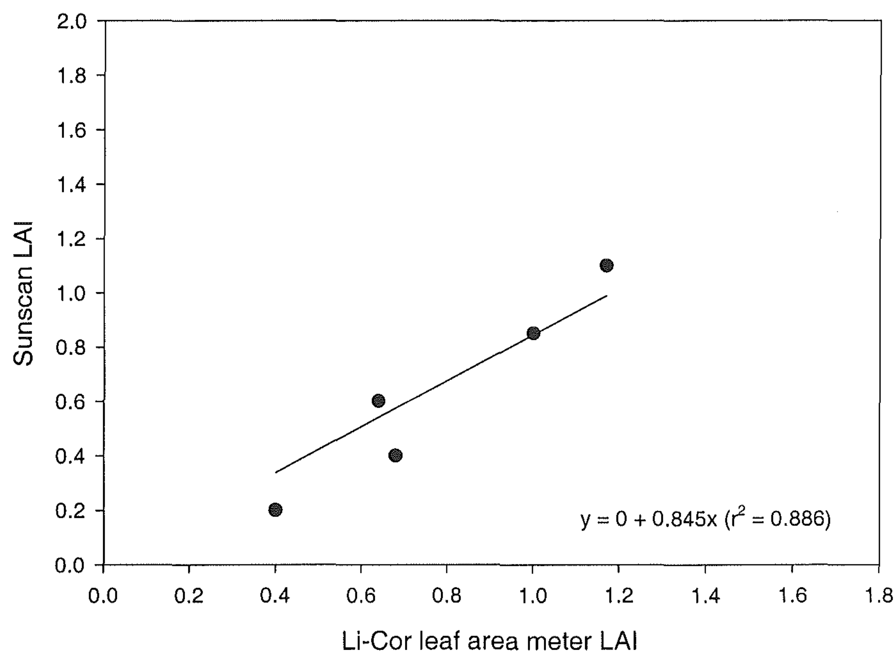
McLenegan, R. D. 2001. Senior Tutor Soil and Physical Sciences Group, Lincoln University, 12/10/2001.

Pay, J.M. 2002. Technical Officer, Plant Sciences Group, Lincoln University. 14/01/2002.

Stewart, A. 2002. Professor, Plant Sciences Group, Lincoln University. 08/02/02.

Appendix 1.

Calibration of the Sunscan Canopy Analysis System with a Li-Cor leaf area meter on the 13/12/2001.



APPENDIX 2.

Calculations required for the determination of weighted mean absolute growth rate (WMAGR), Duration of growth (DUR) and maximum crop growth rate (CGR_{max}) using MLP (Ross *et al.*, 1979).

<u>Generalised Logistic Functions</u>

$$WMAGR = \frac{(bC)}{2(T+2)}$$

$$DUR = \frac{2(T+2)}{b}$$

$$C_{max} = \frac{(bC)}{T+1^{\frac{(T+1)}{T}}}$$

<u>Gompertz Functions</u>

$$WMAGR = \frac{(bC)}{4}$$

$$DUR = \frac{4}{b}$$

$$C_{max} = \frac{(bC)}{e}$$

<u>Logistic Functions</u>

$$WMAGR = \frac{bC}{6}$$

$$DUR = \frac{C}{WMAGR}$$

The maximum crop growth rate was found by generating the slope at the point of inflexion in MLP. This corresponds to the M parameter.