PT015
Improved productivity of the french fry industry in Victoria

Rene de Jong
Agriculture Victoria

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PT015

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IMPROVED PRODUCTIVITY OF THE FRENCH FRY INDUSTRY IN VICTORIA

Final report of project PT015 to the Horticultural Research & Development Corporation February, 1994

Department of Agriculture

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FINAL REPORT TO H.R.D.C.

IMPROVED PRODUCTIVITY OF THE POTATO FRENCH FRY INDUSTRY IN VICTORIA

By René de Jong, Department of Agriculture, Ballarat, Victoria.
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1. Summary

Industry summary

Seed management: Potential yield of the subsequent crop was related to the number of stems and tubers produced per unit area but may be limited by moisture stress. The higher the number of stems and tubers per area, the higher the potential yield provided no significant stresses occur. However, a reduction in average tuber size occurred if stem and tuber population was maximised. Current processor contracts encourage growers to grow potato crops to maximise yield. This can be achieved establishing plant populations of about 120,000 plants per hectare.

Growers have been encouraged to use relatively small seed (175 g) and cutting as large as practical (80 g) with adjustments to spacing according to their crop management ability. Managers of Russet Burbank potato crops, able to minimise crop stress, are encouraged to use in-row seed spacings of 35 cm. These strategies in seed management maximise yield potential.

This research can be adopted by working with groups of growers who are encouraged to monitor their own crops. Growers can then compare their managerial performance over time and with others and relate to, and use these results.

The effect of latitude on Russet Burbank clones: The effects of latitude were of no commercial significance in relation to yield and quality. However, results from this work showed that Russet Burbank clones in Victoria (Ruen and Netted Gem) produce a higher percentage of marketable potatoes for processing compared to the clone used in Tasmania (Vancouver). This was related to the stem and tuber production characteristics of the clones. The Tasmanian French fry industry, through the seed certification system, can introduce the Victorian clones and produce a higher percentage of marketable potatoes for processing and thus benefit from this work.

Nutrition: Soil tests are a reliable way to budget the application of phosphorus (P) at planting on Russet Burbank potatoes. Based on soil available phosphorus levels (Olsen method) a predictive model was developed to generate recommendations on the rates of phosphorus fertiliser required at planting to obtain 95% maximum potential yield on krasnozem soils in the Central Highlands of Victoria. Critical nutrient levels for the concentration of phosphorus in potato petioles at various growth stages were determined to achieve 95 percent potential yield. Application of phosphorus fertiliser rates up to 150 kg/ha at planting improved Russet Burbank potato yields by 15 to 60 percent over a 5 to 46 ppm range of soil available phosphorus levels (Olsen method) and improved Kennebec potato yield by up to 40 percent over the same soil available P range. Higher soil phosphorus levels reduced the magnitude of yield response from applied phosphorus fertiliser. Up to 20 percent less fertiliser was required to maximise yield using Kennebec compared to Russet Burbank. Growers are urged to use soil tests to refine their fertiliser needs to prevent under utilisation of land, water and fertiliser resources or wasting fertiliser.

Similar results were found for potassium nutrition. However the yield improvements are expected to be only 10 to 15 percent over the range of soil available potassium levels (Skene method) of 145 to 636 ppm. There was no evidence to suggest that additional phosphorus fertiliser needed to be used other than at planting, provided there were no other nutrient deficiencies.

The use of soil tests and sound interpretations based on this results from this project can be used to precisely budget fertilisers for growing Russet Burbank potatoes in the Central Highlands. This research can be adopted by processing growers as well as growers using varieties other than Russet Burbank or Kennebec by promoting the use of soil and tissue testing and accurate interpretations based on this and similar nutrition work done in Tasmania and South Australia. Testing laboratories and others who interpret and recommend nutrition strategies must use this information to maximise adoption by the industry.

***Irrigation*:** Monitoring soil moisture of selected paddocks using the neutron probe demonstrated movement of water beyond the root zone if irrigation exceeded about 20 mm per application. This suggests that nutrients may be leached and water wasted. Growers have been encouraged to apply 20-25 mm of water per irrigation and water more frequently (depending on weather conditions) but as yet growers are poorly equipped to do so.

The need to irrigate more frequently than the current 6 - 7 day cycle is important to optimise water use. Growers will adjust water management if they see clear evidence of the financial benefits of changing management to irrigate more frequently and evenly.

***Variety evaluation*:** Ongoing French fry variety evaluation began as part of this project but has since become a project on its own. Yield and quality assessments of potential French fry varieties of potatoes enables the industry to select improved varieties as appropriate. To date, a new variety has not been released for the French fry industry since the introduction of Russet Burbank about 8 years ago. However, when a variety is released all the benefits of evaluation will be passed on to the processing industry which will then become more competitive.

***Technology transfer*:**

Research in this project has been generally reported to industry through the media, presented at meetings and discussed with groups specifically concerned with the topic being reported. The adoption rate of the principles of research findings in this project has been less than anticipated, having been good for nutrition and poor for seed management and irrigation. To overcome this a potato management package based on group activities has recently been developed as part of the project. This group work is expected to have a greater impact on growers and increase the level of adoption of the principles found in this research. The adoption rate is expected to be accelerated and more sustained over a longer time.

Technical summary

***Seed management*:** Potential yield was related to the number of stems and tubers produced per unit area but may be limited by moisture stress. The higher the numbers of stems and tubers per area, the higher the potential yield provided no significant stresses occur. However, a reduction in average tuber size occurred if stem and tuber population was maximised. About 120,000 stems per hectare was found to be optimum as averaged over the two years of the experiments. In 1990/91 when the season was warm and believed to have caused stress to potato crops, the highest yield was obtained at the widest spacing and corresponded to 113,490 stems per hectare. In 1991/92, in milder conditions, the highest yield was achieved at 35 cm spacing corresponding to 128,313 stems per hectare. Average tuber weight decreased as spacing narrowed. Where the

highest yields were obtained, average tuber weight was between 167.5 and 187.9 g. The incidence of stem end discolouration reduced as spacing decreased from 45 cm to 25 cm.
Large cut seed (80 g) produced the highest potential for yield. However, if 120,000 stem per hectare is considered optimum, at 35 cm spacing the cut seed weight of 45 g was calculated as optimum.

The effect of latitude on Russet Burbank clones: Results from this work showed that the currently used Russet Burbank clone(s) in Victoria (Ruen and Netted Gem) produced a more marketable sample of potatoes compared to the Tasmanian clone (Vancouver). This was related to the stem and tuber production characteristics of the clones.

Although yield was not affected, the emergence of potatoes from seed grown at the more northerly latitude was significantly poorer. Tuber and stem numbers increased from seed produced at the more northerly latitude. These results may have been related to the effect of either temperature or day length on the physiological age of the seed used.

Nutrition: Research on Russet Burbank potatoes showed a decreasing linear relationship between the rate of phosphorus fertiliser required at planting to obtain 95% maximum potential yield and available soil phosphorus levels on krasnozem soils in the Central Highlands of Victoria.
A rate of 145 kg/ha of phosphorus (banded at planting) was required on soils with 5 ppm P in the soil (Olsen method) decreasing to a requirement of 50 kg/ha of phosphorus (banded at planting) on soils with 40 ppm P in the soil (Olsen method).

Critical phosphorus levels required in Russet Burbank potato petioles at various growth stages to achieve 95 percent potential yield are as follows:

Length of longest tuber (mm)	% P levels
hook	0.43 - 0.52
10 - 15	0.45 - 0.57
35 - 45	0.35 - 0.47
75 - 85	0.21 - 0.26

Application of appropriate phosphorus fertiliser at planting improved Russet Burbank potato yields by 15 to 60 percent over the range of soil available phosphorus levels (Olsen method) 5 to 46 ppm, and improved yield by up to 40 percent for Kennebec potatoes over the same soil available P range.

Similar results were found for potassium nutrition. However the yield improvements are expected to be only 10 to 15 percent over the range of soil available potassium levels of 145 to 636 ppm.

Irrigation: Monitoring irrigation of selected paddocks using the neutron probe demonstrated movement of water beyond the root zone if irrigation exceeded about 20 mm per application. While more water can be applied and possibly stored in the soil, there is evidence of increasing leaching when more than 20 mm of water is applied to the soil. This was generally found to be the case and suggests that nutrients may be leached and water wasted.

Variety evaluation: Yield and quality assessments of varieties for French fry use is ongoing and has resulted in highlighting the potential of Ranger Russet which was released in Idaho, USA in 1991 and the breeding lines 88-102-24 and 88-102-2 developed at Toolangi.

2. Recommendations

Extension/adoption

The adoption of the recommendations from this research has met with some resistance with the question emerging about whether "conventional" extension techniques are effective.

Recognising the "resistance" to adoption, a program of group monitoring has been devised where growers are able to monitor their management, follow recommended procedures and take action based on self assessment over time and by comparison with the "group". A management package for growers is being developed and implemented with a small group of growers. A better understanding of their management (and hence highlighting weaknesses) will lead to a desire to alter management if it can be shown that there are gains to be made. This will require close liaison between the facilitator and members of the group.

There also is a need for "appropriate" extension. Recipe recommendations require mechanisms that provide answers for individual situations rather than broad answers for everyone. Farmers like to have face to face contact with an information provider as this offers the opportunity for questions to be raised and discussed and clarifications to be addressed. This can be addressed within group activities. There is also potential for a crop management consulting service in the Central Highlands (to which McCain Foods (Aust) P/L have already contributed by providing an overseas consultant to monitor, assess and recommend management of potato crops). Growers have become increasingly aware of the need to take soil tests, adjust seed sizes, take frequent tissue tests for nutrition monitoring and monitor crop water use using the neutron probe.

Agribusiness such as the soil and tissue testing laboratories, representatives (fertiliser and chemical field staff) and banks for example, require improved knowledge of technical and general farm management practices to assist with decision making which will aid productivity.

Directions for future research

Future research is required in the following areas:

1. Determine extension methods farmers require to access and use information and techniques
2. Determine plant and stem population dynamics under local conditions to improve understanding of the effects of population on yield and quality. This could also incorporate studies on the uniformity of populations on yield and tuber size.
3. Determine and quantify why seed grown at more northerly latitudes has poorer emergence than seed grown at more southerly latitudes.
4. To identify and improve understanding of why application of water greater than 20 mm results in a proportion of water moving beyond the root zone of the crop (ie soil structure, volume of water applied over time etc).
5. Determine recommendations for post planting applications of fertilisers and assess the effects of method of application and soil type.
6. Develop systems to monitoring field measurements such as soil temperature, seed temperature, crop water use, climatic data etc thereby minimising costs of monitoring essential information to increase productivity.
7. Generate information packages and decision support software utilising data from nutrition research to facilitate reliable interpretation standards.
8. Determine the effect of soil structure, chemistry and biology on the relationship between soil nutrient levels and fertiliser response.
9. Develop a data base linking farmers, soil and tissue testing laboratories and the end user and collate field information with market information to establish relationships (computers are grossly underutilised in agriculture and agribusiness).
10. Develop computer softwear which could be used to assist with the collation of information generated by monitoring/discussion groups.
11. Develop mathematical modelling in crop production and marketing systems for improved planning.

Financial/commercial benefits of adoption

Using McCains data on tuber size changes over 3 seasons from 12 growers between 1990 to 1992, and extrapolating the relationship between the change in the average tuber weight and yield from the seed management trial data, the increase in yield over the 3 year period has been 5.3 percent. This amounts to an extra 2500 tonnes or $450,000 to all contract growers.

Nutrition. Based on an informal questionnaire done during September 1992 of soil and tissue test usage, there had been a 68 percent increase in the number of growers using soil tests and a 300 percent increase in the number of growers using tissue tests over a 5 year period up to 1992. The change from the previous year was 11 percent increase (soil test) and 78 percent increase (tissue test). About 80 percent of those questioned currently use a soil or tissue test. Assuming an average increase of just 3 percent in yield for a third of Russet Burbank growers and a saving of $40/ha (10 kg of phosphorus at $4/kg), the increase in productivity would include an extra 500 tonnes of potatoes valued at $90,000 and a saving of $33,000 by using less phosphorus fertiliser. The benefits of the research and extension into phosphorus and promotion of soil and tissue testing alone will have generated at least $123,000 in increased productivity in the Central Highlands in one year.

Seed management. Changes in seed management have been considerable over a 3 year period from 1991 to 1993 due to our extension, field monitoring and recommendations by McCains field staff and the introduction of contract seed cutting into the area. The changes that have occurred during the 3 years include an increase in the percentage of cut seed weights in a desirable range of 35-63 g by about 5 percent, a 12 percent reduction in the percentage of seed weighing less than this and about a 10 percent increase in the weight of seed weighing more than the desired weight. These results suggest a general shift to larger cut seed size and put the increase in productivity at about $10,000 (as extra yield).

Irrigation. Evidence of benefits associated with irrigation improvements are more difficult to define due to lack of comprehensive data on changes in grower management and the differences in seasonal conditions.

Quality data from McCains shows large changes in fry colour and dry matter between seasons. However, 3 year running averages show no changes in dry matter and a 3 percent reduction in fry colour, which is probably not statistically significant.

The evidence of change is largely extrapolated from tuber size characteristics and changes in yield associated with these as known from research data. The effects of seasonal conditions have the most significant effect on yield and quality from year to year. For example, last year, the district experienced numerous thunderstorm activities with an unusually high rain fall. This reduced the need to irrigate by at least 50 percent and increased the disease pressure on crops. The weather conditions that occur during seed cutting and planting are also important factors that affect germination and early crop vigour, and ultimately yield.

In summary, yield improvements of about 5.3 percent and cost savings of $33,000 amount to an improvement in productivity of 5.7 percent over a 3 year period. Ongoing improved extension including potato crop management groups and ongoing consulting services should see this figure double in 2 to 3 years. This project has contributed to the improved productivity of the French fry industry alongside other influences to the value of about $500,000 with expected ongoing increasing benefits in the future of a further $500,000 in the next 2 to 3 years and reducing in the future.

Resource use will have improved but an estimate of this can only be based on the above productivity improvements.

3. Technical report

Attached are draft research papers summarising the work on seed management, the effect of latitude on Russet Burbank clone performance and phosphorus nutrition.

Effect of spacing and seed size on the yield and quality of Russet Burbank potatoes grown in southern Australia.

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Summary

Spacing of potato seed within the row and seed size have a significant effect on the performance of the subsequent crop. Spacing had a significant effect on yield but the results differed between years. Spacing at 25 cm compared to 45 cm resulted in highly significant increases in stem and tuber numbers per hectare, and highly significant reductions in average tuber weight and the number of tubers per plant. A significant reduction in stem end discolouration was also measured at 25 cm compared to 45 cm spacing. Before cutting, relatively small seed (175 g compared to 350 g) increased the number of tubers per hectare by 9% in both years, and affected the number of stems per hectare, average tuber weight, emergence, yield and dry matter in at least one year out of two. Seed cut to 80 g compared to 40 g significantly increased the number of tubers and stems per hectare, tubers and stems per plant, yield and decreased average tuber weight. Effects on dry matter were variable.

Effects on yield were greatest due to spacing (although variable), followed closely by cut seed size and then by seed size before being cut. Quality was largely unaffected by spacing or seed size. Seed management by spacing and seed size has been shown to be a significant tool to manipulate potato productivity.

Introduction

The seed size used for planting commercial crops of Russet Burbank in Australia is 100 - 350 g. Seed is normally cut to 30 - 80 g before being planted. Spacing of seed within rows is 25 - 45 cm depending on whether the crop is for seed production or processing into French fries. Growers often aim to use large seed and most do not aim for a target weight for cut seed.

Under local conditions in the Central Highlands, the effect of seed size and spacing on Russet Burbank potatoes for processing is not well understood. The effect of seed size on the quality of the subsequent crop has not been investigated adequately. Spacing work has been done before but not with attention to seed size. Seed size and spacing has a major influence on the yield and size distribution of a potato crop (Iritani *et al* 1972, Wurr 1974, Struik *et al* 1990, Cox and Rushton 1977, Mulligan 1970, Mundy and Bowles 1972). These workers found that large seed an closer spacing increased yield and the size of tubers produced was smaller. Most seed used in their experiments was not cut prior to planting.

The size of potatoes for processing is becoming increasingly important and growers require highest possible sustainable yields to improve their international competitiveness.

This paper is a summary of the effect of seed size, before and after being cut, and spacing on the yield and quality of Russet Burbank potatoes for French fry use in Victoria.

Materials and methods

Trials were conducted over a 2 year period in 1990/91 and 1991/92 to investigate the effect of in-row spacing and the size of Russet Burbank potato seed on the yield and quality of the subsequent crop.

Sites

The trials were conducted in the Central Highlands in western Victoria on clay loam soils with the following the paddock histories : (i) 1990/91 - grain crop the previous year preceded by 5 years of pasture; (ii) 1991/92 - pasture for the previous 6 years. Details of soil nutrient, pH and electrical conductivity levels are presented in Table 1.

Table 1. Summary of trial site details of nutrient availability, dates and site locations.

Soil measurements, dates	1990/91	1991/92
available phosphorus ppm (Olsen)	33	18
Available potassium ppm (Skene)	200	628
pH water/CaCl	5.3/4.4	5.6/4.8
electrical conductivity	0.06	0.10
planting date	27/11/1990	29/11/1991
emergence date	17/12/1990	20/12/1991
harvest date	23/4/1991	1/6/1992
map location	37^0.35'S/144^0.06'E	37^0.26'S/143^0.44'E

Row spacing was 80 cm and the plots were 2 rows X 5 m long at both sites.

Treatments

The treatments were: (i) seed size before cutting - 175 $\pm$50 g and 350 $\pm$100 g: (ii) seed size after cutting - 40 $\pm$10 g and 80 $\pm$10 g: (iii) in-row spacings - 25 cm, 35 cm and 45 cm. Fourth field generation certified potato seed (mother seed) was used. After storage at 4°C, the seed was allowed to warm to at least 12°C, graded to the required sizes before cutting and then cut by hand to the required sizes. Before planting, the seed was placed in well ventilated bags for at least 3 days to assist in rapid healing of the cut seed surfaces.

Measurements

Yield categories were calculated from the following weight ranges: (i) total yield from all potatoes harvested; (ii) processing yield from all potatoes weighing 75 g or more (iii) no. 1 grade from all potatoes weighing 75 - 450 g. Yield results are presented in tonnes per hectare (t/ha). The district's major French fry processor, McCain Foods (Aust) P/L accept potatoes in the processing category described above.

Average tuber weight was measured from tubers in the processing grade only. Emergence is presented as a percentage of the number of seed pieces planted and was measured from the number of groups of stems per plot after the tops died down. Fry colour was assessed by cutting slices of potatoes approximately 1.5 mm thick that were fried in safflower oil at 185 - 190°C until bubbling ceased, after about 2½ minutes. Frying was done within 2 weeks of harvest on 20 slices cut longitudinally from 10 potatoes in the 150 - 250 g weight range. Fry colour was measured by a visual colour rating within the range 1 to 10 where 1 is extremely light, 10 is dark brown bordering on black and 7 is marginal.

Specific gravity (S.G.) was measured on potato samples in the 150 - 250 g weight range and converted to percent dry matter using the formula:

$$\text{percentage dry matter} = \frac{\text{specific gravity} - 0.983214}{0.004813}$$

where

$$\text{specific gravity} = \frac{\text{weight of potatoes in air}}{\text{weight of potatoes in air} - \text{weight of potatoes in water}}$$

Stem end discolouration was measured as the percentage of potatoes showing distinct discolouration at the stem end of the fried longitudinal potato slices.

Statistical design

A randomised block design was used with 6 replicates in 1990/91 and 5 replicates in 1991/92. The results were analysed using Genstat V.5. with treatmentstructure statement "spacing*seedsize*cutseed" (Payne 1987).

Climatic conditions

Both sites received 25-35 mm of irrigation at 5-8 day intervals depending on weather conditions. Seasonal conditions for each year varied as shown in Table 2.

Table 2. Climatic conditions during the growing periods in the trials.
(Bureau of Meteorology, 1991-1992)

Year	Climate variable	Nov	Dec	Jan	Feb	Mar	Apr	May
1990/91	Maximum (C)	20.0	24.3	25.5	25.8	23.0	17.5	14.7
	Minimum (C)	7.5	9.6	11.1	8.6	7.6	5.1	4.6
	Rainfall (mm)	60	21	75	3	12	37	12
1991/92	Maximum (C)	18.9	21.4	20.5	23.6	23.8	18.0	13.6
	Minimum (C)	5.4	9.1	8.5	10.4	11.0	7.6	4.4
	Rainfall (mm)	49	139	74	16	31	49	89

Fertiliser

Fertiliser was used at rates in accordance with district recommendations based on soil tests. Phosphorus was applied as triple superphosphate, potassium as potassium chloride and nitrogen as ammonium nitrate at the following rates: (i) 1990/91: P=60 kg/ha, K=180 kg/ha, N=100 kg/ha; (ii) 1991/92: P=150 kg/ha, K=50 kg/ha, N=100 kg/ha.

Results

Effect of spacing

Yield, average tuber weight and emergence. The effect of spacing on yield differed between years. Figure 1 shows that increasing the spacing of seed within a row from 25 cm to 45 cm significantly increased both processing yield ($P<0.001$) and no. 1 grade yield ($P<0.01$) by 12% and 8% respectively in 1990/91. However, in 1991/92 the effect was reversed. Processing yield decreased by 10% ($P<0.01$) and no.1 grade yield decreased by 13% ($P<0.001$) as spacing increased.

Increased spacing did not significantly affect total yield in 1990/91 but significantly ($P<0.001$) decreased the total yield by 12% in 1991/92.

As spacing increased from 25 cm to 45 cm, the average weight of processing grade tubers increased ($P<0.001$) by 21% in both years (Figure 2). Spacing did not significantly affect emergence.

Stem and tuber numbers. There was a significant decrease in stem and tuber numbers per hectare and significant increase in the number of tubers per plant as spacing increased from 25 cm to 45 cm in both years. The number of stems per hectare decreased ($P<0.001$) by 38% in 1990/91 and 44% in 1991/92 as seed spacing increased from 42 cm to 45 cm. The number of tubers per hectare significantly decreased ($P<0.001$) by 21% in 1990/91 and 44% in 1991/92 as spacing increased from 25 cm to 45 cm (Figure 3). In both years, the number of stems per plant were not influenced by changes in seed spacing. The number of tubers per plant increased significantly ($P<0.001$) as spacing increased from 25 cm to 45 cm in both years (Figure 2).

Fry colour, dry matter and stem end discolouration. Spacing had no effect on the fry colour or percentage dry matter of the potatoes. Stem end discolouration was affected by spacing in 1991/92 only. Wider spacing, from 25 cm to 45 cm significantly ($P<0.01$) increased the incidence of stem end discolouration by 23%.

Figure 1. Relationship between seed spacing and yield.

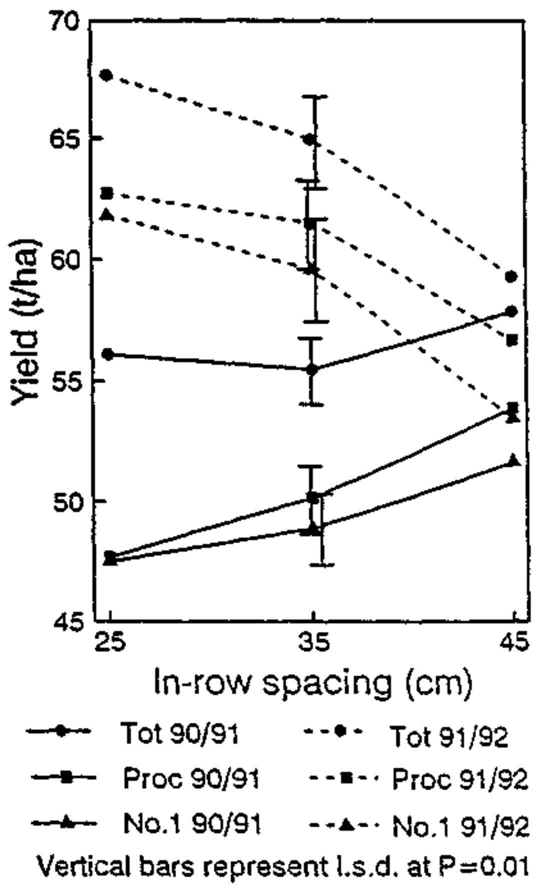


Figure 2. Relationship between seed spacing and average tuber weight, and the number of tubers per plant.

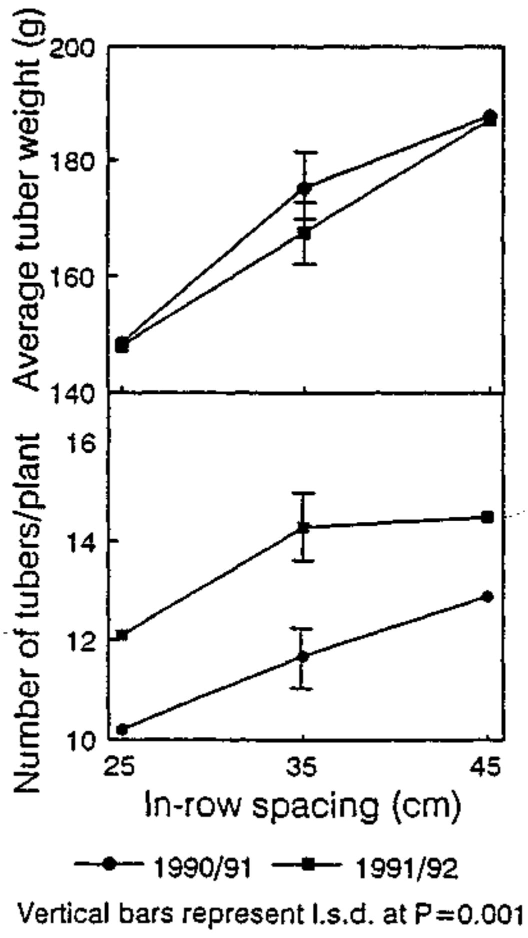
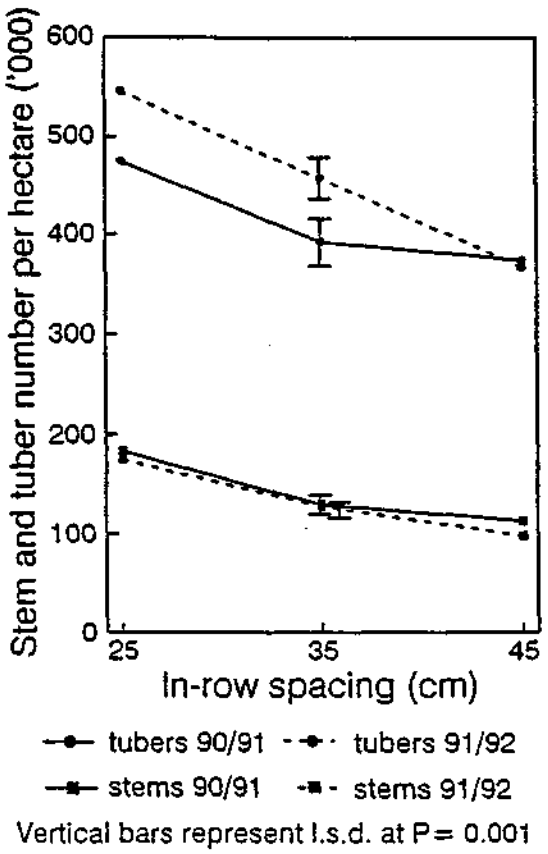


Figure 3. The relationship between seed spacing and stem and tuber number per hectare.



Effect of seed size before cutting

Yield, average tuber weight and emergence. Table 3 shows as the size of seed before cutting decreased, yield increased in 1990/91 only, and average tuber weight decreased in both years, and emergence increased in 1990/91 but not in 1991/92. In 1990/91, using seed weighing 175 g compared to 350 g (before cutting) significantly ($P<0.05$) increased total, processing and no. 1 grade yields, all by 5%. There were no significant differences of the effect of seed size before being cut, on yield in 1991/92.
Average tuber weight was not significantly affected by seed size before cutting in 1990/91. However, in 1991/92, average tuber weight increased by 8% ($P<0.01$) when 350 g seed was used compared to 175 g seed before the seed was cut. In 1990/91, there was no effect of seed size before cutting on emergence. However, emergence was significantly ($P<0.05$) increased by 4% when 175 g seed (before cutting) was used compared to 350 g seed (before cutting) in 1991/92.

Stem and tuber numbers. Small sized seed before cutting significantly increased the number of tubers per hectare in both years, increased the number of stems per hectare in 1991/92 only, and increased the number of tubers per plant in 1990/91 only (Table 3). The number of stems per hectare increased significantly ($P<0.01$) by 8% using 175 g seed (before cutting) compared to using 350 g seed (before cutting) in 1991/92 only. No difference was observed in stem number per hectare due to seed size in 1990/91. The number of tubers per hectare was 9% higher ($P<0.001$) when 175 g seed (before cutting) was used instead of 350 g seed (before cutting) in both years. The number of stems per plant was not significantly influenced by seed size before being cut in either year. The number of tubers per plant increased ($P<0.01$) by 8% using 175 g seed (before cutting) compared to 350 g seed (before cutting) in 1990/91 only. There were no significant differences in the number of tubers per plant in 1991/92, or the number of stems per plant in both years due to seed size before cutting.

Table 3. Effects of seed size before cutting and seed size after cutting on Russet Burbank potato yield and quality.

	Seed size before cut			Seed size after cut		
	175gm	350gm	s.e.d.	40gm	80gm	s.e.d.
			1990/91			
Total yld (t/ha)	58.0	54.9	0.97	53.9	59.0	0.97
Process yld (t/ha)	51.8	49.4	1.00	49.4	51.9	1.00
No. 1 gr yld (t/ha)	50.6	48.1	1.04	47.7	51.0	1.04
Av. tuber wgt (g)	168	174	3.2	180	161	3.2
Percent emerg.	96	94	1.3	94	96	1.3
Stems/ha ('000)	142	143	3.8	126	158	3.8
Tubers/ha ('000)	433	394	11.0	363	464	11.0
Stems/plant	3.9	4.0	0.09	3.5	4.3	0.09
Tubers/plant	12.0	11.1	0.29	10.3	12.9	0.29
Percent D.M.	20.5	20.3	0.08	20.3	20.5	0.08
Fry colour	7.7	7.5	0.17	7.5	7.7	0.17
Stem end discolour	67	68	3.9	66	69	3.9
			1991/92			
Total yld (t/ha)	64.6	63.4	1.33	60.0	68.0	1.33
Process yld (t/ha)	60.7	59.9	1.32	57.5	63.1	1.32
No. 1 gr yld (t/ha)	59.6	57.0	1.39	54.5	62.0	1.39
Av. tuber wgt (g)	161	174	2.9	185	150	2.9
Percent emerg.	94	90	1.6	91	93	1.6
Stems/ha ('000)	140	128	3.5	101	167	3.5
Tubers/ha ('000)	480	442	10.9	375	547	10.7
Stems/plant	3.9	3.8	0.08	3.0	4.8	0.08
Tubers/plant	13.9	13.3	0.31	11.8	16.0	0.31
Percent D.M.	19.9	19.8	0.09	20.0	19.7	0.09
Fry colour	6.6	6.6	0.12	6.6	6.6	0.12
Stem end discolour	46	50	4.3	51	46	4.3

Fry colour, dry matter and stem end discolouration. There were no significant differences in either year, on fry colour or stem end discolouration due to seed size before cutting. In 1990/91 only, dry matter increased using 175 g seed (before cutting) instead of 350 g seed (before cutting). No significant difference occurred in dry matter in 1991/92 due to seed size before cutting.

Dry matter increased significantly ($P<0.05$) by 1% in 1990/91 when 175 g seed (before cutting) was used compared to 350 g seed (before cutting) (Table 3). The influence of seed size before cutting on the percentage of dry matter was not significant in 1991/92.

Effect of cut seed size

Yield, average tuber weight and emergence. Seed cut to 80 g compared to seed cut to 40 g significantly increased total, processing and no. 1 grade yields, and reduced average tuber weight in both years. Emergence was not affected by cut seed size. Table 3 shows in 1990/91, total, processing and no. 1 grade yields were significantly increased ($P<0.05$) by 9%, 5% and 6% respectively by using 80 g cut seed instead of 40 g cut seed. In 1991/92, total, processing and no.1 grade yields increased significantly ($P<0.01$) by 12%, 9% and 12% respectively where 80 g cut seed was used compared to 40 g cut seed. Average tuber weights were reduced ($P<0.01$) by 11% in 1990/91 and 19% in 1991/92 when 80 g cut seed was used instead of 40 g cut seed.

Stem and tuber numbers. Large cut seed (80 g) seed produced highly significant more stems and tubers (per hectare and per plant) in both years compared to smaller (40 g) cut seed. Table 3 shows cut seed weighing 80 g produced significantly ($P<0.01$) more (20% in 1990/91 and 39% in 1991/92) stems per hectare than cut seed weighing 40 g. The number of tubers per hectare significantly increased ($P<0.001$) by 22% in both years when 80 g cut seed was used instead of 40 g cut seed.

There was a 19% and 38% increase ($P<0.001$) in the number of stems per plant in 1990/91 and 1991/92 respectively when 80 g cut seed was used instead of 40 g cut seed. The number of tubers per plant were significantly ($P<0.001$) increased when 80 g cut seed was used instead of 40 g cut seed. The increases were 20% in 1990/91 and 30% in 1991/92.

Fry colour, dry matter and stem end discolouration. Fry colour and stem end discolouration were not affected by cut seed size in both years. The effect on dry matter of cut seed size was variable between the years. In 1990/91, dry matter increased significantly ($P<0.05$) by 1% when 80 g cut seed was used instead of 40 g cut seed (Table 3). However, dry matter decreased ($P<0.01$) by 2% in 1991/92 when 80 g cut seed was used compared to 40 g cut seed.

Interactions

In 1990/91, interactions were found between seed size before cutting and seed size after cutting on the number of stems per plant and the number of stems per hectare. Large seed before cutting (350 g) cut small (40 g) (3.4 stems per plant, 121,458 stems per hectare) and small seed before cutting (175 g) cut small (40 g) (3.6 stems per plant, 130,903 stems per hectare) produced significantly ($P<0.001$) fewer stems per plant/hectare than 175 g seed (before cutting) cut to 80 g (4.1 stems per plant, 152,569 stems per hectare). The greatest number of stems per plant/hectare was produced by 350 g seed (before cutting) cut to 80 g (4.52 stems per plant, 164,375 stems per hectare) this was significantly different ($P<0.05$) to 175 g seed, cut to 80 g.

In 1991/92, similar interactions were found between seed size before cutting and seed size after cutting on the number of stems per plant. Seed before cutting of 350 g, cut to 40 g (3.0 stems per plant) and 175 g seed before cutting, cut to 40 g (3.0 stems per plant) produced significantly ($P<0.001$) fewer stems per plant than pre cut seed weighing 350 g cut to 80 g (4.6 stems per plant). Seed weighing 350 g before cutting and cut to 80 g in turn produced significantly ($P<0.01$) fewer stems per plant than 175 g seed (before cutting) cut to 80 g.

In 1991/92, combinations of wide in-row plant spacings (45 cm) and small cut seed (40 g) produced significantly ($P<0.01$) fewer stems per hectare (75,250) and significantly higher ($P<0.001$) average tuber weight (210 g) than the next widest spacing (35 cm) and using 40 g cut seed. At the other extreme, in-row seed spacing of 25 cm and using large cut seed (80 g) produced the highest ($P<0.001$) number of stems per hectare (216,375) and the lowest ($P<0.05$) average tuber weight (137 g) compared to using the next widest spacing (35 cm) but still using the same cut seed size (80 g). The treatments using the closest spacing (25 cm) and the smallest cut seed size (40 g) was not significantly different to the widest spacing (45 cm) and the largest cut seed size (80 g) for the number of stems per hectare or average tuber weight.

Emergence was significantly ($P<0.05$) lower where 350 g seed (before cutting) is cut small (40 g) compared to any other combination of before seed size and cut seed size.

Discussion

The most significant and consistent trends in the results due to any of the treatments over the 2 years was due to the number of stems and tubers per hectare and average tuber weight, followed by the number of tubers per plant and then the number of stems per plant. The remaining parameters measured showed inconsistent or single year differences only. The effects of the treatments were mainly on stem and tuber populations per area and average tuber weight.

Spacing effects

Many workers relate yield differences due to seed size and spacing with population densities of stems and tubers. European workers Mundy and Bowles 1972, Wurr 1974, Bleasdale 1965, Proctor and Smartt 1976, Struik *et al* 1990, and Mulligan 1969, who studied populations based on spacing and seed size effects, related yield differences with stem and tuber population per unit area. They used seed that was (1) planted uncut rather than cut and (2) in the weight range 10 - 191 g. They concluded that higher rather than lower stem number per area produced higher yields, smaller tubers and, where recorded, more tubers. Similarly, Iritani *et al* (1972) found that closer spacing, and large seed produced the highest yields. These findings are consistent with the results reported in this paper for stem and tuber populations and average tuber weight in both years of the study and yield in 1991/92 as influenced by changes in spacing. The yield response to spacing differed between years. It appears that higher potential yield is possible by close spacings in mild years as in 1991/92. However, during warm years (1990/91) when moisture stress is likely, wider spacings are believed to be an advantage as the competition for moisture is not as great (Entz and LaCroix 1984). In 1990/91 when weather conditions were warm and moisture stress is likely to have occurred, in-row spacing of at least 45 cm, produced the highest yield. However, in 1991/92 when milder weather conditions prevailed, 35 cm in-row spacing produced the highest yields. Spacings below this did not produce statistically higher yields. However, spacing greater than 35 cm produced significantly lower yield. The corresponding stem populations when the highest yields were achieved were 113,490 stems per hectare in 1990/91 (45 cm) and 128,131 stems per hectare 1991/92 (35 cm). Judging from this, a population of about 120,000 stems per hectare would be a desirable target to achieve.

Average tuber weight decreased as spacing narrowed. Chucka (1945) and Painter *et al* (1977) found that tuber weight decreased with closer plant spacing which is probably a reflection of the increased competition between plants for water and fertiliser resources. Between years, average tuber weights were similar despite differences in the seasonal conditions between the years. Based on the spacings that produced the highest yields, growers could expect average tuber weights between 167.5 and 187.9 g.

In 1990/91, the number of tubers per plant increased as spacing widened up to 45 cm. However, in 1991/92, the number of tubers per plant increased up to 35 cm after which there was no increase in the number of tubers per plant at wider spacing (45 cm). Svennson (1962) found the number of tubers per plant is affected by spacing and, as reported here, increased with wider spacing.

Stem end discolouration was found to increase as seed spacing widened from 25 cm to 45 cm during 1991/92. Stem end discolouration is considered to be related to the formation of sugars that are developed when early season stress affects the developing potatoes (Iritani 1981). Although stem end browning appeared to be worse in 1990/91, the effect of spacing was only found in 1991/92. Miller and Martin (1985) and Shock *et al* (1992) found that stem end discolouration was more commonly observed in tubers grown from well watered plants than in tubers from plants which were stressed due to lack of water. This suggests that widely spaced plants had access to more water resources and is probably why the effect of spacing on stem end discolouration was observed. The precise cause of the problem is not well understood.

Seed size before cutting

The effect of seed size before cutting was most significant on the number of tubers per hectare which was consistently higher when the smaller sized seed (175 g) was used compared to large seed (350 g) before cutting. In 1990/91, the effects of seed size before cutting were increases in the number of tubers per hectare, yield, the number of tubers per plant and dry matter when 175 g seed was used. In 1991/92, the effects of using 175 g seed before cutting were increased emergence and numbers of stems and tubers per hectare, whereas average tuber weight decreased. It is likely that all the effects relate to the cutting of the seed before planting. The number of eyes per unit mass on a seed tuber before cutting will be greater on small tubers than large tubers. When cut to the same size, a small tuber, before cutting, will have more eyes than a large tuber, before cutting, if the cut pieces weigh the same.

Seed size after cutting

The size of cut seed had a major influence on the yield and quality of Russet Burbank potatoes. In both years, large cut seed (80 g) consistently produced higher numbers of stems and tubers per hectare, stems and tubers per plant, and yield but reduced the average weight of tubers. The effects on dry matter were variable between years. In 1990/91, large cut seed (40 g) compared to small cut seed (40 g) produced higher dry matter. However, in 1991/92 dry matter decreased with the use of large cut seed. Iritani *et al* (1972) and Entz and LaCroix (1984), using cut seed weighing between 14 - 67.9 g, found that large seed increased stem and tuber populations, yield and reduced average tuber size. Proctor and Smartt 1976, Wurr 1974, Mundy and Bowles 1972 and Cox and Rushton 1977 reported that large seed produced higher yields explaining that large seed potatoes have significantly more food reserves allowing emerging plants to begin growth at a rapid rate. This is confirmed by Iritani *et al* (1972) who showed that increasing seed piece weight per stem increased yield.

Interactions

In both years, the number of stems per plant (and stems per hectare in 1990/91 only) were affected by an interaction between seed size before cutting and seed size after cutting. Using the numbers that quantify the treatments, the order in which the interactions increased the number of stems per hectare and per plant is shown where bracketed treatments are not significantly different: 1990/91 - (350/40, 175/40) < 175/80 < 350/80, and in 1991/92 - (350/40, 175/40) < 350/80 < 175/80. This indicates that the size of seed before cutting becomes more influential as the size of the cut seed becomes larger. It may be possible that small seed (before cutting), cut large, may respond better to mild conditions by producing more stems. On the other hand, large seed before cutting and then cut large may produce more stems under stressful climatic conditions.

In 1991/92, interaction between spacing and the size of cut seed influenced the number of stems per hectare and average tuber weight. Using the numbers that quantify the treatments, the order in which the interactions increased the number of stems per hectare and decrease average tuber weight is shown where bracketed treatments are not significantly different: 45/40 < 35/40 < (45/80, 25/40) < 35/80 < 25/80 (stems per hectare) and for average tuber weight 45/40 < 35/40 < (25/40, 45/80) < 35/80 < 25/80. This shows that the combination of wide spacing and small cut seed minimised the number of stems produced per hectare produced and maximised average tuber weight whereas close spacing and large cut seed maximised the number of stems produced per hectare and minimised average tuber weight. The combination of close spacing (25 cm) and small cut seed (40 g), and wide spacing (45 cm) and large cut seed (80 g) produced similar numbers of stems per hectare and average tuber weights which were not significantly different. This indicates that spacing may be adjusted if seed sizes are different so as to maintain uniform results in crops.

In 1991/92, emergence was influenced by an interaction between seed size before cutting and after cutting seed size. Large seed before cutting (350 g) cut to 40 g significantly reduced emergence compared to other combinations of seed size before cutting and seed size after cutting. This is probably due to the combination of large seed size before cutting (350 g), cut small (40 g) that favours the selection low eye numbers which occasionally results in no eyes on a piece of seed and hence no emergence from that seed piece. This was confirmed by visual inspection to identify the reason for any misses.

Conclusion

Seed size before and after cutting and spacing play a significant role in the plant population of a crop. As these can be managed by potato growers, there are opportunities to improve the yield and quality of potato crops. Although no one can predict seasonal conditions ahead of time, there is scope for growers to adjust their plant spacing according to their ability to minimise moisture stress. While these results do not prove that weather conditions influenced the results on yield, Iritani *et al* 1972 found that different seasonal conditions affect the crop and Entz and LaCroix (1984) postulate about the effects.

A desirable target to achieve for the number of stems per hectare is about 120,000, with a lower target if stress is expected (down to about 100,000) and higher targets if stress can be countered with a high level of crop management (up to about 130,000). To achieve 120,000 stems per hectare by managing seed size at an average in-row plant spacing of 35 cm, the cut seed size should be about 45 g in weight (assuming a linear relationship between cut seed size and the number of stems per hectare).

Growers and researchers can benefit by attention to spacing and seed size and to do so, records of these, the numbers of stems produced per plant, and hectare, and of climatic conditions should be kept for future referral.

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Effect of latitude of seed production on the performance of clones of Russet Burbank potatoes in southern Australia

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Summary. In the Northern Hemisphere it has been shown that potato tubers with greatest vigour are produced at higher latitudes. The effect of latitude on potato seed for commercial use has not been studied in Australia. There are at least four different clones of Russet Burbank grown for processing in southern Australia and their performance for French fry use at different latitudes has not been evaluated. In this study, four clones of Russet Burbank were grown at 5 different locations representing different latitudes. Seed from these treatments were then grown at two French fry production locations, in Victoria and Tasmania, for evaluation of the effects of latitude on seed for French fry production. Latitude had a significant effect on the performance of seed in the production trials. Higher latitudes (increasingly southerly locations), increased plant emergence, increased plant vigour, delayed maturity, and reduced stem and tuber numbers. Differences between the Tasmanian, Ruen and Netted Gem clones were small and restricted to the numbers of stems and tubers produced, and yield. The Ballarat clone was late maturing and had a high total but low marketable yield due to high levels of oversized and misshapen tubers. However this clone also showed least stem-end browning. Certain interactions were detected between clone and latitude effects but these have no practical significance.

Introduction

Potatoes in southern Australia are clonally multiplied from a few pathogen tested plants for six generations before commercial release. This system of multiplication along with selection has resulted in the development of many individual clones for most potato cultivars.

Russet Burbank is the predominant cultivar grown in southern Australia for processing as French fries. The clone used in Tasmania came from Vancouver in British Columbia, Canada. A mixture of approximately equal quantities of the Ruen and Netted Gem clones of Russet Burbank are grown in Victoria. A recent field selected clone called Ballarat Russet has been used on a relatively small scale in Victoria from non-certified seed.

The performance of seed potatoes is known to vary between different seed production locations when using pathogen tested certified seed potatoes. These differences in performance appear to be due to factors other than disease levels.

Seed potatoes grown in the Arran Pilot district of Scotland, at three locations with a maximum latitude difference of 5°11', were found to have no differences in performance (Goodwin *et al* 1966). In the USA and in Britain it is a widely held view that the most vigorous seed is grown at relatively high latitudes. Apart from natural control of virus disease through suppression in aphid numbers (due to unfavourable climate for aphids), it is unclear why seed produced at higher latitude is better. Plants grown from seed produced in Saskatchewan had superior yields compared to seed produced in the USA and were more vigorous, maintained a higher leaf area index and matured later (Wahab *et al* 1990). These workers are now investigating the physiological and biochemical basis for differences in growth and productivity.

According to classical definition physiological aging does not commence until after dormancy break (Wurr 1980 and O'Brien and Allen 1981). However, observations by Jeoung *et al* (1983) suggest that influences prior to tuber dormancy may affect the characteristics of the subsequent crop. If seed production environment affects physiological age it may be expressed through the number of stems and tubers produced by the subsequent crop and ultimately as yield

(Grice 1988).

Evaluation of Russet Burbank clones done in Tasmania (Beattie 1990) and Victoria (Kirkham pers. coms) resulted in the selection of the "Vancouver" clone for commercial use in Tasmania (called the Tasmanian clone) and the selection of the "Ruen" and "Netted Gem" clones for commercial use in Victoria. However, no work has been done on the effect of latitude.

Materials and methods

Location of seed production treatments

Early generation seed tubers of Tasmanian, Ruen and Netted Gem clones of Russet Burbank were grown at Wilmot, Trowutta and Forthside in the state of Tasmania and at Colac and Ballarat in the state of Victoria to produce the equivalent of certified seed ready for production evaluation. A field selection grown in small quantities in Ballarat and named Ballarat Russet was also included in this trial. Although it was two generations older than the other clones, visual inspections showed that it was satisfactory as certified seed. Seed from this clone was grown at Forthside, Colac and Ballarat only for production trial evaluation.

Seed has certified status if it has been grown in the field for 4 years and, after annual crop and tuber inspections, has no more than 2.5 percent of most common fungal, viral or bacterial diseases.

After the seed was grown to maturity at each location it was harvested and immediately cool stored at 4°C until the end of October, to minimise physiological aging due to temperature. The seed was then transported to each production trial location and the clones grown under the same conditions at each location. Average daily maximum and minimum temperatures and total rainfall for each month during the growing season is given in Figure 1.

Production trials

Production evaluation trials were conducted in Tasmania and Victoria representing two district environments for testing the seed stocks. At both sites 50 g set pieces were planted in double row plots approximately 5 m long (32 sets in Tasmania, 28 in Victoria). The trials were harvested after the latest maturing plants had senesced.

At both sites and in each plot, stems were removed and counted at harvest and the average number of stems per plant was calculated and recorded. The number of tubers was recorded at harvest and the average number of tubers per plant was calculated. Emergence was recorded at both sites. Tubers were weight and quality graded and counted in each category. In Tasmania the weight grades were: less than 80 g, 80-250 g, 250-450 g and over 450 g. Processing grade included all potatoes weighing greater than 80 g and No.1 grade grade included potatoes weighing 80-450 g. In Victoria these grades were the same except 75 g was used instead of 80 g.

In Victoria only, slices of potatoes approximately 1.5 mm thick were fried in safflower oil at 185 - 190°C until bubbling ceased, after about 2½ minutes. Potato slices were fried within 2 weeks of harvest on 20 slices cut longitudinally from 10 potatoes in the 150 - 250 g weight range. Fry colour was measured by a visual colour rating within the range 1 to 10 where 1 is extremely light, 10 is dark brown bordering on black and 7 is marginal. Stem end discolouration was assessed by counting the number of fried slices with significant dark colour at the stem end expressed as a percentage of the total number of slices fried.

In Tasmania only, plant vigour was recorded on 18 December 1990 and again on 25 January 1991 using a subjective scale where 1 is low vigour and 5 is high vigour. Vigour was rated according to visual appearance. Maturity was recorded during March 1991 using a subjective scale where 1 is all leaves dead and 5 is all leaves green. Misshapen tubers were weighed and recorded. The remaining production trial details are in Table 2.

Table 1. Seed production location site details and dates.

Site	Latitude	Altitude metres asl	Seed production dates: Planting date	Seed production dates: Harvest date
Wilmot	41°20'S	300	13/11/89	16/4/90
Forthside	41°12'S	120	21/11/89	7/5/90
Trowutta	41°05'S	180	28/11/89	27/4/90
Colac	38°32'S	100	6/12/89	16/5/90
Ballarat	37°30'S	450	11/11/89	11/5/90

Figure 1. Maximum and minimum daily temperatures, and total rainfall per month at each seed production location between November 1989 and May 1990.

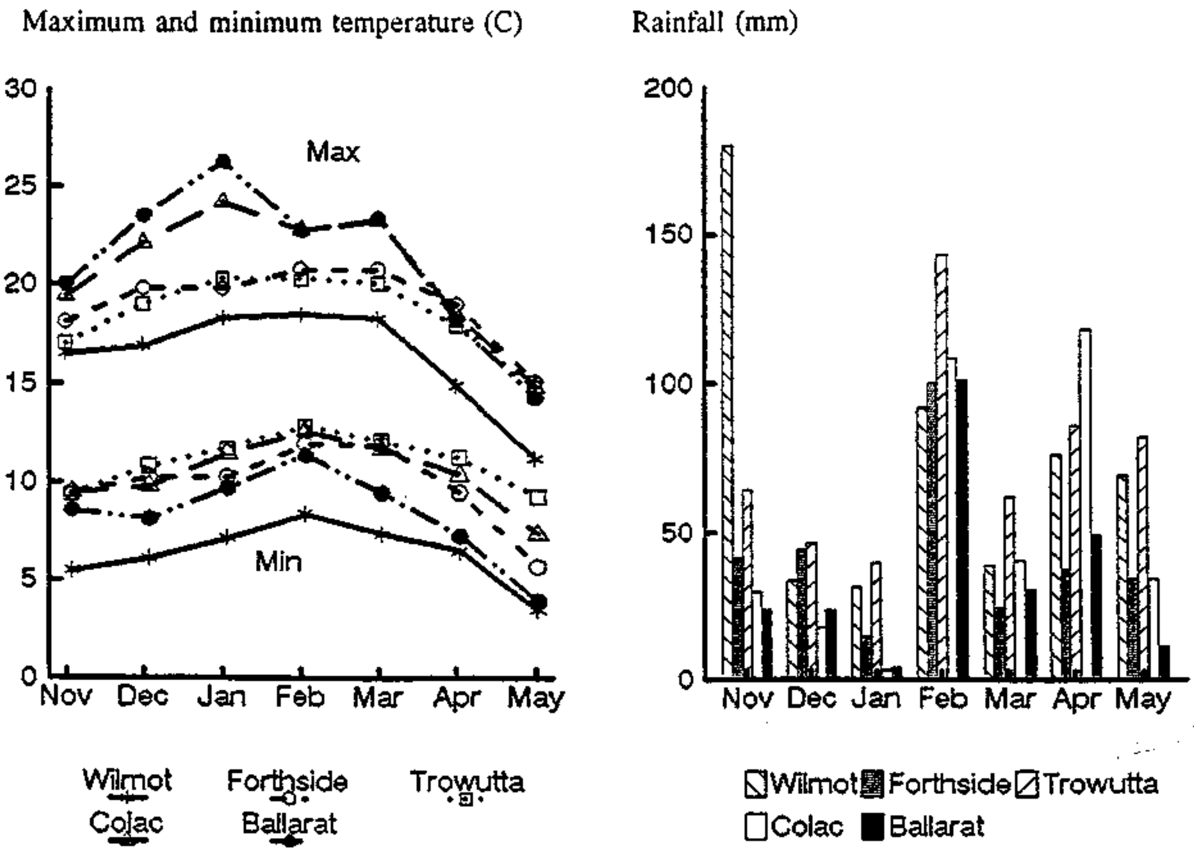

Table 2. Production trial details.

Description	Victoria	Tasmania
Fertiliser N:P:K (kg/ha)	75:235:131	121:132:209
Between row spacing (mm)	850	810
Within row spacing (mm)	350	300
Planting date	7 November 1990	30 October 1990
Harvest date	21 May 1991	15 April, 1991
Number of sets per plot	28	32
Number of replicates	6	6
Measurements:		
emergence	yes	yes
yield	yes	yes
stem number per plant	yes	yes
tuber number per plant	yes	yes
fry colour	yes	no
stem end discolouration	yes	no
vigor	no	yes
maturity	no	yes
misshapen	no	yes

Results of the Tasmanian and Victorian production trials were analysed separately. Analyses were done using the missing plot estimation method in Genstat 5. to overcome the non-orthogonal data set of the different number of clones used at some sites (Payne *et al* 1987).

Results

Latitude effects

The location of seed production had a significant effect on emergence, vigor, maturity, stem number and tuber number. In the Victorian trial there were also differences in percentage marketable yield. Results of means and significance are summarised in Table 3.

In both production trials in Victoria and Tasmania, emergence of Ballarat grown seed was significantly lower with losses due to seed piece breakdown.

In the Tasmanian production trial, seed produced at lower latitudes (Ballarat, Colac) displayed significantly less vigor on 18 December 1990, significantly greater vigor on 25 January 1991 and was significantly later maturing than seed produced at higher latitudes in Tasmania (Wilmot, Forthside). Seed produced at Ballarat produced significantly more stems per plant than seed produced elsewhere. The number of tubers produced per plant was significantly higher from seed produced at Trowutta compared to Wilmot.

In the Victorian production trial seed from Colac produced significantly more stems per plant than seed from the other latitudes and, produced significantly more tubers per plant than seed grown at Wilmot and Trowutta. Number 1 grade yield as a percentage of total yield was significantly higher from seed produced at Colac and Forthside compared to seed grown elsewhere. Cooking quality was significantly lower (better) from seed produced at Colac and Forthside compared to seed produced at other locations except Trowutta. There were no other significant differences detected for yield and none for misshapen tubers or stem end discolouration.

Table 3. Mean effects of seed production location.

Seed source	Wilmot	Forthside	Trowutta	Colac	Ballarat	mean	P[a]	lsd 5%
			Victoria					
Germination %	98.1	98.8	97.7	95.7	89.0	95.9	-	-
(ANG)	85.7	86.6	85.3	80.8	71.9	82.1	***	4.8
Total yld (t/ha)	67.6	63.5	66.5	64.3	62.3	64.9	ns	-
No.1 yld (t/ha)	48.6	49.1	47.8	50.0	46.0	48.3	ns	-
No.1/total (%)	72.0	77.3	72.0	77.4	73.8	74.5	-	-
(ANG)	58.1	61.8	58.2	61.9	59.4	59.9	***	2.9
Stems/plant	2.5	2.9	2.6	3.3	2.9	2.8	***	0.2
Tubers/plant	7.1	7.9	7.2	8.6	7.9	7.7	***	1.0
Fry colour	7.7	7.1	7.4	7.2	7.7	7.4	*	0.5
Stem end discol	50.3	42.3	43.2	44.4	39.4	43.9	-	-
(ANG)	44.2	38.5	40.0	41.3	37.2	40.2	ns	-
			Tasmania					
Germination %	95.2	96.5	95.0	93.9	90.2	94.2	-	-
(ANG)	80.1	82.4	79.7	77.4	74.2	78.7	*	5.6
Total yld (t/ha)	66.3	66.3	67.3	67.7	66.6	66.8	ns	-
No.1 yld (t/ha)	53.6	53.1	55.1	54.4	53.3	53.9	ns	-
No.1/total (%)	81.5	81.1	82.4	80.8	80.5	81.2	-	-
(ANG)	65.1	64.9	66.0	64.7	64.6	65.1	ns	-
Stems/plant	2.7	2.8	2.8	2.7	3.1	2.8	***	0.2
Tubers/plant	7.4	7.7	8.0	7.9	7.8	7.8	*	0.5
Vigor 18/12	3.9	3.9	3.8	3.4	3.4	3.7	***	0.4
25/1	4.1	4.0	4.2	4.3	4.3	4.2	***	0.2
Maturity	3.7	3.8	3.6	3.5	3.5	3.6	**	0.2
Misshapen (t/ha)	4.5	4.2	3.0	4.5	4.9	4.5	ns	-

[a] *,**,*** = probability of 5%, 1% and 0.1% respectively, ns = not significant
(ANG) = angular transformation of the previous percentage results

Clone effects

In both production trials clonal variation was detected for stem number, tuber number, total yield and marketable yield. In the Tasmanian production trial only, clonal variation also existed for vigor, maturity and levels of misshapen tubers. In the Victorian production trial only, clonal variation existed for fry colour and stem end discolouration. Results are summarised in Table 4.

At both production trial sites the Ballarat clone produced significantly less stems per plant and significantly less tubers per plant than the other clones.

In the Tasmanian production trial, the Ballarat clone produced significantly higher total yield and lower number 1 grade, and lower number 1 grade yield as a percentage of total yield than the other clones. The Tasmanian clone produced significantly fewer stems per plant and fewer tubers per plant than the Ruen clone. The Tasmanian clone was significantly later maturing than Netted Gem. The Ballarat clone was significantly more vigorous on 25 January 1991, later maturing and had more misshapen tubers than the other clones.

In the Victorian production trial the Ballarat clone produced significantly lower total and number 1 grade yields than all other clones and significantly lower number 1 grade yield as a percentage of total yield. The Tasmanian clone produced significantly lower number 1 grade yield as a percentage of total yield compared to the Ruen and Netted Gem clones. The Tasmanian clone produced significantly less stems per plant than Netted Gem and significantly less tubers per plant than the Ruen and Netted Gem clones. Fry colour was significantly lighter (better) in colour from the Ballarat clone than any other clone. The Ballarat clone also produced significantly less stem end discolouration than the other clones.

Table 4. Clone means

Clone	Tasmanian	Ruen	Netted Gem	Ballarat	mean	P[a]	lsd 5%
			Victoria				
Germination %	98.1	96.1	95.8	94.4	95.9	-	-
(ANG)	83.1	82.4	82.8	80.0	82.1	ns	-
Total yld (t/ha)	67.2	66.0	65.3	61.0	64.9	*	4.8
No.1 yld (t/ha)	49.6	51.8	51.1	40.7	48.3	***	3.5
No.1/total (%)	74.2	78.7	78.2	66.9	74.5	-	-
(ANG)	59.5	62.8	62.3	54.9	59.9	***	2.0
Stems/plant	2.0	3.0	3.1	2.4	2.8	***	0.2
Tubers/plant	7.6	8.3	8.6	6.5	7.7	***	0.5
Fry colour	7.5	7.5	7.6	7.1	7.4	*	0.4
Stem end discol	45.2	54.8	56.2	19.5	43.9	-	-
(ANG)	42.1	48.0	48.6	22.2	40.2	***	6.8
			Tasmania				
Germination %	95.1	94.4	93.4	93.8	94.2	-	-
(ANG)	80.3	79.6	77.7	77.4	78.7	ns	-
Total yld (t/ha)	64.4	64.1	64.9	74.1	66.8	***	2.7
No.1 yld (t/ha)	54.5	56.4	55.3	49.4	53.9	***	3.0
No.1/total (%)	84.8	88.0	85.4	66.9	81.2	-	-
(ANG)	67.4	69.9	67.8	55.1	65.1	***	2.6
Stems/plant	2.8	3.0	2.9	2.5	2.8	***	0.2
Tubers/plant	7.7	8.1	8.0	7.2	7.7	***	0.4
Vigor 18/12	3.5	3.8	3.8	3.7	3.7	ns	-
25/1	4.0	4.0	4.0	4.8	4.2	***	0.2
Maturity	4.0	4.1	4.2	2.3	3.6	***	0.2
Misshapen (t/ha)	2.9	2.1	3.1	8.9	4.3	***	1.7

[a] *,**,*** = probability of 5%, 1% and 0.1% respectively, ns = not significant
(ANG) = angular transformation of the previous percentage results

Clone x seed production location (interaction) effects

Significant interactions occurred for maturity, stem number and tuber number.

In the Tasmanian trial the highest stem number was produced by Netted Gem from Ballarat and the lowest by the Ballarat clone produced at Forthside. The highest number of tubers per plant was produced by the Ruen clone from Trowutta and the lowest from the Ballarat clone grown at Wilmot.

In the Victorian trial the highest stem number was produced by Netted Gem grown at Colac and the lowest by Ballarat clone grown at Ballarat. The highest tuber number was from Netted Gem grown at Colac and the lowest from the Ballarat clone grown at Ballarat.

There was a significant difference in fry colour according to origin of seed. Seed from Forthside and Colac produced tubers which had the lightest (best) fry colour and seed from Ballarat and Wilmot produced the darkest (poorest) fry colour. No other differences were detected.

Discussion

Relatively higher latitude (more southerly latitude in the southern hemisphere) increased emergence, stem and tuber numbers. In the Tasmanian production trial, late vigor was lower and early vigor and maturity higher from seed grown at higher latitude. Absolute yields were unaffected by latitude. The results show that early plant growth from emergence through to early establishment is favoured by seed production location at a higher latitude. However, late season vigor and late maturity result from growing seed at lower latitudes. Whilst these results favour the production of seed in higher latitudes, they did not translate to higher yield.

The mechanism involved is understood by many researchers to be related to the physiological age of the plants which is influenced by the combination of time and stress (amount of time at higher than optimum temperature). The data on climate included in this paper shows a relationship of higher maximum temperatures, little difference in minimum temperatures and dryer conditions at lower latitudes compared to higher latitudes used in this study.

The clone effects were mainly due to the differences between the Ballarat clone and the other clones. The Ballarat clone, whilst displaying variable yields between the production trials, had lighter fry colour and had a significantly lower incidence of stem end discolouration, which is a major problem in the French fry industry in southern Australia. It has greater late season vigor and matures later than the other clones, which indicates that it is a hardier type and is likely to withstand greater moisture and heat stress than the remaining clones.

The Ruen and Netted Gem clones had higher yields of number 1 grade as percentage of total yield than the Tasmanian clone. These differences have not been detected before under Australian conditions.

The interactions found are considered to be of no practical significance.

Conclusions

This study was done to identify the degree of influence of the effect of latitude on seed performance and whether there was a "best" clone from the main clones available.

The effect of latitude was largely confined to growth parameters which normally influence yield but no yield differences were observed. It is probable that the differences in latitude between the sites were not large enough to influence yield but were large enough to influence some of the other parameters.

The Ballarat clone shows promise with regard to fry colour and stem end discolouration and appears to be more hardy than the other clone later in the season. This clone may need to be spaced closer as the number of stems and tubers per plant is consistently lower than the other clones. Its performance is likely to alter significantly if plant population is changed and may result in superior performance compared to the other widely used clones. The Ruen and Netted Gem clones produced a better number 1 grade sample than the Tasmanian clone and should be used as the standard clones in Tasmania.

The underlying effect of seed production location may be due to temperature and or the response to daylength.

Further work is warranted to investigate the germination of seed at different latitudes and the optimum plant spacing for the Ballarat clone.

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The phosphorus nutrition of Russet Burbank potatoes grown on krasnozem soils: the effect of soil and fertiliser phosphorus on yield, petiole phosphorus and tuber quality.

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Summary. The response of Russet Burbank and Kennebec potatoes to different levels of soil and fertiliser phosphorus (P) was compared on the krasnozem soils of the Central Highlands in Victoria. Field experiments were conducted at 12 sites over 3 years to examine the effects of applied P (banded at planting) at rates up to 475 kg/ha on yield, quality characteristics and petiole P concentrations and the correlation of yield response with available soil P (Olsen method) and soil P sorptivity measures of P adsorbed, P buffered and P Retention Index.

There were significant ($P \leq 0.05$) yield increases in response to increased rates of applied P at the majority of sites. These yield responses to applied P were significantly ($P \leq 0.001$) correlated with available soil P (Olsen method) for both varieties using mitscherlich models (adj. $R^2 = 0.78$). There was a significant ($P \leq 0.05$) difference between the mitscherlich models used to describe this correlation for the two varieties. The critical available soil P (Olsen method) values were 29 and 67 mg/kg for Kennebec and Russet Burbank respectively.

For Russet Burbank there was a significant ($P \leq 0.05$) decreasing linear correlation between the amount of P fertiliser required to achieve 90-95 % maximum yield and increasing available soil P levels (Olsen method). The predictive models of either yield response or the amount of P fertiliser required, were not significantly ($P \geq 0.05$) improved by including soil sorptivity measurements.

P fertiliser had significant ($P \leq 0.05$) effects on tuber size distribution of both varieties, whilst its effect on tuber set and quality differed between the varieties.

There were significant ($P \leq 0.05$) mitscherlich correlations between yield response and petiole P concentrations for both varieties. The following critical petiole P ranges have been proposed to assist in the assessment of the P status of Russet Burbank crops in Victoria; 0.43-0.52, 0.45-0.57, 0.35-0.47, 0.21-0.26 % when the average length of the longest tubers are; hook, 10-15, 35-45 and 75-85 mm respectively.

Data is presented that suggests available soil P (Olsen method) can be used to predict the likely yield response and the amount of P fertiliser required to optimise yield, across a range of P sorbing krasnozem soils, although significant differences exist between the cultivars Kennebec and Russet Burbank.

Introduction

Since 1985 the major French fry potato variety grown for processing in Australia has changed from Kennebec to Russet Burbank. Grower experience indicates that Russet Burbank produces lower yields than Kennebec when grown under the same management conditions in the Central Highlands of Victoria. Maier *et al.* (1989a) found soil P analysis was a useful predictor of potatoes response to applied P provided the effect of soil-type was taken into consideration. Research on other crops has shown that including P sorptivity measurements improves predictive models of yield response and fertiliser requirements based on available soil P for various extraction methods (Ozanne and Shaw 1968; Holford and Cullis 1985; Holford *et al.* 1985). Plants can only utilise phosphate present in soil solution, which is controlled by the amount of phosphorus adsorbed by the soil and the affinity of the soil for phosphorus (ie. P sorptivity) (Allen and Jeffery 1990). P sorptivity can be measured using sorption isotherms (eg. P adsorbed, P buffering capacity) or a single point P-sorption index such as the P Retention Index (PRI) (Allen and Jeffery 1990). Current fertiliser recommendations for P on Central Highland krasnozems are based on correlations established with available soil P (Olsen method) for Kennebec (Strange and Marshall 1989). However, the P fertiliser requirements of Kennebec and Russet Burbank may be significantly different as suggested by the consistent differences in their potassium fertiliser requirements on Tasmanian krasnozem soils reported by Chapman *et al.* (1992).

Potato growers are increasingly using tissue testing as an indicator of the potato crop's nutritional status. Maier *et al.* (1989b) established a critical nutrient range for total P in potato petioles when the average length of the longest tuber was 5-10 mm. However, many potato growers sample their potato crops at various growth stages and there are no critical nutrient ranges established based on tuber length other than at the 5-10 mm stage. The change in cultivar and the increased use of soil and tissue tests to predict fertiliser requirements has necessitated an assessment of the P nutrition of Russet Burbank potatoes on the krasnozem soils of Victoria.

This study compared the response of Russet Burbank and Kennebec potatoes to soil and fertiliser P on the krasnozem soils of Victoria's Central Highlands. It aimed to establish P fertiliser recommendations (based on available soil P (Olsen method) and soil P sorptivity measurements) to maximise the yield and quality of Russet Burbank potatoes. In addition, the study aimed to determine critical nutrient ranges for Russet Burbank potato petioles over a range of growth stages based on tuber length.

Materials and methods

Field experiments

Field trials were conducted over a 3 year period to investigate the effect of P fertiliser on the yield and quality of Russet Burbank and Kennebec potatoes, and the correlation between yield response and available soil P (Olsen method). Sites in commercial Russet Burbank potato crops in the Central Highlands were chosen to provide a wide range of soil P levels. The soil type, location, planting and harvest dates, details of the treatments and number of replicates are summarised in Table 1.

The experimental design was a randomised block. As shown in Table 1, various rates of P from 0-475 kg/ha (as Triple Superphosphate) were applied to Russet Burbank, whilst only 2 rates (0, 120 kg/ha) of P were applied to Kennebec. At all sites, for both cultivars, 40-220 kg/ha K (as Potassium Chloride) and 100-180 kg/ha N (as ammonium nitrate or ammonium sulphate) were applied according to paddock history for nitrogen and soil test values for potassium.

Basal and treatment fertiliser were placed in a double band 5 cm either side and below the seed piece with a tractor-mounted planter/fertiliser applicator. Certified seed for both varieties was used to plant all trials. Row spacing at the majority of sites was 80 cm, however at site 3 it was 85 cm and at sites 8 and 12 it was 90 cm. Within row spacing was 35-38.5 cm for Russet Burbank and 20 cm for Kennebec. Each plot consisted of 2 rows, 6 m in length and separated by 1-2 m of purple skinned (cv. Toolangi Delight) potatoes. Guard rows between plots were included at sites 3 and 6 but omitted from all other sites, because no significant cross-feeding occurred (K.L.Freeman, unpublished data). Cultivation, pest and disease management and irrigation were carried out by the grower.

Following natural senescence tubers were dug using a two-row digger and yield categories were calculated from the weight ranges; 0-75 g, 75-280 g, 280-450 g, >450 g. Total yield was calculated from the sum of the above weight ranges, whilst processing yield was the sum of the yield categories above 0-75 g. The number of tubers in each weight category was recorded and used to calculate the average processing tuber weight and the number of tubers per plant.

A sample of 15 tubers was taken from the 75-280 g category to determine fry colour and specific gravity (S.G.). Slices of potatoes approximately 1.5 mm thick were fried in safflower oil at 185-190 °C until bubbling ceased, after about 2.5 minutes. Crisp slices were fryed within 2 weeks of harvest, taking 20 slices cut longitudinally from 10 potatoes. Fry colour was measured using a subjective colour rating system within the range 1 to 10, where 1 is extremely light, 10 is dark brown and 7 is marginal. Specific Gravity was measured using the formula:

$$S.G. = \frac{\text{weight of potatoes in air}}{\text{weight of potatoes in air - weight of potatoes in water}}$$

Analytical Methods

Soil. A representative soil sample was taken from the surface 10-15 cm of the selected site areas approximately 6 weeks prior to planting. The soil samples were then dried in a forced draught 40°C oven for a minimum of 3 days, ground to pass through a 2 mm sieve and analysed for the following:

a) pH (1:5, soil : 0.01M $CaCl_2$)
b) Olsen P (Olsen *et al.* 1954)
c) Colwell P (Colwell 1965)
d) Skene K (0.05M HCl extractable potassium)

A 100 mm wide auger was used to collect soil samples at 10 cm intervals down the profile at each trial site, which were used for Northcote and Greater soil classification (Northcote 1971; Stace *et al.* 1968). A 0.5-1 kg soil sample was collected from virgin soil adjacent to fencelines near the trial sites and analysed for Fe_2O_3, Al_2O_3 (Coffin 1963), P adsorption (Pads), P buffering (Pbuff) and P Retention Index (PRI) using the methods described by Allen and Jeffrey (1990).

Plant. Samples of 30-50 petioles of the youngest fully expanded leaves (P-YFEL, usually the third or fourth leaf from the apex) where collected from each plot when the average length of the largest tubers were:

a) hook (hook stage)
b) 5-10 mm (5-10 mm tuber stage)
c) 35-40 mm (35-40 mm tuber stage)
d) 70-75 mm (70-75 mm tuber stage)

The plots were then bulked within treatments and the petioles were washed, dried in a forced draught oven at 65 °C, ground and analysed for P using X-ray Fluorescence Spectrometery (XRF).

Statistical Methods

Yield and quality data were analysed by analysis of variance. Linear, quadratic and mitscherlich models were fitted to the Russet Burbank yield data using P fertiliser rate as the independent variable. The best fitting model was used to estimate maximum yield, the yield without P and the rate of P required to achieve 90 (X_{90}) and 95 (X_{95}) percent of maximum yield. For Kennebec yield data, yields with either no fertiliser or 120 kg P/ha (maximum yield) were calculated from treatment means. For both cultivars at all sites relative yields were defined as 100 x (yield without P/maximum yield).

Relative yields, weighted by the inverse of their variance, were correlated with available soil P and multiple regression analysis was used to see if adding sorptivity measures (Pads, Pbuff or

PRI) improved the model. Non-linear regression analysis was used to test the significance of variety interactions in the mitscherlich model between relative yield and available soil P. Critical values for the mitscherlich model at 90 % were used to calculate critical available soil P values for the two varieties.

For Russet Burbank data, the rate of P required to achieve X_{90} and X_{95}, weighted by the inverse of their standard errors, were correlated with available soil P and these linear models were used to generate recommendations on fertiliser requirements at planting.

For each growth stage the effect of the rate of applied P on the total P concentration in P-YFEL was determined by analysis of variance on pooled site data for the zero and maximum P rate treatments.

To estimate the critical total P concentration in the P-YFEL associated with tuber yield response to P, the total P concentration from each of the P treatments for each site were correlated with the total relative tuber yields from those sites. The relative yields were determined for each site by expressing the mean treatment yields as percentages of the maximum mean treatment yield for that site. Mitscherlich models with critical values at 90 and 95 % were used to calculate critical petiole P ranges.

Results

P fertiliser and tuber yield

Significant yield responses to P fertiliser were recorded at the majority of sites for both Kennebec and Russet Burbank cultivars (Table 2). At 11 out of the 12 sites, Russet Burbank showed significant ($P \leq 0.05$) increases in total and processing yield in response to applied P fertiliser. At 7 of the 9 sites where the cultivar Kennebec was included for comparison, there were significant ($P \leq 0.05$) increases in total or processing yield in response to applied P.

The mean relative processing yields for responsive sites were 65 % (range 11-89 %) and 65.3 % (range 19-91 %), the mean relative processing yields for non-responsive sites were 94 % and 94.3 % (range 94-95 %) for Russet Burbank and Kennebec respectively.

Total tuber yields from maximum yielding treatments varied for Russet Burbank from 49.6-75.9 t/ha and for Kennebec from 58.8-74.4 t/ha over all sites.

The total and processing yield responses for Russet Burbank at each site were modelled using linear, quadratic and mitscherlich equations. For all responsive sites, mitscherlich models gave the best fit and are described in Table 2.

Correlation of yield response with available soil P and P sorptivity measurements.

As shown in Table 3, for both varieties significant ($P \leq 0.05$) correlations existed between each of the indicators of P sorptivity (PRI, Pads, Pbuff) and Fe_2O_3 and Al_2O_3. Al_2O_3 had the highest correlation ($r=0.919$, $P \leq 0.001$) with Pbuff.

For both varieties there was a significant ($P \leq 0.001$) mitscherlich correlation between the yield response to applied P fertiliser and available soil P (Table 4). Multiple regression analysis showed that the inclusion of one or more of the soil P sorptivity measures did not increase the percentage variance (adj. R^2) in relative yield already explained by the available soil P variable. When linear, quadratic and mitscherlich models were fitted to the relationship between relative yield and available soil P, the mitscherlich model gave the best fit (adj. R^2 = 0.78).

The relationship between relative yield and available soil P for each variety was compared, and as shown in Table 4, the effect of variety was significant ($P \leq 0.05$) for the A (intercept) variable of the equation. Fig. 1a. illustrates the comparative effects of the varieties in their relationship between yield response and available soil P. The critical available soil P concentrations for the mitscherlich model at 90 % relative yield were 29 mg/kg for Kennebec and 67 mg/kg for Russet Burbank.

For Russet Burbank there was a significant ($P \leq 0.05$) correlation between the P fertiliser required to achieve 90-95 % of maximum yield and available soil P as shown in Fig. 1b. The inclusion of soil sorptivity measures via multiple regression analysis did not improve this model.

P fertiliser and tuber size distribution

P fertiliser significantly ($P \leq 0.05$) effected the tuber size distribution of both varieties. There was only one site (site 9) where increasing P fertiliser resulted in a significant ($P \leq 0.05$) yield increase but had no significant ($P \geq 0.05$) effect on the tuber size distribution of Russet Burbank potatoes. At all other sites, where significant ($P \leq 0.05$) yield increases from P fertiliser were recorded, there were significant ($P \leq 0.05$) changes in tuber size distributions for both varieties. At sites where there was no significant response to P fertiliser there was also no significant ($P \geq 0.05$) effect on tuber size distribution.

As shown in Table 5, at the majority of sites for both Russet Burbank and Kennebec, the effect of increasing applied P reduced the percentage of tubers below 280g and increased the percentage of tubers over 280g.

At sites 3 (Russet Burbank only), 5 and 8 (Kennebec only) increasing the rate of applied P had a variable effect on tuber size distribution. At site 3, increasing applied P significantly ($P \leq 0.05$) increased the percentage of Russet Burbank tubers less than 75g and significantly ($P \leq 0.05$) reduced the percentage of tubers over 280g. At site 5, increasing the applied P significantly ($P \leq 0.05$) increased the percentage of Kennebec tubers in the 75-280g category and significantly ($P \leq 0.05$) reduced the percentage of tubers over 280g. At site 8, the only significant effect of increasing applied P on Kennebec tuber size distribution was to significantly ($P \leq 0.05$) reduce the percentage of tubers over 450g.

The effect of applying P on the average weight of tubers in the processing yield grade differed between the varieties. Kennebec produced larger processing tubers than those of Russet Burbank (Fig. 2). For Russet Burbank increasing P fertiliser significantly ($P \leq 0.05$) increased average processing tuber weight at 9 of the 12 sites, except at site 3 where it reduced average processing tuber weight. However, for Kennebec the effect of P fertiliser on the average processing tuber weight was significant ($P \leq 0.05$) at only 4 out of the 9 sites. Sites 1 and 2 showed a significant ($P \leq 0.05$) increase in average processing tuber weight whilst sites 5 and 8 showed a significant ($P \leq 0.05$) decrease in average processing tuber weight.

P fertiliser and tuber set

The effect of P fertiliser on tuber set differed between the two varieties. For Russet Burbank, at 10 of the 12 sites, increasing the amount of P fertiliser significantly ($P \leq 0.05$) increased the number of tubers set by 32 % to an average of 10.7 tubers/plant (Table 6). In contrast, for Kennebec at 6 of the 9 sites there was no significant ($P \geq 0.05$) effect of P fertiliser on the number of tubers/plant. At sites 1, 2 and 5 P fertiliser significantly ($P \leq 0.05$) increased the number of tubers by 42 % to an average of 5.2 tubers/plant (Table 6).

P fertiliser and tuber quality
The effect of P fertiliser on the specific gravity of tubers was different for the two varieties (Table 7). For Kennebec increasing the rate of P fertiliser applied had no significant ($P \geq 0.05$) effect on tuber specific gravity at all sites, except site 10 where it reduced tuber specific gravity. For Russet Burbank the effect of increasing P fertiliser on specific gravity was related to the available soil P level. For sites with less than 27 mg/kg (Olsen P), P fertiliser had a significant ($P \leq 0.05$) effect on tuber specific gravity. For sites with greater than 27 mg/kg (Olsen P), P fertiliser had a significant ($P \leq 0.05$) effect on tuber specific gravity at only one of the six sites. Where P fertiliser had a significant ($P \leq 0.05$) effect on tuber specific gravity it reduced the specific gravity at all sites except site 2.

The effect of P fertiliser on fry colour was not significant ($P \geq 0.05$) for both Kennebec and Russet Burbank at the majority of sites (data not shown).

P fertiliser and petiole P concentrations
Increasing the rate of P fertiliser resulted in significant ($P \leq 0.05$) increases in the concentration of P in the petioles of both varieties (Fig. 3.). For both varieties there was a significant ($P \leq 0.05$) positive correlation between yield response and increasing concentration of P in the petioles (Fig. 4.). Table 8 shows the critical petiole P ranges for Russet Burbank potatoes over the 4 growth stages. The critical petiole P range for Kennebec at the 5-10 mm tuber stage was 0.37-0.42 %.

Discussion
Available soil P (Olsen method) is a useful predictor of potatoes yield response to P fertiliser for the Central Highlands krasnozem soils. Maier *et al.* (1989a) also found available soil P (Olsen method) effective in separating responsive and non-responsive sites for potatoes grown on loamy sand-sandy clay loam soils.

To ensure correct prediction of yield response based on available soil P (Olsen method), soil type and cultivar need to be considered. Maier *et al.* (1989a) found soil type to be an important component in the accurate interpretation of soil test results for potatoes with the critical value for coarse grain sandy soils being much lower than those for the heavier textured loamy sand to sandy clay loam soils. For Kennebec, our critical soil P concentration of 27 mg/kg (Olsen P) on krasnozem soils is higher than that reported by Maier *et al.* (1989a) of 14.8 mg/kg (Olsen P). We suggest our higher value reflects the higher clay-loam texture of the krasnozem soils.

For certain varieties, the effect of cultivar on the relationship between yield response and available soil P (Olsen method) is significant. Maier *et al.* (1989a) found no significant effect of cultivar on critical soil P concentration ranges, however at the majority of their sites the varieties used were Kennebec and Coliban. At the only site where they included the variety Russet Burbank there was a significant cultivar x P rate interaction. Chapman *et al.* (1992) found a consistent difference between the varieties Kennebec and Russet Burbank in their critical soil potassium concentrations and suggested these difference may be due to Russet Burbank being less effective at extracting potassium from the soil. Our results show a significant effect of variety on the critical soil P concentrations (Table 4) suggesting Russet Burbank is also less effective at extracting P from the soil than the Kennebec cultivar.

The addition of P sorptivity and buffering measures did not improve the amount of variability explained in the model between yield response and available soil P (Olsen method). For other crops taking into account the soil sorptivity as well as the available P has given substantial improvements in the predictive models (Holford and Cullis 1985). Results from this work and that of Maier *et al.* (1989a) show active iron and aluminium were significantly ($P \leq 0.001$)

positively correlated with the P sorption indexes. However, our results showed that adding these terms into either the yield response or the fertiliser-required models did not improve the amount of variation (adj. R^2) accounted for. Although all sites were located on similar soil-types there was a wide range in P sorptivity (66-1000 mL/g PRI) and therefore if sorptivity was to significantly improved the model it would have been expected to, over this sorptivity range. Montgomery and Rubenis (1978) also found P sorption indices did not give higher correlation coefficients than those obtained with available soil P (Olsen method).

Significant linear correlations existed between the amount of fertiliser required to achieve 90-95 % of maximum yield and available soil P (Olsen method). These models were not improved by the addition of sorptivity measures. Holford *et al.* (1985) found that for wheat crops there was a poor correlation between several soil P extraction methods and crop fertiliser requirements. Holford and Cullis (1985) found a model incorporating P buffer capacity improved the prediction of fertiliser requirements for wheat. These contrasting results may be related to the effect of irrigation on P availabilitity.

In previous work with potatoes correlating soil tests (Maier 1986; Maier *et al.* 1989a; Chapman *et al.* 1992) models have been developed based on estimates of responsiveness but not the amount of fertiliser required to achieve these responses. This work with potatoes grown on the krasnozems soils in central Victoria has developed a model using available soil P (Olsen method) to predict the fertiliser requirement of potatoes (Fig. 2.). This model can provide soil testing laboratories and consultants, not only with estimates of likely response, but with estimates of actual fertiliser requirements. Soil type and cultivar are likely to be important factors when developing models predicting fertiliser requirements.

Our results show total P concentrations in the petiole initially increased between hook and the 5-10 mm tuber stage, and then declined over time throughout the growing season. Other researchers (Bates 1971; Home and Nylund 1978; Dow and Roberts 1982; Roberts and Dow 1982; Tyler *et al.* 1991; Lewis 1992) have reported the decline of petiole P concentrations over time in potato and other crops. The first sampling time reported by these workers was after the 5-10 mm tuber stage and therefore did not show the initial increase in petiole P concentration reported in our results. The period between hook stage and the 5-10 mm tuber stage may actually underestimate the potato crops yield potential based on total P concentration in the P-YFEL. Our results highlight the importance of correctly identifying the potato growth stage for accurate and meaningful interpretation of the critical nutrient ranges for petiole P.

The critical total P concentration ranges for the 4 growth stages in Table 8 show that our critical nutrient range (CNR) at the 5-10 mm tuber stage is similar to that reported by Maier *et al.* (1989b) of 0.41-0.53 % but higher than the CNR reported by Sparrow *et al.* (1992) of 0.36-0.40 %. It is difficult to compare our results with overseas work establishing critical nutrient ranges over time for Russet Burbank (Roberts and Dow 1982) as their sampling time was based on days after 2 cm tuber length compared to our sampling schedule based on tuber lengths. However, their results of a CNR of 0.38-0.45 % P at the 3 cm tuber stage to 0.14-0.17 % at the end of the season, 70 days after the first sampling, shows a similar pattern to our declining CNR from 0.45-0.57 % at the 5-10 mm tuber stage to 0.21-0.26 % at the 75-85 mm tuber stage (approximately 65 days after emergence). To our knowledge this is the first work in Australia for the Russet Burbank cultivar showing critical nutrient ranges for P in the P-YFEL over time (Table 8).

P fertiliser affected other yield and quality characteristics such as tuber set, tuber size distribution and S.G.. The effect of P fertiliser on tuber size distribution was similar for both varieties resulting in an increase in the proportion of large tubers. The effect of P fertiliser on tuber set and S.G. differed between the varieties. However, for Russet Burbank it was possible to apply P at rates that optimised yield response without adverse effects on tuber quality.

P fertiliser can significantly reduce the specific gravity of Russet Burbank potatoes. This effect was only observed at one site for the Kennebec cultivar suggesting that the effect of P on S.G. is more pronounced for the Russet Burbank cultivar.

Conclusions

This work has shown that Russet Burbank and Kennebec have different P yield response correlations with available soil P (Olsen method). A model has been developed using available soil P to predict the fertiliser requirements of Russet Burbank potatoes on the krasnozems of central Victoria. This study has also defined critical petiole P ranges over a number of tuber stages, enabling the assessment of the P status of Russet Burbank crops in Victoria throughout the growing season.

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Captions

Fig 1. Effect of soil available phosphorus (Olsen method) on (a) relative processing yields for Russet Burbank (○, ———) and Kennebec (, - - -) and (b) the amount of phosphorus fertiliser required to achieve 90 % (———) and 95 % (- - -) maximum yield for Russet Burbank.

Regression equations for relative yields are:

Russet Burbank: $Y = 90.8 - 89.8 \exp(-0.06x)$ (adj $R^2=0.78$)

Kennebec: $Y = 104.7 - 89.8 \exp(-0.06x)$ (adj $R^2=0.78$)

Regression equations for P fertiliser are:

90 %: $Y = 122.4 - 2.8x$ (F 1,9 = 25, adj R^2 =0.71)

95 %: $Y = 156.5 - 2.6x$ (F 1,9 = 13, adj R^2 =0.54)

Fig 2. Effect of phosphorus fertiliser on the average processing tuber weight of (a) Russet Burbank (□, 0 kg P/ha; ■, for sites 1, 2, 4, 9, 10 475 kg P/ha, for sites 5, 7, 8, 12 375 kg P/ha, for sites 3, 6 400 kg P/ha) and (b) Kennebec (□, 0 kg P/ha, ■, 120 kg P/ha). Vertical bars represent standard errors for each site.

Fig 3. Effect of phosphorus fertiliser on the phosphorus concentration in petioles of Russet Burbank potatoes at four tuber stages (□, 0 kg P/ha; ■, for sites 1, 2, 4, 9, 10 475 kg P/ha; for sites 5, 7, 8, 12 375 kg P/ha; for sites 3, 6 400 kg P/ha.) Vertical bars represent standard errors at each tuber stage.

Fig 4. Relative yield of tubers in relation to total phosphorus concentration in Russet Burbank petioles when the average length of the longest tubers were (a) hook (b) 5-10mm (c) 35-45mm and (d) 75-85mm.

Regression equations are:

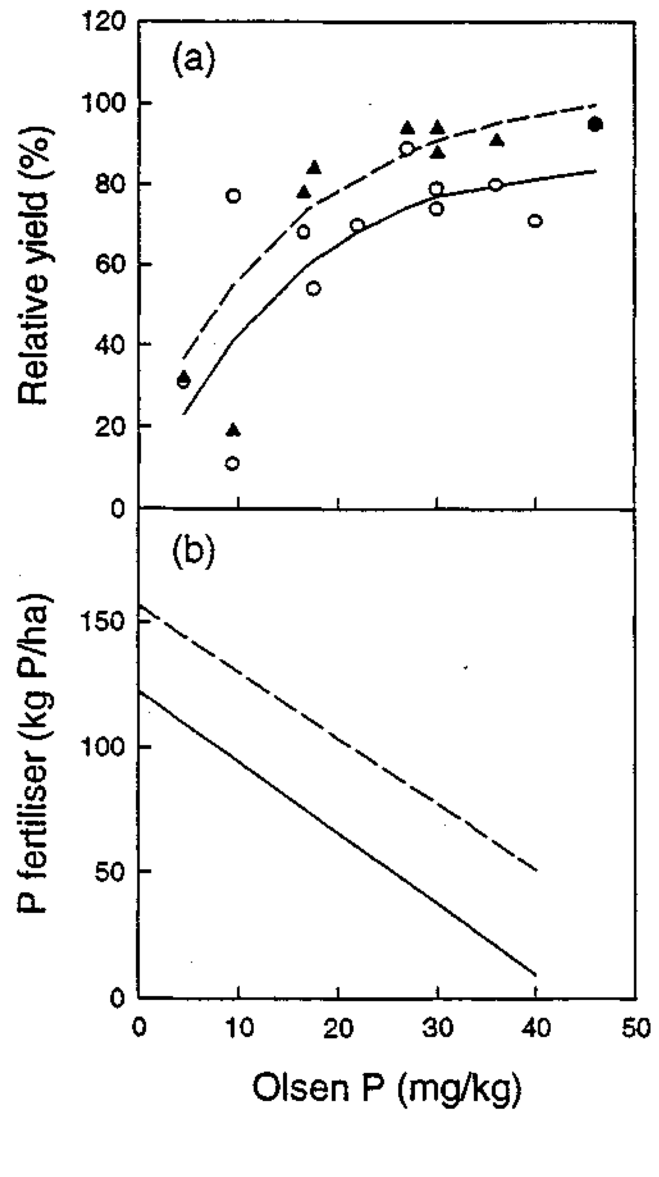
(a) $Y = 1.00 + 1.3 \exp(-5.7x)$ (F 2,69 = 18.8, adj R^2 = 0.33)

(b) $Y = 0.94 + 4.3 \exp(-10.1x)$ (F 2,65 = 45.9, adj R^2 = 0.57)

(c) $Y = 0.97 + 3.5 \exp(-11.4x)$ (F 2,73 = 70.2, adj R^2 = 0.65)

(d) $Y = 0.99 + 3.4 \exp(-17.5x)$ (F 2,73 = 60.5, adj R^2 = 0.61)

Fig 1.



(a)
(b)
Relative yield (%)
P fertiliser (kg P/ha)
Olsen P (mg/kg)
0
20
40
60
80
100
120
0
50
100
150
0
10
20
30
40
50

ig 2

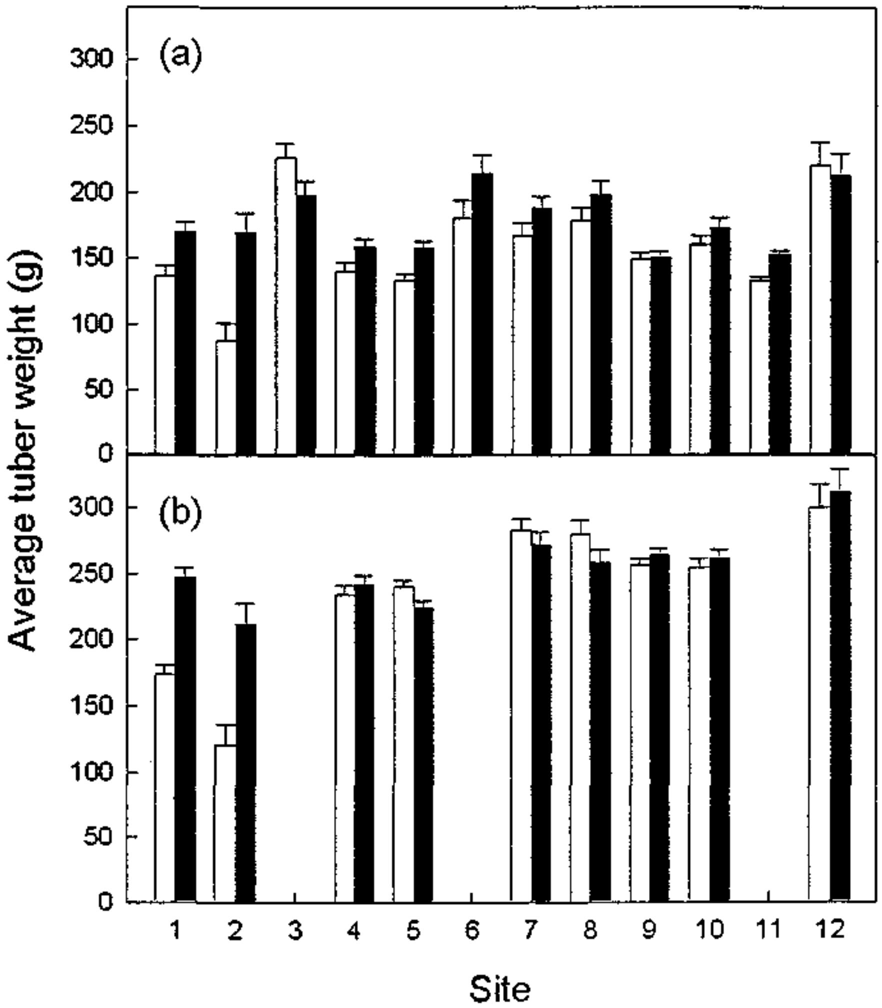
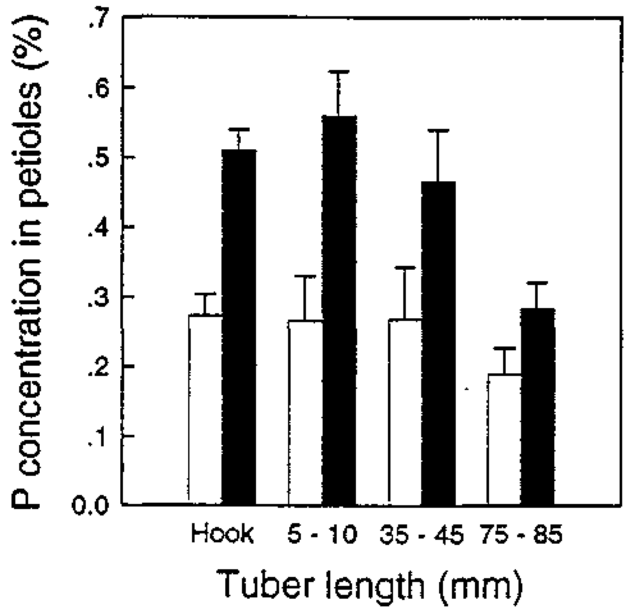

(a)
(b)
Average tuber weight (g)
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
Site

Fig 3.



P concentration in petioles (%)
0.0
.1
.2
.3
.4
.5
.6
.7
Hook
5 - 10
35 - 45
75 - 85
Tuber length (mm)

Fig 4

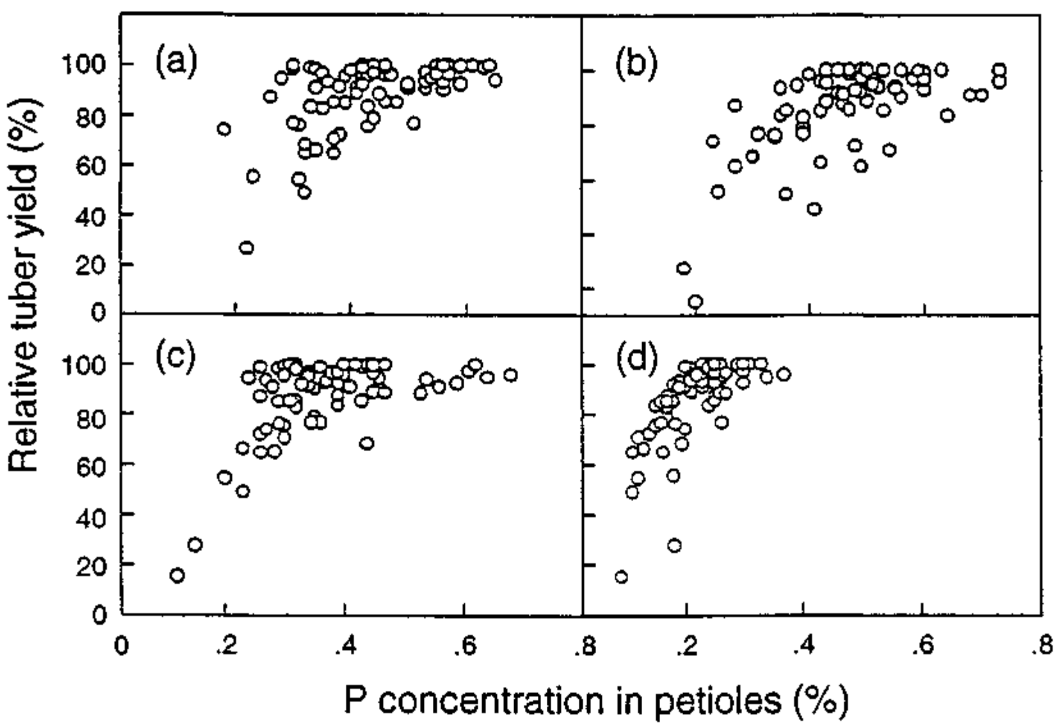

(a)
(b)
(c)
(d)
Relative tuber yield (%)
0
20
40
60
80
100
0
.2
.4
.6
.8
P concentration in petioles (%)

Table 1. Details of experimental sites

Site	Location	Soil[A] Classification	Planting Date	Harvest Date	Cultivar	Phosphorus rate (kg/ha)	Number of Reps.
1	Waubra	Krasnozem Gn 4.11	22.xi.91	25.v.92	Russet Burbank Kennebec	0,20,40,60,120,200,275,375,475 0,120	7 7
2	Waubra	Lithosol Uf 1.43	11.xi.91	5.v.92	Russet Burbank Kennebec	0,20,40,60,120,200,275,375,475 0,120	7 7
3	Bungaree	Krasnozem Gn 4.11	29.xi.89	8.v.90	Russet Burbank	0,40,80,120,180,250,300,400	5
4	Ascot	Krasnozem Gn 4.11	14.xi.91	29.vi.92	Russet Burbank Kennebec	0,20,40,60,120,200,275,375,475 0,120	7 7
5	Clarkes Hill	Krasnozem Gn 4.11	4.xii.90	14.vi.91	Russet Burbank Kennebec	0,50,100,150,225,300,375 0,120	5 5
6	Ascot	Krasnozem Gn 4.11	22.xi.89	23.iv.90	Russet Burbank	0,40,80,120,180,250,300,400	5
7	Millbrook	Red Earth Gn 2.11	28.xi.90	15.v.91	Russet Burbank Kennebec	0,50,100,150,225,300,375 0,120	5 5
8	Dean	Haplic Xerosols Um 6.13	15.xi.90	16.v.91	Russet Burbank Kennebec	0,50,100,150,225,300,375 0,120	5 5
9	Newlyn	Krasnozem Gn 4.11	21.xi.91	11.v.92	Russet Burbank Kennebec	0,20,40,60,120,200,275,375,475 0,120	7 7
10	Bullarook	Krasnozem Gn 4.11	18.xi.91	4.v.92	Russet Burbank Kennebec	0,20,40,60,120,200,275,375,475 0,120	7 7
11	Clarkes Hill	Krasnozem Gn 4.11	27.xii91	16.vi.92	Russet Burbank	0,275,375	10
12	Tourello	n.a.[B], Uf 4.3	26.xi.90	30.iv.91	Russet Burbank Kennebec	0,50,100,150,225,300,375 0,120	5 5

[A] Great Soil Group (Stace *et al.* 1968); Northcote (1971) classification
[B] n.a., not available

Table 2. Control yields and regression equations relating tuber yields to rate of applied phosphorus and relative yields for all sites

Control yields are yields of plots not receiving phosphorus fertiliser (t/ha); Y, total or processing tuber yield (t/ha); x, rate of phosphorus application (kg/ha); relative yield is 100 x (yield without phosphorus/maximum yield)

Site	Soil P (mg/kg)	Russet Burbank Relative Yield (%)	Adj. R^2	Regression Equation	Kennebec Relative Yield (%)	Control Yield (t/ha)	Signif.
				Total tuber yield			
1	5	32	0.93**	y=69.4-47.4exp(-0.02x)	33	23.1	**
2	9	19	0.93**	y=46.7-38exp(-0.02x)	22	11.4	**
3	9	76	0.34*	y=49.6-11.8exp(-0.01x)	n.a.[B]	n.a.	n.a.
4	17	69	0.75**	y=54.8-17exp(-0.01x)	79	43.3	**
5	18	58	0.87**	y=50.1-21.1exp(-0.02x)	83	52.8	**
6	22	73	0.51**	y=42.9-11.6exp(-0.02x)	n.a.	n.a.	n.a.
7	27	88	0.27*	y=51.9-6.2exp(0.03x)	94	64.2	n.s.
8	30	74	0.61**	y=48-12.4exp(-0.03x)	93	58.3	**
9	30	79	0.66**	y=54.6-11.4exp(-0.02x)	88	56.8	**
10	36	81	0.67**	y=49.9-9.7exp(-0.01x)	92	52.8	**
11	40	67	**	33.5	n.a.	n.a.	n.a.
12	46	95	n.s.[A]	y=51.63+0.007x	94	58.5	n.s.
				Processing tuber yield			
1	5	31	0.92**	y=65.9-46.9exp(-0.02x)	32	21.9	**
2	9	11	0.93**	y=43.8-38.9exp(-0.02x)	19	9.1	**
3	9	77	0.32*	y=47.4-11exp(-0.01x)	n.a.	n.a.	n.a.
4	17	68	0.74**	y=50.5-16.3exp(-0.01x)	78	41.7	**
5	18	54	0.87**	y=43.5-19.9exp(-0.02x)	84	51.2	**
6	22	70	0.54**	y=40.1-11.9exp(-0.01x)	n.a.	n.a.	n.a.
7	27	89	0.24*	y=50.5-5.8exp(-0.02x)	94	63.4	n.s.
8	30	74	0.62**	y=45.7-11.8exp(-0.03x)	94	57.3	n.s.
9	30	78	0.67**	y=52.8-11.3exp(-0.02x)	88	55.9	**
10	36	80	0.6**	y=46.1-9.3exp(0.01x)	91	51.2	**
11	40	64	**	28.3	n.a.	n.a.	n.a.
12	46	95	n.s.	y=48+0.006x	95	56.8	n.s

** $P \leq 0.001$ [A] n.s., not significant ($P \geq 0.05$)
* $P \leq 0.05$ [B] n.a., not available

Table 3. Selected soil chemical properties of surface (0-15 cm) soils for each experimental site and inter-correlations between these properties

PRI, Phosphorus Retention Index; Pads, phosphorus adsorbed; Pbuff, phosphorus buffering capacity;Fe_2O_3, free iron oxide; Al_2O_3, free aluminium oxide.

Site	Olsen P[A] (mg/kg)	Colwell P[B] (mg/kg)	PRI[C] (mg/kg)	Pads[C] (mg/kg)	Pbuff[C] (mg/kg)	Fe_2O_3[D] (%)	Al_2O_3[D] (%)	pH $CaCl_2$
1	4.5	21	130	110	21	4.8	0.3	4.1
2	9.4	13	86	80	18	3.5	0.3	4.1
3	9.5	n.a.[E]	260	170	25	8.4	0.8	4.8
4	16.6	55	250	160	26	4.9	0.5	4.5
5	17.6	85	200	120	44	7.6	1.2	4.7
6	22	n.a.	230	140	23	5.5	0.4	4.8
7	27	100	530	240	37	6.8	0.8	4.8
8	30	65	1000	580	95	8.9	1.6	5.2
9	30	114	410	200	35	7.3	0.9	4.7
10	36	168	520	260	63	7.5	1.5	4.7
11	40	138	790	400	74	6.9	1.2	4.7
12	46	86	66	77	15	2.2	0.2	5.0
Correlation matrix (r)								
Olsen P	1.000							
Colwell P	0.763*	1.000						
PRI	0.438	0.471	1.000					
Pads	0.390	0.345	0.981**	1.000				
Pbuff	0.399	0.484	0.936**	0.942**	1.000			
Fe_2O_3	0.132	0.489	0.776*	0.724*	0.815*	1.000		
Al_2O_3	0.367	0.633	0.810*	0.774*	0.919**	0.919**	1.000	
pH	0.799*	0.520	0.603	0.605	0.584	0.434	0.563	1.000

* $P \leq 0.05$
** $P \leq 0.001$
[A] Olsen *et al.* 1954
[B] Colwell 1965
[C] Allan and Jeffery 1990
[D] Coffin 1963
[E] n.a., not available

Table 4. Accumulated analysis of variance table for mitscherlich regression model fitted to relative yield and available soil P data for Russet Burbank

A, is the intercept; B is the distance between the intercept and the asymptote; R, is the curvature.

Source of variation	d.f	Error sum of square	Error mean square	variance ratio	F prob
+ Effect of Olsen P	2	781.06	390.53	30.73	<.001
+ Effect of variety on A	1	81.06	81.10	6.38	0.023
+ " " " " B	1	1.58	1.58	0.12	0.730
+ " " " " R	1	11.51	11.51	0.91	0.356
Residual	15	12.71	12.71		
Total	20	1065.88	53.29		

Table 5. The effect of phosphorus fertiliser on tuber size distribution.
0, 0 kg P/ha; for sites 1, 2, 4, 9 and 10 Max is 475 kg P/ha; for sites 5, 7, 8 and 12 Max is 375 kg P/ha; for site 6 Max is 400 kg P/ha; for site 3 Max is 300 kg P/ha; 120, 120 kg P/ha.

Site	Tuber Weight (g)	Russet Burbank			Kennebec		
		0	Max	Signif.	0	120	Signif.
1	0-75	11	4	**	5	2	**
	75-280	83	76	**	74	46	**
	280-450	6	16	**	18	43	**
	> 450	0	4	**	3	9	**
2[A]	0-75	16	6	**	22	5	**
	75-280	80	71	**	74	49	**
	280-450	3	16	**	4	31	**
	> 450	1	7	**	0	15	**
3	0-75	4	6	*			
	75-280	55	64	n.s.[C]	n.a.[D]	n.a.	n.a.
	280-450	29	20	**			
	> 450	12	10	n.s.			
4	0-75	9	7	*	4	3	n.s.
	75-280	84	78	**	51	46	*
	280-450	5	12	**	34	33	n.s.
	> 450	2	3	*	11	18	**
5	0-75	19	13	*	3	5	n.s.
	75-280	80	80	n.s.	53	59	*
	280-450	1	6	*	33	28	*
	> 450	0	1	n.s.	11	8	**
6	0-75	11	7	**			
	75-280	69	64	*	n.a.	n.a.	n.a.
	280-450	18	24	*			
	> 450	2	5	*			
7	0-75	3	3	n.s.	1	2	n.s.
	75-280	83	73	*	32	35	n.s.
	280-450	11	19	*	41	43	n.s.
	> 450	3	5	n.s.	26	20	n.s.
8[B]	0-75	5	5	n.s.	1	3	n.s.
	75-280	75	66	*	37	40	n.s.
	280-450	15	18	n.s.	32	35	n.s.
	> 450	5	11	*	30	22	*
9	0-75	4	4	n.s.	2	1	n.s.
	75-280	83	81	n.s.	41	38	n.s.
	280-450	12	12	n.s.	39	44	*
	> 450	1	3	n.s.	18	17	n.s.
10	0-75	8	8	n.s.	3	2	n.s.
	75-280	79	71	*	45	41	n.s.
	280-450	10	17	**	33	33	n.s.
	> 450	3	4	n.s.	19	24	**
11	0-75	16	12	*			
	75-280	79	77	n.s.	n.a.	n.a.	n.a.
	280-450	4	10	**			
	> 450	1	1	n.s.			
12	0-75	6	7	n.s.	3	4	n.s.
	75-280	59	64	n.s.	33	36	n.s.
	280-450	20	20	n.s.	24	23	n.s.
	> 450	15	9	n.s.	40	37	n.s.

[A] 0 = 20 kg P/ha
[B] 0 = 50 kg P/ha
[C] n.s., not significant $P \geq 0.05$
[D] n.a., not available
** $P \leq 0.001$
* $P \leq 0.05$

Table 6. The effect of fertiliser phosphorus on the number of tubers/plant

Responsive, sites where phosphorus fertiliser had a significant ($P \leq 0.05$) effect on the number of tubers/plant; Non-responsive, sites where the effect of phosphorus fertiliser on the number of tubers/plant was not significant ($P \geq 0.05$); P0, 0 kg P/ha; for Kennebec P Max is 120 kg P/ha; for Russet Burbank at sites 1, 2, 4, 9,10 P Max is 475 kg P/ha; at sites 2, 6 P Max is 400 kg P/ha; at sites 5, 7, 8, 12 P Max is 375 kg P/ha; average and range values are for pooled site data.

	Russet Burbank		Kennebec	
	Responsive	**Non-responsive**	**Responsive**	**Non-responsive**
P0 Average	7.3	8.9	2.95	3.9
(range)	(4.65 - 9.36)	(8.72 - 9.09)	(2.36 - 3.99)	(3.8 - 4.2)
P Max Average	10.7	9.7	5.2	4.4
(range)	(7.9 - 13.6)	(9.21 - 10.1)	(4.87 - 5.67)	(3.98 - 5.08)

Table 7. The effect of phosphorus fertiliser on tuber specific gravity

P max, for sites 1, 2, 4, 9 and 10 P max is 475 kg P/ha; for sites 5, 7, 8 and 12 P max is 375 kg P/ha for site 3 P max is 400 kg P/ha; for site 6 P max is 180 kg P/ha.

Site	Olsen P	Russet Burbank			Kennebec		
		0 (kg P/ha)	P Max	Signif.	0 (kg P/ha)	120 (kg P/ha)	Signif.
1	5	1.092	1.085	**	1.080	1.079	n.s.
2	9	1.087	1.090	*	1.079	1.082	n.s.
3	9	1.092	1.089	*	n.a.[B]	n.a.	n.a.
4	17	1.090	1.088	*	1.084	1.084	n.s.
5	18	1.084	1.080	*	1.076	1.075	n.s.
6	22	1.082	1.080	*	n.a.	n.a.	n.a.
7	27	1.084	1.083	n.s.[A]	1.076	1.078	n.s.
8	30	1.089	1.089	n.s.	1.081	1.080	n.s.
9	30	1.086	1.083	*	1.076	1.076	n.s.
10	36	1.086	1.087	n.s.	1.075	1.071	*
11	40	1.080	1.080	n.s.	n.a.	n.a.	n.a.
12	46	1.086	1.084	n.s.	1.075	1.077	n.s.

* $P \leq 0.05$
** $P \leq 0.001$

[A] n.s., not significant $P \geq 0.05$
[B] n.a., not available

Table 8. Critical nutrient ranges for phosphorus in the P-YFEL of Russet Burbank potatoes

Tuber length, is the average length of the longest tuber; critical nutrient ranges, are values of 90 and 95 % respectively from the mitscherlich model fitted to relative total tuber yield and total phosphorus.

Tuber length (mm)	Critical nutrient range (%)
Hook	0.43 - 0.52
5 - 10	0.45 - 0.57
35 - 45	0.35 - 0.47
75 - 85	0.21 - 0.26