Fertiliser responses in potatoes – an overview of past Ravensdown research

MD Craighead[1] and RJ Martin[2]

Ravensdown Fertiliser Co-operative Ltd, PO Box 1049, Christchurch
[1](current address: Nutrient Solutions Ltd, 19 Aynsley Tce, Christchurch)
[2]New Zealand Institute for Crop & Food Research Ltd, Private Bag 4704, Christchurch, Canterbury

Abstract

The effect of N, P and K fertilisers on fresh yield, bruising and tuber dry matter (or specific gravity) of seed or main crop potatoes was examined over 20 years in a series of trials, 2 at Pukekohe and 13 in Canterbury. Trials on seed crops showed no significant effect of N or K on yield or internal bruising. Main crop potato yield responses to K bore no relation to soil exchangeable K levels. Potassium applied as KCl increased yield but reduced tuber dry matter content compared to K applied as K_2SO_4. Nitrogen generally increased main crop and winter potato yields up to an optimum rate but often reduced tuber dry matter. Foliar N had no effect on yield.

Additional key words: potassium, potassium form, nitrogen, phosphorus, seed potatoes, crisp potatoes, fry potatoes, internal bruising, quality, dry matter, specific gravity, leaching

Introduction

Potatoes are an important part of the New Zealand diet and an increasing proportion are grown for processing into potato crisps and French fries as consumer demands change (Lammerink, 1989). Market premiums also exist for early season and winter potatoes, and in Canterbury for seed potatoes. While growers want reasonable yields, each market has particular requirements for size, shape, colour and process quality (Genet, 1992) and so a large variety of local and imported cultivars are grown to meet these market requirements. Depending on the type of market and cultivar, potato marketers often suggest different management practices, many of which are based on overseas knowledge. However, New Zealand's soil and climatic conditions and crop rotations are unique and some local adjustments to overseas 'recipe' approaches are necessary.

A potato crop has been variously quoted as removing approximately 3-5 kg nitrogen (N), 0.4-0.8 kg phosphorus (P) and 4-6 kg potassium (K)/tonne of tubers (Allison *et al.*, 1999; Perrenoud, 1983). Yields range from 15-50 t/ha for early season and seed potatoes to 40-80 t/ha for table and process potatoes, hence there is a large variation in the nutrient demands of each crop. Fertiliser practices need constant adjustment to take into account soil reserves of nutrients and how efficiently nutrients are utilised. This paper reports on some of the fertiliser trials undertaken by Ravensdown staff since 1982/83 in an attempt to keep abreast of the nutrient requirements of new cultivars and specific markets.

Methods

Seed potato trials (S)

Five seed potato trials (Seed 1-5) were undertaken in Mid Canterbury primarily to look at the effect of fertilisers on the internal bruising of tubers. In two of these trials (S4 and 5) yield was also measured. Treatments included rates of K (all trials), form of K (S2), extra N (S3 and 5) and different NPK fertilisers (S4). One K trial (S1) included K in the presence and absence of iron (Fe). Site and treatment details are given in Table 1. The trials were all harvested commercially using the same potato harvester.

All trials were replicated, however in Seed 1-3 an equal number of tubers were taken from each replicate and bulked for bruising. In these trials the readings were repeated using two sizes of tuber, the smaller <85 g, the larger 85-140 g, i.e. the intermediate grades of tubers.

Main crop and winter potato trials (P & W)

Seven irrigated trials (Process 1-7) were carried out on stony soils at Seadown and Levels Plain in South Canterbury. These investigated the effects of rates of N (P1, P3, P6, P7), forms of N (P1, P6), rate of K (P3, P7), form of K (P1-3), and rate of P (P5-7) on main crop potatoes for the crisp and fry process markets. Three other trials, at Lincoln (P8) and Pukekohe, winter potatoes (W1 and 2), investigated the effect of rate and timing of N fertilisers on potato yield and quality. The first two trials (P1 and 2) were harvested using a commercial harvester, the remainder were harvested using a potato lifter and/or hand harvested. Site conditions and experimental details are given in Table 1.

All Canterbury trials were on Recent and Yellow Grey Earths (or Pallic soils), and the soils at Pukekohe were Brown Granular Loams (or Granular soils), (Hewitt 1992). All Canterbury process trials were irrigated to prevent moisture stress. The Pukekohe trials, under a higher rainfall climate, and the seed trials under adequate rainfall were not irrigated.

Crop husbandry

All trials were replicated (S4 twice, the remainder 3 or 4 times). Most involved plots consisting of at least four rows in width with the edge rows usually not sampled. Plots were a minimum of 10 m but more often 20 m long and in some instances used the full length of a paddock, c. 100-300 m long. Fertiliser treatments were applied and crops managed in a manner as close as possible to grower practice. Where trials involved planter fertiliser treatments these were applied through the planter (S4-5, P1-2, 5-6), otherwise planter treatments were applied on the furrow at planting and mounded in.

Measurements

Measurements included the fresh yield of tubers (the harvested yield after rejects such as rotten and undersize tubers are removed), which where applicable was split into process (crisp/fry), and seed and table grades (seed grade 28-112 g tubers, table >112 g). In trials S1-5, P2 and 3, bruising grade was calculated by the falling bolt technique from bruising depth (mm) x intensity of bruising (grade 0-5), 24 hours after a 150 g steel rod was dropped on the stem end of the tuber from 300mm height. The score typically ranges from 0 (low) to 40 (high). In all main crop (process) trials, tuber quality was assessed after harvest by determining the specific gravity (SG) of a representative number of tubers (specific gravity being the difference in the suspended weight of tubers between air and water), ideally processors desire SG > 1.081. In the two winter potato trials (W1-2) the dry matter (DM) % was used instead of specific gravity as the quality measure, calculated after the oven drying of tubers, ideally DM >20.4%. In two process trials, P1 and 2, dry matter of tubers was also remeasured after 8 months storage in chillers at Bluebird Food Ltd., Timaru. Soil and drainage water N concentrations were also measured using soil solution nitrate samplers in the two Pukekohe trials (W1 and 2).

Results

Internal bruising (Blackspot)

In the seed trials (S1-5), bruising was very low (mean 4.2) and did not differ greatly between sites (range 2.1-7.0). Potassium form and rate, Fe, N rate and P rate had no significant ($p<0.05$) effect on internal bruising. On three sites (S1-3) where internal bruising was measured on two different size tubers, small and medium size tubers, there was little difference between the two size tubers, 3.9 vs 4.2 respectively.

In process trials P2 and 3, internal bruising was uniformly higher (mean 13.7) than in the seed grade trials and the range was greater (9.0-21.0). Fertiliser treatments had no significant or meaningful impact on internal bruising. However in one trial (P2) large (>170 g) and medium (112-170 g) tubers were isolated and larger tubers had significantly more bruising, 17.4 vs 12, $p<0.001$, (data not presented).

Potassium (2a K rate)

There was no effect of applying up to 100 kg K/ha on seed potato tuber yield in S4 and 5 (Table 3).

In one paddock used for process trials P1 and 2, there appeared little yield difference between 53 and 210 kg K/ha (Table 5). For process potatoes (P3), applying 210 kg K/ha increased total and process grade yield, but slightly decreased tuber specific gravity ($p<0.05$) irrespective of K fertiliser form (Table 4). 280 kg K/ha did not further increase yield. Russet Burbank potatoes (P7) also showed no significant yield response to applying 430 kg K/ha compared to 210 kg K/ha, 59.9 and 57.5 t/ha respectively.

Potassium (2b K form)

Potassium chloride gave 11% higher yields than K_2SO_4 in process trials P2 and 3 (significant at 10% and 5% respectively) but slightly reduced tuber specific gravity especially in P3, $p<0.05$, (Tables 4 and 5). In P2 there was a significant linear increase in yield (from 58 to 64 t/ha) and decrease in tuber specific gravity as KCl was substituted for K_2SO_4 at a constant application rate of 210 kg K/ha (Table 5). Internal bruising score tended to decline with increasing chloride, but the trend was not linear. Where sulphate and chloride treatments were in adjacent rows it was noted that chloride treated plants had longer stem length (data not presented).

Table 1. Site conditions for 15 seed and process potato trials in Canterbury and South Auckland.

Trial	Cultivar	Season	Soil Type	Region[2]	Treatments kg/ha	Other Fertiliser kg/ha	Soil Olsen P	Soil QTK	Crop History
Seed 1 (S1)	Iwa	1982/83	Mayfield silt loam	Ashburton Methven	0, 50, 100, 150kgK +/- Fe	60kgN, 50kgP	10	15	Ex 2yr wheat
Seed 2[1] (S2)	Iwa	1982/83	Mayfield silt loam	Ashburton Methven	0, 50, 100kgK as SO_4 or Cl	60kgN, 50kgP	10	15	Ex 2yr wheat
Seed 3[1] (S3)	Rua	1982/83	Mayfield silt loam	Ashburton Methven	0, 50, 100kgN or 0, 50, 100kgK	50kgP with 50kgN (K treats) or 50kgK (N treats)	14	4	Ex barley
Seed 4 (S4)	Iwa	1983/84	Waimakariri silt loam	Ashburton Methven	9 NPK fertilisers (30-56kgN, 0-75kgK)	37kgP	16	5	Ex pasture
Seed 5 (S5)	Ilam Hardy	1984/85	Barrhill sandy loam	Barrhill	48 or 68kgN, 95 or 145kgK	49kgP	13	5 (TBK 2.2)	Ex crop
Process 1 (P1)	Ilam Hardy	1992/93	Lismore stony silt loam	Seadown	70kgNat planting using MAP or 120kgN at planting using DAP with K as Cl or SO_4 (72 vs 122kgN, 54-66kgP, 50-56kgK)	Extra 86kgN applied in two sidedressings	28	7	Ex greenfeed, broad beans
Process 2 (P2)	Ilam Hardy	1992/93	Lismore stony silt loam	Seadown	210kgK as Cl or SO_4 split 0/210, 70/140, 140/70, 210/0	176kgN, 66kgP	28	7	Ex greenfeed, broad beans
Process 3[1] (P3)	Fianna	1993/94	Lismore stony silt loam	Seadown	0, 70, 140, 210, 280kgK as Cl or SO_4	238kgN, 68kgP	20	5	Ex wheat
Process 4[1] (P4)	Fianna	1993/94	Lismore stony silt loam	Seadown	Extra 0 or 50kgN at planting, extra 0, 50 or 100kgN day35	86kgN at planting, 40kg day 70, 68kgP	20	5	Ex wheat
Process 5[1] (P5)	Agria	1996/97	Lismore stony silt loam	Seadown	0 or 25kgMg, 0 or 49kgNa (results not mentioned), 84 or 124kgP	266kgN, 147kgK	29	10	Ex crop
Process 6[1] (P6)	Kennebec	1996/97	Lismore stony silt loam	Seadown	240 and 290kgN, 84 and 124kgP, additional N applied as CAN or Urea	147 kgK	29	10	Ex crop
Process 7 (P7)	Russet Burbank	1997/98	Lismore stony silt loam	Levels	266 or 331kgN, 80 or 112kgP, 210 or 437kgK, 2 alternative NPK inputs (results not mentioned)		38	8	Ex onions
Process 8 (P8)	Russet Burbank	1999/00	Templeton silt loam	Lincoln	0, 150, 300kgN, plus split N as early solid, and later foliar forms	150kgP, 250kgK	28	17	Ex barley, ex pasture
Winter 1 (W1)	Ilam Hardy	2000	Patamahoe clay loam	Pukekohe	0, 252, 350, 472kgN plus 1 foliar treatment at 350kgN	200kgP, 175kgK, 67kgMg	159	30	Ex greenfeed and potatoes
Winter 2 (W2)	Ilam Hardy	2001	Patamahoe clay loam	Pukekohe	0, 80, 160, 240, 480kgN	200kgP, 175kgK, 67kgMg	187	31	Ex greenfeed and potatoes

[1] Seed 2 and 3 in same paddock as were process 3 and 4 and process 5 and 6 – all trials were separate from each other but in a similar part of the paddock
[2] Seed trials in Mid Canterbury, Process trials in South Canterbury bar P8 (Central Canterbury), Winter trials in South Auckland

Table 2. Response to nitrogen fertiliser at planting in two seed potato trials in Mid Canterbury, 1983/84 and 1984/85.

	N used kg/ha	Seed t/ha	Tuber Yield Table t/ha	Total t/ha
Seed 4 – treatments where N isolated from K effects				
Nitrophoska 12-10-10	45	19.6	12.4	32.1
Cropmaster 15-10-10	56	18.2	13.1	31.3
Ammophos 12-10-10	45	17.1	12.7	29.8
DAP/K_2SO_4 12-13-13	30	14.7	11.3	25.9
Cropmaster 13-14-15	32	14.8	9.9	24.8
$LSD_{5\%, 4df}$		n.s.	n.s.	n.s.
Seed 5 – N effects only				
Base	28	18.5	3.9	22.4
+ 20kgN	48	18.2	4.4	22.7
+ 40kgN	68	18.1	5.2	23.3
$LSD_{5\%, 6df}$		n.s.	n.s.	n.s.
Linear trend		$p<0.05$	$p<0.05$	n.s.

Table 3. Effect of potassium on tuber yield of two seed potato trials in mid Canterbury.

	Seed 4 – 1983/84, soil QTK 5			Seed 5 – 1984/85, soil QTK 5	
	Seed yield t/ha	Total yield t/ha		Seed yield t/ha	Total yield t/ha
No K	15.51	25.85	45kgK	18.47	22.36
19kgK	17.50	28.97	95kgK	18.39	22.02
37kgK	14.66	25.94	145kgK	18.60	22.56
$LSD_{5\%, 2df}$	n.s.	n.s.	$LSD_{5\%, 6df}$	n.s.	n.s.

Table 4. Forms and rates of potassium on the total and process grade yield and tuber specific gravity of Fianna potatoes (P3), Seadown , 1993/94.

Trial Process 3	Total Tuber Yield t/ha	Process Grade Yield t/ha	Process Grade Specific Gravity
Rate of K			
Nil K	74.4	65.9	1.097
70kg K	74.7	65.9	1.095
140kg K	75.4	66.4	1.096
210kg K	81.1	72.8	1.095
280kg K	79.8	71.4	1.095
$LSD_{5\%, 12df}$ nil vs K	5.06	5.41	0.0015
$LSD_{5\%, 21df}$ K rate	5.02	4.87	0.0017
Form of K			
K_2SO_4	75.6	66.8	1.097
KCl	79.9	71.4	1.094
$LSD_{5\%, 21df}$	3.55	3.44	0.0012
Significance of Interaction Form x Rate	n.s.	n.s.	n.s.

Table 5. Effect of the form of basal potassium fertiliser used on 'Ilam Hardy' potatoes on tuber yield and quality at Seadown, 1992/93.

	Total Yield t/ha	Oversize Yield t/ha	Crisp Grade Tubers: Crisp yield t/ha	Specific Gravity	Bruising Score
Process 1					
53kgK as K_2SO_4	59.7	3.9	50.5	1.089	21.0
53kgK as KCl	62.5	4.6	52.2	1.087	19.8
$LSD_{5\%, 7df}$	2.76	n.s.	1.60	n.s.	n.s.
Process 2					
0KCl / $210K_2SO_4$	58.0	4.5	49.1	1.091	20.7
70KCl / $140K_2SO_4$	59.0	5.1	50.0	1.082	18.4
140KCl / $70K_2SO_4$	61.5	5.6	52.0	1.084	19.7
210KCl / $0K_2SO4$	63.7	5.6	52.6	1.081	19.3
$LSD_{5\%, 6df}$	5.60	*	n.s.	0.0065	1.04
Linear trend[1]	*	*	**	**	n.s.

[1] n.s. indicates not significant, * >0.05 p <0.1, **p<0.05, linear trend as KCl transposed for K_2SO

Table 6. Main nitrogen1 effects on market yield and specific gravity of five Process grade potato trials in Canterbury.

Crisp/Small Fry Potato Trials									Large Fry Potato Trials					
Process 1 - Ilam Hardy 1992/93			Process 4 – Fianna 1993/94			Process 6 Kennebec 1996/97			Process 7 – Russet Burbank 1997/98			Process 8 – Russet Burbank 1999/00		
N kg/ha	Yield t/ha	SG	N kg/ha	Yield t/ha	SG	N kg/ha	Yield t/ha	SG	N kg/ha	Yield t/ha	SG	N kg/ha	Yield t/ha	SG
	--	--		--	--		--	--		--	--	0	59.4	1.099
160	50.3	1.089	151	72.2	1.089		--	--		--	--	150	73.0	1.088
210	52.4	1.087	201	74.1	1.091		--	--		--	--		--	--
	--	--		--	--	242	50.6	1.072	236	51.9	1.075		--	--
	--	--	251	76.0	1.089		--	--	266	53.6	1.074		--	--
	--	--		--	--	292	50.4	1.072	307	55.4	1.075	300	79.3	1.086
	--	--		--	--		--	--	331	59.9	1.075		--	--
$LSD_{5\%}$	1.6	n.s.		3.6	n.s.		n.s.	n.s.		5.6	n.s.		4.2	0.0038
Linear trend	--	--		p<0.05	n.s.		--	--		p<0.05	n.s.		--	--

[1]N applied as extra planter N in Process 1, extra sidedressing N in Process 4, 6, 7, extra moulding N in Process 8_4

Table 7. Total and market tuber yield, dry matter and total nitrogen leached in two 'Ilam Hardy' winter potato trials, Pukekohe, 2000, 2001.

	Total Yield t/ha		Market Yield t/ha		% DM		Total N leached kg N/ha	
kgN/ha	**2000**	**2001**	**2000**	**2001**	**2000**	**2001**	**2000**	**2001**
0	12.7	16.0	7.2	8.5	19.4	23.4	81.9	24.6
80	--	31.1	--	25.3	--	22.9	--	33.3
160	--	43.3	--	38.1	--	21.6	--	47.8
240	28.5	48.0	24.1	44.1	18.0	20.8	167.0	54.5
350	29.7	--	23.9	--	18.0	--	219.4	--
480	30.0	50.4	25.0	46.8	18.0	20.0	207.8	134.6
p	<0.001	<0.001	<0.001	<0.001	0.007	<0.001	0.006	<0.001
$LSD_{5\%}$	4.46	3.24	5.74	3.63	0.82	0.67	68.9	21.22
df_{error}	9	20	9	20	9	20	9	20

Table 8. Response to extra phosphate on potatoes in three South Canterbury trials.

Trial	Cultivar	Soil Olsen P µg/ml	Treatment Comparison	Yield at 84 kg P/ha t/ha	Yield at higher P rate t/ha
Process 5	Agria	29	84kg vs 124kgP	74.3	78.5
Process 6	Kennebec	29	84kg vs 124kgP	53.7	59.9
Process 7	Russet Burbank	38	80kg vs 112kgP	53.7	55.7
			Mean	60.5	64.7
			$LSD_{10\%, 2df}$	3.47	

In two trials, P1 and 2 after storage of tubers in chillers for 8 months the form of K did not consistently alter the result (data not presented) nor did dry matter content significantly change (P1 mean after storage 20.8 vs mean after harvest 21.4, P2 mean 20.4 vs 20.7% DM).

Nitrogen

In seed trials S4 and 5, where the effect of additional planter N fertiliser could be isolated from other nutrient effects, the use of up to 40 kg N/ha on seed yield was minimal (Table 2). However there was a tendency for more N to increase total yield.

In process trials in Canterbury, there was a significant ($p<0.05$) response to increasing N fertiliser rates up to over 200 kg N/ha in all trials (P1, P4, P7 and P8) except one (P6), (Table 6). Addition of N fertiliser up to approximately 150 kg N/ha significantly reduced tuber specific gravity at Lincoln (P8), but higher applications used at other sites did not reduce specific gravity further (Table 6).

At Pukekohe (W1 and W2), N increased yield but also increased the amount of N leached from the soil and decreased tuber dry matter content (Table 7). Yields did not increase at N rates higher than 160-240 kg N/ha. In W2, yield and tuber dry matter were similar irrespective of whether 80, 160 or 240 kg N/ha was split two thirds at planting and one third at emergence or visa versa (data not presented).

In two trials (P8 and W1) there was no yield or quality benefit in applying some of the N as foliar N instead of solid N fertilisers (P8 – solid N split applied 73.4 t/ha, foliar N split applied 74.5 t/ha, both significantly less ($p<0.05$) than applying all N by moulding 79.3 t/ha; W1 – at 350 kg N/ha applied, solid N 29.7 t/ha, some foliar N 27.8 t/ha, 18.0 and 18.3% DM respectively).

Phosphate

In three separate trials (P5-7), with Olsen P levels of 29-38 µg/ml, there was a 7% yield increase, ($p<0.073$) at P fertiliser applications of 112-124 kg P/ha compared to 80-84 kg P/ha (Table 8).

Discussion

Internal bruising

Seed potato treatments aimed at reducing internal bruising concentrated on K as growers considered this may have some influence. In England Rogers-Lewis (1980) found increasing K generally decreased bruising, but while this may be true when using K on soils of low K status, it does not necessarily hold when using K on soils of higher K status (McGarry *et al.*, 1996). Maier *et al.* (1986) also found less bruising at higher K rates on some sites in Australia, particularly when using KCl as opposed to K_2SO_4 and providing the site was K responsive. In New Zealand seed potatoes are grown in the Methven and Sheffield areas on soils of medium-high to high K reserves (Cornforth and Sinclair, 1984). Hence perhaps it is not surprising that K had little influence on bruising in all seed trials, irrespective of the site, cultivar or year.

The greater range in internal bruising observed in the process grade trials may partly reflect seasonal and cultivar differences, and potato growers and scientists (McGarry *et al.*, 1996) have commented on how bruising varies between years. Internal bruising incidence was highest in P1 and 2, which were grown in the stoniest paddock, and where tubers were machine harvested. Physical and mechanical damage are likely to contribute to more bruising (Hodgson *et al.*, 1974; Rogers-Lewis, 1980), as can handling, storage and storage temperatures, although the evidence for storage can be conflicting (McGarry *et al.*, 1996). The higher mean bruising grade in the process trials compared to the seed trials is likely to be an effect of tuber size, as shown by the P2 data. This is in agreement with previous observations by Rogers-Lewis (1980). Larger tubers seem more predisposed to internal bruising, defined as membrane damage, probably as a result of reduced turgor (Hodgson *et al.,* 1974; Hughes, 1980). In P3 the reduction in bruising is likely to be related to a reduction in specific gravity (Table 5), in Britain some cultivars are more predisposed to bruising, particularly high dry matter varieties (Archer, 1988). Chapman *et al.,* (1992) also noted reduced bruising with increasing application of K in Tasmania but only on some sites. Work in England and the Netherlands has shown that internal bruising is lower in tubers of >2.5% K and large applications of KCl will both decrease tuber dry matter and increase tuber K content (Archer, 1988). Nitrogen is also known to reduce tuber dry matter (Martin, 1995) also probably indirectly leading to reduced bruising.

Potassium

Potassium is required to both maximise yield and in very deficient situations to improve quality, however high rates (Chapman *et al.,* 1992; Panique *et al.,* 1997) will reduce tuber specific gravity. High rates of K may reduce yield, in England yield decreases are common >250 kg K/ha (Archer, 1988), although in USA this only occurred above 280 kg K/ha if K_2SO_4 rather than KCl was used (Panique *et al.,* 1997).

In the early 1980's, when the seed potato trials (S1-5) were undertaken, planter fertiliser application rates used by growers (typically 35-70 kg K/ha) were much less than the amount removed by a crop (90-170 kg K/ha). Yet there was a lack of yield response to K treatments where yield was measured, despite the low soil QTK values.

Similarly in the main crop (crisp/fry grade) potatoes K responses were maximised at levels much lower than crop removal, (a 60 t/ha crop could remove at least 260 kg K/ha, Chapman *et al.,* 1992; Loue in Perrenoud 1983). 210 kg K/ha seemed adequate for a 75 t/ha Fianna crop at soil QTK 5 (P3) and 210 kg K/ha gave a similar yield for Russet Burbank to 437 kg K/ha on a soil of QTK 8 (P7). On a 60 t/ha Ilam Hardy crop (P2) even 53 kg K/ha may have been adequate (soil QTK 7).

This emphasises the high reserves of K in most arable Canterbury soils are contributing significantly to the crops demands. A soil QTK of 5-6 is below the suggested optimum for potatoes in New Zealand of 12-20 (Clarke *et al.,* 1986). It may be more applicable to use soil tests which take more into account the K reserves of the soil. The tetraphenylboron (TBK) test of Jackson (1985) can be used on sedimentary but not allophanic soils. This is currently being improved (Carey and Metherell 2003) so this may assist in modifying K recommendations. Based on the above results and taking into account typical crop removal values it would appear the soils used in the seed and process trials are supplying in excess of 100 kg K/ha. All process trials involving K were on Lismore soils and Winchmore Research Station data for this soil suggests >100 kg K/ha is released annually under pasture (Metherell, pers. comm.).

In a review of potato responses to K fertilisers in the UK, Allison *et al.* (2001) showed that soil exchangeable K was a poor predictor of the probability of a yield increase, and that the optimal K application is rarely >170-210 kg K/ha, even on soils with <than 120 mg exchangeable K/litre. A QTK of 5-6 on Canterbury soils approximates 100-120 mg K/litre on a volume or 110-130 mg/kg of soil on a weight basis, (by ammonium acetate extraction). Allison *et al.* (2001) suggest that the release of K in the soil may be related to management practices such as cultivar choice and irrigation practice, and consider this an area requiring further research. In Tasmania, Chapman *et al.* (1992) found fertiliser K responses on soils of up to 300-400 mg/kg of bicarbonate extractable K, although the critical K level has been set at 150 mg/kg (Sparrow pers. comm.). In the USA, in Wisconsin, Panique *et al.* (1997) found K responses unlikely at soil values >125 mg K/kg of soil (unknown method), although they acknowledge other critical values in USA vary with region and laboratory methods for example from 88 mg K/kg (by the Bray P_1 method) in Wisconsin to 200 mg K/kg (bicarbonate extractable K) in Washington State, both on sandy soils.

From a yield perspective it is desirable to use KCl and this is still the major source of K used in Australia and New Zealand (Maier, 1986; Murdoch pers. comm.). Perrenoud (1983) found more sets of experimental results favouring yield benefits from chloride over sulphate, particularly at K rates up to 165 kg K/ha. Above this rate of K, yield reductions were generally the case. Conversely American studies have suggested the sulphate form can be favoured for yield as well as quality (Panique *et a.l* 1997) at least up to 280 kg

K/ha, although other US studies have not found consistent yield differences between KCl and K_2SO_4. Soil nutrient loadings may play a role here. In New Zealand soils, particularly in Canterbury process grade potatoes are grown on free draining soils under irrigation, and so are less likely to have high background nutrient loadings (which contribute to soil solution conductivity). This means more K in the chloride form could be used before switching to sulphate to maintain tuber quality. The observation that chloride treatments generate longer stems than sulphate treatments has also been noted by Panique *et a,.* (1997).

Potassium sulphate produced higher tuber dry matter than KCl at equivalent rates of K, in agreement with Panique *et al.* (1997) and Perrenoud (1983). While this may be a reflection of the reasonably high K application rates used in these trials, Allison *et al.* (2001) found in Britain that KCl only reduced tuber dry matter content when the optimal K application rate was exceeded, Archer (1988) suggested you could expect up to 1% lower dry matter when using KCl at normal application rates. There appeared little effect of the form of K on tuber dry matter content following storage (trials P2 and 3), perhaps because results were quite variable. Work by SCPA (1997) would suggest tubers grown using K_2SO_4 retain higher dry matter than those grown using KCl. If a minimum quality standard has to be met, the best compromise would be to use a mixture of both K forms, but as the amount of K required increases, use more in the sulphate form. However, it is difficult to make reliable recommendations about the form of K fertiliser to use until K application rates are sorted out. Currently economics determine the form of K fertiliser used, as K_2SO_4 is more than twice as expensive as KCl.

Nitrogen

Seed potatoes

In the seed trials it was difficult to isolate responses to a small amount of additional N. Nitrogen inputs are deliberately low, as surplus N was considered to increase tuber size rather than number (Archer, 1988), downgrading the crops value and necessitating spraying to desiccate the crop prior to harvest. In S5, where the paddock had been previously cropped, more than 28 kg N/ha tended to increase table yield at the expense of seed yield effectively reducing the crop's economic value. However in S4 which followed pasture, 45 kg N/ha seemed slightly better than 30-32 kg N/ha without sizing tubers at the expense of seed yield. While there was some slight difference in the formulation of the fertilisers that may have affected the release of P in particular, the higher N treatments had either similar or lower water soluble P than the low N treatments. Early work (Smith, 1977) suggests lower water soluble P may be beneficial, although Archer (1988) considers it important to use fertilisers containing higher water soluble P. Hence, it is more likely the N effect is real. Further in S4, it is likely that there would be a delay in mineralisation of the pasture N incorporated during cultivation and so the crop could be temporarily short of N, thus affecting tuber set. This result highlights the importance of modifying recommendations to take account of crop history and soil husbandry.

Main crop (process) potatoes

Yield responses to N fall into two categories, those for mid season crisp/small fry process potatoes (P1-6) and those for large fries (P7-8). In the crisp grade process trials, (all at Seadown), yields increased up to 210-250 kg N/ha. It is uncommon in England to get responses to N above 250 kg N/ha (Archer 1988). Yield differences between trials may partly relate to seasonal differences and when the crop was actually harvested (although all crops were taken to maturity, Agria matures faster than Fianna while Russet Burbank is a late maturing variety). Also cultivars such as Fianna (P3 and 4) produced larger tubers than Ilam Hardy and Kennebec, and gave higher yields than Agria grown in the same paddock in the same year, suggesting they are also more efficient at utilising N than other cultivars. Different responses to N between cultivars has previously been noted in New Zealand (Mountier and Lucas, 1981). Paddock N status may account for some yield difference between trials, although historically at Seadown there is little difference between the paddocks used. Topsoils usually only contribute 40-80 kg N/ha (with an additional 20-30 kg expected from the subsoil).

In both Russet Burbank trials the highest N rate (>300 kg N/ha) gave the highest yield. Russet Burbank is likely to require more N than other potato cultivars because they are long season potatoes and so are in the ground longer than most other cultivars. Hence they need to maintain a green canopy for longer if they are to size tubers. The large response to 331 kg N/ha in trial P7 (Table 6) may be confounded by timing as it received its extra N by receiving a later N application (and 4 rather than 3 side dressings). At Lincoln (P8) the best treatments applied all N by moulding, of which at least 50% was at planting (Martin *et al.*, 2001a). This is generally the recommendation used in England (Archer, 1988) although on lighter soils under irrigation some N could be slightly deferred as could the last (and extra) N application on Russet Burbank potatoes. Appropriate monitoring techniques such as petiole nitrate measurements may help with this decision (Martin *et al.*, 2001a). Although high rates of N will reduce tuber dry matter content (Perrenoud, 1983; Martin, 1995) this was only evident for Russet Burbank at Lincoln (P8), the only trial with a nil control. The other 2 Russet Burbank trials provided at least 150 kg N/ha as their lowest rate and it is possible that the greatest impact of N on quality is at low rates of N.

Winter potatoes

On winter potatoes at Pukekohe, growers use high rates of N (>400 kg N/ha). This is much higher than would be expected from crop removal (Martin *et al.*, 2001b), even allowing for much poorer efficiency of utilisation during the winter. In both years yield was maximised by at the most 240 kg N/ha. Additional N reduced tuber dry matter, but as the winter market is predominantly for table consumption, this aspect of quality is less important than it is for process crops. The greatest concern with additional N is the increased risk of N leaching. While leaching approximately doubled when using 240 kg N/ha compared to no fertiliser, this rate was still much lower than current grower practice (Martin *et al.*, 2001b). Rainfall had a significant impact on leaching. Leaching was much higher in 2000 than in 2001 as the winter was wetter, however the crop was also planted a month earlier and the site was subject to higher rainfall events early in the winter.

In the two trials, which included foliar N sprays, only a small portion was applied as foliar N. Only 16kg of 350 kg N/ha applied at Pukekohe (Martin *et al.*, 2001b), and either 25 kg N of 150 kg N/ha (split twice) or 112.5 kg N of 300 kg N/ha (applied as 9 applications) at Lincoln (Martin *et al.*, 2001a). Hence the lack of response to foliar N in these two trials is not surprising. Most N had to be applied before tuber initiation to get high yields (P8), when insufficient foliage is present to justify foliar applications. Growers are interested in foliar sprays because they can be added with regular copper sprays for blight control. However, weekly applications of foliar N at 12.5 kg N/ha at Lincoln caused considerable leaf scorch. Therefore, foliar fertilisers are unlikely to contribute to main crop potato yields, but could have a role if small amounts of additional N are required on some seed potato crops.

Phosphorus

In the three crisp/fry grade trials where additional P was involved all three gave a slight response to the additional P, despite the high soil Olsen P values (>29). The 7% response to P is economic as the additional cost of P equates to only $70-85 worth of superphosphate. In England, P responses have been observed over a wide range of soil P status sites, but as the response curve is fairly flat it is difficult to give optimal rates, except that it lies somewhere between 87-175 kg P/ha (Archer, 1988). Tubers remove only a small amount of P, approx 0.5 kg P/t (Perrenoud, 1983) despite the high rates of P recommended. Phosphorus utilisation from fertiliser did not exceed 30% and was generally much lower (Smith, 1977). Russet Burbank potatoes were the most responsive of the three cultivars used and this could be related to a less prolific root system (phosphorus aids root development as well as starch phosphorylation in potatoes) and in turn poorer set. Growers prefer to set only 8-10 tubers/plant in order to size tubers for the large fry market, this compares with the 10-15 tubers often set for other main cropping potatoes.

Conclusions

1. Internal bruising was largely independent of fertiliser. However, large tubers were more prone to bruising than small tubers and so internal bruising was lower in seed trials compared to process crop trials.
2. Potassium had no yield effect on seed potatoes despite low soil QTK values. Maximum yield responses on process crop potatoes were no more than 210 kg K/ha due to high soil K reserves. However, potassium chloride significantly increased yield over potassium sulphate but at the expense of lower specific gravity. A mixture of both sources of potassium is suggested with the proportion changing as the potassium requirement increases.
3. Seed potatoes may respond to some N (30-50 kg N/ha) at planting without necessarily increasing total yield through affecting tuber sizing. Crop history and husbandry also

need to be considered. Further work may be justified in this area.

4. Main crop potatoes on cropped soils respond to 200-250 kg N/ha but long season main crop potatoes may require 300 kg N/ha or more. Ideally the extra N should be applied as an extra sidedressing.
5. Foliar N fertiliser treatments did not alter yield.
6. On winter potatoes 160-240 kg N/ha maximised yield with minimal increase in N leached. Pukekohe growers could significantly reduce N inputs to their crops.
7. There was a slight response to increasing P on main crop potatoes above 80-85 kg P/ha despite high Olsen soil P values (>29 µg/ml), particularly on Russet Burbank potatoes. Further work may be useful at higher rates, especially on long season potatoes.

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