Phosphorus Management for Irrigated Potato Production in Manitoba (A04516)

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Background

In 2001-02, Manitoba produced an estimated 12.8 million cwt of processing potatoes valued at $97.3 million. While phosphorus is routinely applied to most potato fields in Manitoba, much of the research regarding potato responses to P in Manitoba was conducted in the 1960's. More recently, Geisel (1995) and Tomasiewicz (1994) conducted field trials to assess P response in irrigated potato. In five field trials conducted from 1991 through 1994, Geisel (1995) reported significant yield increases with P application in two of five trials, with yield increases evident only where soil test P levels were less than 40 lbs acre^{-1} (45 kg ha^{-1}). In a one-year study, Tomasiewicz (1994) found no effect of P application on potato yield or quality for a site that, based on the soil test P level, would have been expected to respond to P fertilization most of the time.

Objective

The objective of this study is to determine the effect of P fertilizer rate in the form of broadcast incorporated monoammonium phosphate on tuber yield and quality, petiole P concentration, and post-harvest soil extractable-P levels for irrigated processing potato.

Materials and Methods

Four field experiments were conducted in Manitoba from 2003 through 2006 to assess the impact of P fertilizer rate on irrigated Russet Burbank potato. Field experiments were conducted at the Canada-Manitoba Crop Diversification Centre (CMCDC) near Carberry, MB, and on a producer field near Douglas, MB (Table 1). Sites with low to moderate soil test P level were selected in all years (Table 1).

A randomized complete block design consisting of four replicates of four P fertilizer rates (0, 34, 67, 100 kg P_2O_5 ha^{-1} as monoammonium phosphate) was established. Individual plots were typically 16 m long, and ranged from 6 to 9 rows wide (Table 1).

Blanket applications of nitrogen, potassium and sulphur-containing fertilizers were made as required to ensure nutrients were non-limiting at all sites. Nitrogen applications were adjusted for each P rate to account for N applied in the form of monoammonium phosphate (MAP) in order to ensure that all treatments received equal rates of fertilizer N. All pre-plant fertilizer was banded shallowly using a Great Plains seeder, or surface broadcast, then thoroughly incorporated. In select years, additional N was topdressed and incorporated at hilling.

Potato (cv. Russet Burbank) was planted between late April and late May depending upon the year (Table 1). Pests were effectively managed and irrigation water applied as required for optimum production.

Sampling procedure

In the spring prior to plot establishment, soil samples were collected. Two methods of sampling were used. For detailed sampling, 12 soil cores (0-15 cm) were collected from each replicate using a hand-held probe. For general sampling, 10 soil cores (0-15, 15-30 and 30-60 cm) were collected from each experiment using a mechanized soil probe.

Plant density in the harvest rows of each plot was determined after emergence. Petiole samples were collected at approximately 10 day intervals throughout the growing season from two interior rows within each plot, avoiding the harvest rows (Table 1). Petiole samples were dried, and the total P concentration was determined.

Shortly before tuber harvest, whole plant samples were collected from an approximate 1.5 m length of one row in each plot, and separated into vines, recoverable roots plus stolons and tubers. In 2005 and 2006, all treatments were sampled; in 2004, only the 0 and 100 kg P_2O_5 ha^{-1} treatments were sampled. The dry weight of each component was determined, and the total P concentration was determined.

Potato tubers were harvested in the third week of September (Table 1). Potato tops were not desiccated prior to harvest. Approximately 11-12 m of two interior rows of each plot was harvested, the exact harvest area measured, and tuber yields determined.

Following harvest, a subsample (typically 20-30 kg) of potato tubers from each plot was graded. The number and weight of tubers in five weight classes (<3 oz, 3-6 oz, 6-10 oz, 10-12 oz, >12 oz) was determined in each year. Using a representative subsample of tubers with a diameter >2", specific gravity and the number and weight of tubers affected by greening, rot, and hollow heart/brown centre were determined. Fry color and the occurrence of sugar ends and dark ends were determined on a separate 25-tuber sample. Fry colour, sugar ends and dark ends were determined in 2004, 2005 and 2006. Sugar content was not determined in 2003 due to a problem during storage.

Soil samples were collected from each plot in the fall after final harvest. Two methods of sampling were used: 1)10 cores/plot were collected from the 0-15 cm depth using a hand-held probe; 2) 2 cores/plot were collected from the 0-15, 15-30, and 30-60 cm depth using a mechanized probe. Soil samples were air-dried and ground. Surface samples were extracted with 0.5 M $NaHCO_3$ and the extractable P concentration determined.

An analysis of variance by site was conducted using Proc GLM (SAS Institute Inc. 1999). Data were analyzed as a randomized complete block design with P rate as a fixed effect. The impact of P rate on crop and soil parameters was further assessed using contrasts. P-values ≤ 0.05 were considered statistically significant.

As outlined by Steel and Torrie (1980), transformations of the data were performed prior to analysis of variance for the percent of tubers with a fry colour of 0 or 1 (the square root of 100 minus the measured percentage was analyzed), and for the percent sugar ends or dark ends (the square root of the data was analyzed).

Results and Discussion

Growing season conditions varied among years (Table 2). Cool conditions prevailed throughout the 2004 growing season and, in 2005, precipitation levels were above-normal in the early part of the growing season.

Total tuber yield varied among years, averaging 380, 306, 463 and 422 cwt $acre^{-1}$ in 2003, 2004, 2005 and 2006, respectively (Table 3; Figure 1). The comparatively lower yields obtained in 2004 were likely due, in part, to cooler growing season conditions, which included frost in August.

Yield and Quality

In general, P fertilization appeared to have limited effects on tuber yield and quality although the experimental sites selected typically had low to medium soil test P levels (Table 1), and would have received a recommendation for P fertilizer based on the "Guide to Commercial Potato Production on the Canadian Prairies" (Western Potato Council 2003). Recommendations for banded P fertilizer range from 78 to 101 kg P_2O_5 ha^{-1} for soils testing low in soil P (0-28 kg ha^{-1}), 45 to 78 kg P_2O_5 ha^{-1} for soils testing medium in soil P (28 to 56 kg ha^{-1}) and 11 to 45 kg P_2O_5 ha^{-1} for soils testing high in soil P (56 to 101 kg ha^{-1}). In previous studies in Manitoba, Geisel (1995) found yield responses with P application only where soil test P levels were less than 45 kg ha^{-1}.

Total tuber yield increased linearly with increasing P fertilizer rate only in 2005 (Table 3). Phosphorus rate had no effect on total tuber yield in 2003 and 2006. In 2004, P rate tended ($P=0.07$) to influence total tuber yield. Closer examination of the data revealed that the treatment receiving 34 kg P_2O_5 ha^{-1} had a numerically lower yield than any other treatment, although the reason for this effect is unclear.

In 2005 and 2006, increasing P rate increased marketable yield (Table 3). A significant linear effect was evident in 2005, and a significant quadratic effect was evident in 2006. In both years, spring soil test P levels were low to medium, and average yields were comparatively higher than in previous years of the study. In 2004, marketable yield followed the same pattern as total tuber yield had, with the treatment receiving 34 kg P_2O_5 ha^{-1} having a lower yield than the remaining treatments, but a higher yield of tubers <3 oz. In part, a somewhat higher soil test P level in 2003, and poor growing season conditions that restricted crop growth in 2004, may have limited crop responses to fertilizer application in those years.

In a few cases, the yield of specific tuber size fractions was influenced by P rate. In 2005, increasing P rate resulted in a linear increase in the yield of tubers >12 oz and tended to reduce the yield of 6 to 10 oz tubers. In 2006, moderate rates of P reduced the yield of tubers <3 oz, while the yield of 3 to 6 oz tubers tended to decline linearly with increasing P rate. However, strong and consistent effects of P on the yield of specific size fractions were not observed in each year. The number of tubers produced per acre was not significantly affected by P fertilizer rate (Table 3).

In general, the rate of P fertilizer applied had limited effects on tuber quality. Specific gravity was not affected by P rate except in 2004 when increasing P rate resulted in a statistically significant linear increase in specific gravity (Table 3). In 2003, P rate tended to influence specific gravity, but increasing P rate had inconsistent effects.

The occurrence of defects such as rot and greening was generally very low throughout the course of the study (Table 4). The occurrence of hollow heart / brown centre averaged 15.2%, 15.1%, 9.5% and 2.1% of the tubers assessed (on a weight basis) in each of 2003, 2004, 2005 and 2006, respectively. Hollow heart / brown centre was sufficiently severe to result in 3.2% of tubers (on a weight basis) to be considered tare in 2003, 2.3% in 2004, 1% in 2005, and 0% in 2006. The rate of P fertilizer applied did not affect the occurrence of hollow heart / brown centre (i.e. $P>0.05$), and had a significant quadratic effect on the tare loss due to hollow heart only in 2003 (data not presented).

For the years in which fry colour was determined (2004 through 2006), an average of 98% or more of the tubers assessed had a fry colour of 0 or 1 (Table 4). Analysis of variance of transformed data (assessing the square root of 100 minus the measured percentage of tubers with a fry colour of 0 or 1) demonstrated no significant effect of P rate (data not presented). In both 2004 and 2005, the percent of tubers affected by sugar ends was low overall, and statistical analysis of transformed data (assessing the square root of the data) revealed no significant effects of P rate. In 2006, the overall percentage of tubers affected by sugar ends and dark ends was numerically higher than in previous years. Analysis of variance of transformed data (assessing the square root of the measured percentage of tuber with sugar ends or dark ends) showed no statistically significant effect of P rate on these parameters (data not presented). However, for both sugar ends and dark ends, contrast analysis revealed a trend toward a quadratic relationship between P fertilizer rate and both sugar ends ($P=0.1253$) and dark ends ($P=0.1119$), with sugar/dark ends increasing with moderate rates of P then declining.

Nutrient status

Petiole P concentration generally declined over the course of the growing season (Fig. 2). In 2004 and 2005, increasing P rate increased petiole P concentration for each sampling date (Fig. 2). In 2006, increasing P rate also increased petiole P concentration in the early part of the growing season, but this effect was not evident for later sampling dates. In 2003, P fertilization similarly increased or tended to increase petiole P concentration at most sampling dates, but effects were not as pronounced as in 2004 and 2005. In previous studies in Manitoba, Geisel (1995) also reported declines in petiole P as plants matured, and increases in petiole P with increasing rates of applied P.

Stark et al. (2004) in an extension bulletin from the University of Idaho recommended that the P concentration in the fourth petiole be maintained above 0.22% beginning at or shortly after tuber initiation through most of tuber bulking. In the current study, petiole P concentration in most treatments at most sites fell below 0.22% as the season progressed even though petiole P typically increased with P application; however, increasing P rate increased marketable yield only in 2005 and 2006. In 2003, petiole P concentrations in the control fell below 0.22% between 65 and 70 days after planting and, in P-fertilized treatments, fell below 0.22% about 80 days after planting. In 2004, the highest P rate (100 kg P_2O_5 ha^{-1}) maintained the petiole P concentration at or above 0.22% for all petiole sampling dates. In that year, petiole P concentrations fell below 0.22% at about 65, 80 and 85 days after planting for the control, the 34 kg P_2O_5 ha^{-1}, and the 67 kg P_2O_5 ha^{-1} rates, respectively. In 2005, petiole P concentration fell below 0.22% in all treatments, approximately 85, 90, 95 and 100 days after planting for the control, the 34 kg P_2O_5 ha^{-1}, 67 kg P_2O_5 ha^{-1} and 100 kg P_2O_5 ha^{-1} rates, respectively. In 2006, petiole P concentration also fell below 0.22% in all treatments, approximately 70 days after planting for the control and the 34 kg P_2O_5 ha^{-1} rate, 75 days after planting for the 67 kg P_2O_5 ha^{-1} rate, and between 75 and 80 days after planting for the 100 kg P_2O_5 ha^{-1} rate. (Tubers were harvested 128, 116, 143 and 140 days after planting in 2003, 2004, 2005, and 2006, respectively.)

Woods et al. (2002) reported that the adequate range for petiole P based on standards used in the northwest United States ranged from 0.22-0.62% in early July, from 0.20-0.50% in late July, and from 0.16 to 0.40% in mid-August. Using these criteria, the petiole P concentration in all treatments in all site-years fell within the adequate range in early July. Petiole P concentration also fell within the adequate range in late July in all years except 2006 where petiole P concentration fell below 0.20% by the July 20th sampling date. In 2003 and 2004, petiole P concentrations were also adequate in mid-August. In 2005, the petiole P concentration in mid-August was <0.16% in the control treatment and the treatment receiving 34 kg P_2O_5 ha^{-1}, equal to 0.16% in the treatment receiving 67 kg P_2O_5 ha^{-1}, and >0.16% in the treatment receiving 100 kg P_2O_5 ha^{-1}, suggesting a P deficiency at this site. In 2006, petiole P concentration in mid-August (August 10th) was <0.16% in all treatments regardless of P rate. At both the 2005 and 2006 sites where petiole P concentrations fell below the adequate range, increasing P rate resulted in a significant increase in marketable yield. In 2005, total yield also increased with increasing P rate.

Estimated P uptake by the potato plant shortly before tuber harvest averaged 18 kg P ha^{-1} in 2004 and 2006, and 22 kg P ha^{-1} in 2005 (data not presented). This estimate included vines, tubers, and recoverable roots plus stolons. Average P uptake in tubers was 14, 18 and 15 kg P ha^{-1} in 2004, 2005 and 2006, respectively. The Manitoba Soil Fertility Guide (Manitoba Agriculture, Food and Rural Initiatives 2007) similarly reports P uptake in tubers of 16 to 19 kg P ha^{-1} for a potato crop yielding 400 cwt $acre^{-1}$. Increasing P fertilizer rate did not result in a statistically significant (i.e. P>0.05) increase in P uptake in 2005 and 2006 where all treatments had been sampled.

Post-harvest soil P content

Detailed sampling of each plot (based on 10 cores/plot to 15 cm) following tuber harvest revealed a significant linear increase in $NaHCO_3$-extactable P content in all years (Table 5). While similar trends were evident from general soil sampling (based on 2 cores/plot), treatment effects were not always statistically significant using this sampling method. The difference in soil test P level between the 100 kg P_2O_5 ha^{-1} treatment and the control ranged from 8 kg extr. P ha^{-1} in 2003 to 47 kg extr. P ha^{-1} in 2004.

Summary

Increasing P fertilizer rate resulted in a significant linear increase in marketable (>3 oz) and total yield in 2005, and a quadratic increase in marketable yield in 2006. Although all site-years had low to medium soil test P levels based on general sampling of the plot area, positive yield responses were observed only at the comparatively higher-yielding sites which averaged >420 cwt acre^{-1}. In part, a somewhat higher soil test P level at the 2003 site, and suboptimal growing conditions that restricted yields in 2004, may have limited crop responses to fertilizer in those years. Phosphorus application had limited effects on the tuber quality parameters measured including specific gravity, defects and fry colour, although effects of P were observed occasionally.

Phosphorus application typically increased petiole P concentration at a given sampling date. At the two of four sites where P application increased marketable yield, petiole P concentrations fell below the "adequate range" (based on standards used in the northwest United States) as the season progressed. At all sites, increasing P rate also resulted in a linear increase in post-harvest soil test P levels in the surface 0-15 cm.

References

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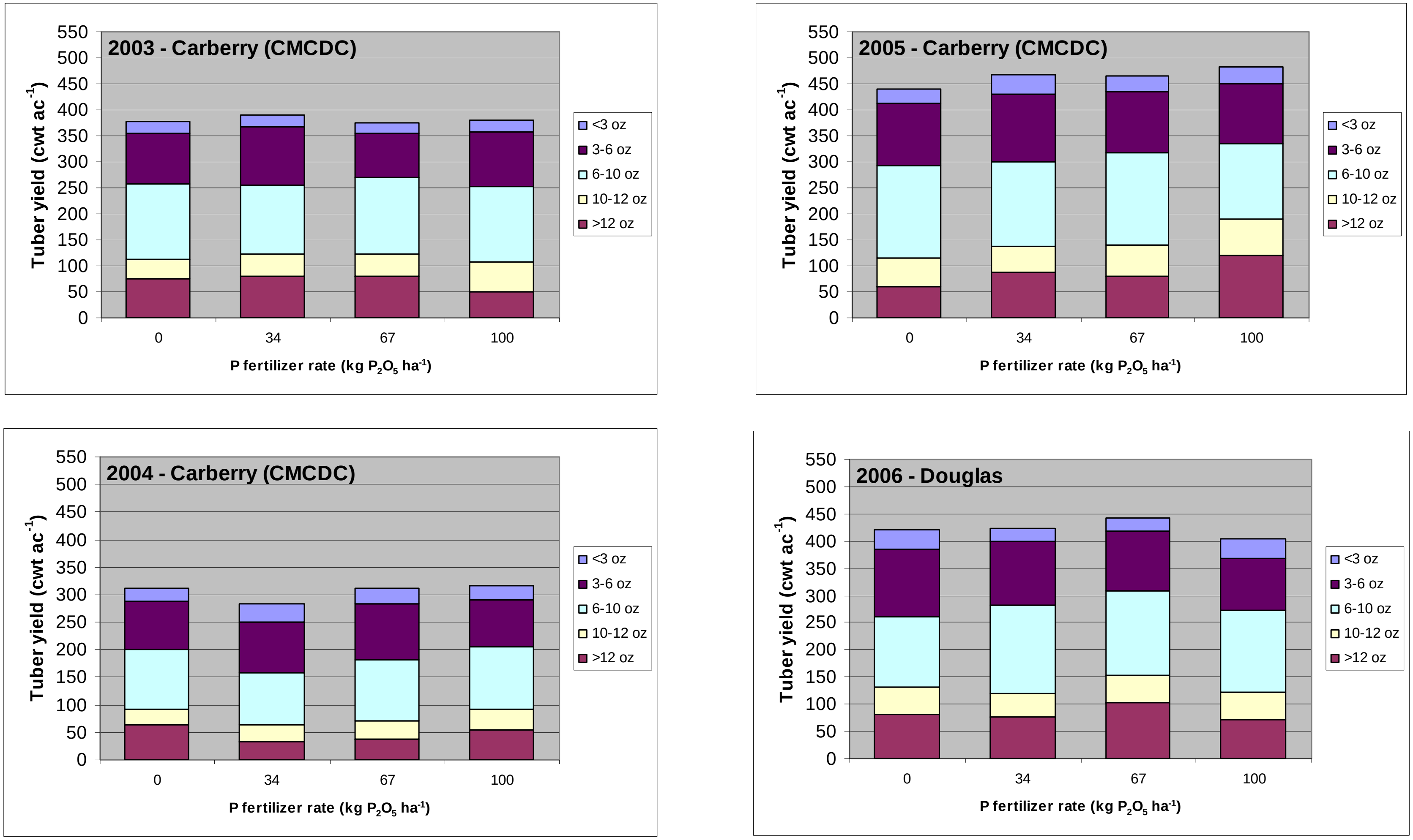

Figure 1. Effect of P fertilizer rate on tuber yield and tuber size distribution in field trials conducted in Manitoba from 2003 through 2006.

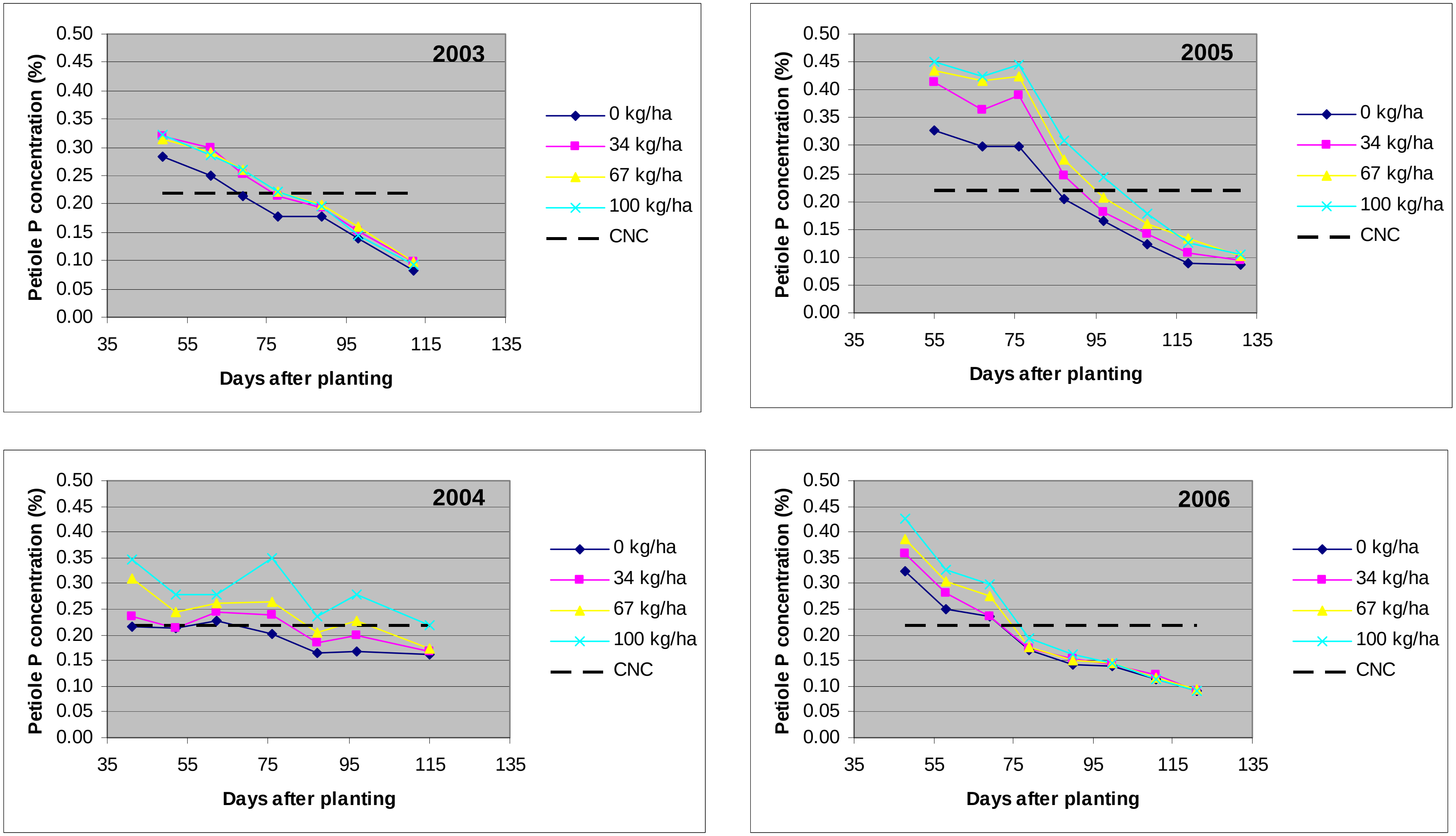

Figure 2. Effect of rate of P fertilizer (kg P_2O_5 ha^{-1} applied as broadcast monoammonium phosphate) on total P concentration in the 4th petiole of irrigated Russet Burbank potato in Manitoba (2003-2006). The critical nutrient concentration (CNC) included as a reference is based on Stark, Westermann and Hopkins (2004).

Table 1. Characteristic and management of experimental sites in Manitoba (2003-2006)

Characteristic[1]		Soil depth	2003 [2]	2004	2005	2006
Site characteristics						
Location			Carberry	Carberry	Carberry	Douglas
pH		0 to 15 cm	6.01	6.16	5.58	6.78
EC		0 to 15 cm	0.36	0.31	0.31	0.72
Texture		0 to 15 cm	loam	loam	loam	loamy sand
	% sand	0 to 15 cm	39.0	39.5	41.5	78.5
	% silt	0 to 15 cm	44.0	42.5	43.0	14.0
	% clay	0 to 15 cm	17.0	18.0	15.5	7.5
%C		0 to 15 cm	n.d.	3.01	3.06	n.a.
%N		0 to 15 cm	n.d.	0.26	0.26	n.a.
NO_3-N (kg ha^{-1})		0 to 60 cm	77	34	43	33
extr. P (kg ha^{-1})						
	general sampling	0 to 15 cm	48	27	38	21
	detailed sampling	0 to 15 cm	57	29	42	n.a.
extr. K (kg ha^{-1})		0 to 15 cm	454	271	466	139
extr. S (kg ha^{-1})		0 to 60 cm	126	58	42	25
Dates of field operations and sampling						
Planting date			21-May	28-May	29-Apr	02-May
Harvest date			26-Sep	21-Sep	19-Sep	19-Sep
Days from planting to harvest			128	116	143	140
Petiole sampling	1		09-Jul	08-Jul	23-Jun	19-Jun
	2		21-Jul	19-Jul	05-Jul	29-Jun
	3		29-Jul	29-Jul	14-Jul	10-Jul
	4		07-Aug	12-Aug	25-Jul	20-Jul
	5		18-Aug	23-Aug	04-Aug	31-Jul
	6		27-Aug	02-Sep	15-Aug	10-Aug
	7		10-Sep	20-Sep	25-Aug	21-Aug
	8		---	---	07-Sep	31-Aug
Whole plant sampling			n.d.	20-Sep	15-Sep	14-Sep
Post-harvest soil sampling			07-Oct	29-Sep	19-Sep	20-Sep
Plot characteristics						
Plot dimensions			5.7 x 16 m	8.5 x 16 m	5.7 x 16 m	5.7 x 16 m
Row spacing (cm)			95	96.5	95	95
In-row spacing (cm)			38	38	37.5	36

[1] Analysis were conducted on soil samples collected in the spring prior to plot establishment with the exception of K and S analysis in 2003 which was conducted on soil samples collected in the fall prior to crop establishment.
[2] n.d. and n.a. indicated that values were not determined or not available at the time of report preparation, respectively.

Table 2. Monthly temperature and precipitation at Carberry, Manitoba (2003-2006)

Month[1]	2003	2004	2005	2006
	----------------------------	----Temperature (°C)----	----------------------------	
April	4.8	4.0	6.8	7.7
May	11.6	6.9	9.5	11.7
June	16.0	13.7	16.3	17.2
July	19.0	17.1	18.5	19.8
August	21.0	13.2	16.5	18.7
September	11.8	13.6	12.9	12.5
October	6.5	5.2	5.8	2.8
	----------------------------	----Precipitation (mm)----	----------------------------	
April	35.4	17.9	11.8	49.4
May	42.8	117.5	58.0	79.8
June	78.2	40.8	123.2	29.4
July	16.4	88.8	92.6	9.8
August	50.2	85.4	25.0	44.6
September	74.2	23.0	10.4	50.0
October	14.6	33.1	14.3	15.5

[1] as reported by Environment Canada (2006) for Carberry CS located at 49° 54' N latitude and 99° 21'W longitude (http://www.climate.weatheroffice.ec.gc.ca)

Table 3. Effect of rate of P fertilizer application on yield of tuber size fractions, specific gravity and tuber numbers for irrigated Russet Burbank potato for four site-year in Manitoba (2003-2006)

Year	P rate (kg P_2O_5 ha^{-1})	Total	<3 oz	3 to 6 oz	6 to 10 oz	10 to 12 oz	>12 oz	Marketable	SG	Tuber Number
		cwt $acre^{-1}$								'000 $acre^{-1}$
2003	0	378.6	22.9	97.6	144.6	37.9	75.6	355.7	1.0888	87.9
	34	390.1	22.1	114.0	130.4	42.9	80.7	368.0	1.0884	93.3
	67	374.1	20.0	85.2	146.1	42.5	80.3	354.1	1.0896	89.7
	100	379.1	22.2	104.3	146.2	56.6	49.6	356.8	1.0863	93.2
	SE	12.3	4.9	11.9	9.5	10.1	14.0	13.5	0.0008	6.3
2004	0	312.0	23.5	89.0	106.5	29.7	63.3	288.5	1.0845	41.0
	34	283.5	33.0	93.5	93.9	31.1	32.0	250.5	1.0848	51.8
	67	311.8	28.6	101.2	112.3	32.1	37.7	283.2	1.0855	53.3
	100	316.3	26.1	85.5	112.5	37.3	54.9	290.2	1.0893	41.8
	SE	8.2	2.4	8.0	6.0	5.3	11.2	8.5	0.0013	5.5
2005	0	441.8	29.0	119.2	177.2	55.0	61.3	412.6	1.0920	116.0
	34	459.8	35.8	129.8	163.7	49.6	87.4	430.4	1.0948	124.0
	67	466.3	31.5	117.2	177.7	59.0	81.1	435.0	1.0903	120.3
	100	483.0	34.4	113.9	145.0	70.0	119.6	448.5	1.0918	120.5
	SE	10.2	4.5	8.4	8.6	7.3	8.5	9.8	0.0017	5.0
2006	0	421.0	36.0	124.8	128.2	50.0	82.2	385.1	1.0863	112.8
	34	423.5	23.9	118.4	160.9	43.7	76.4	399.4	1.0865	104.5
	67	441.5	23.9	108.3	155.3	49.9	104.0	417.6	1.0858	106.5
	100	403.3	35.6	95.9	150.2	49.7	71.9	367.7	1.0868	105.3
	SE	11.5	2.6	11.1	12.8	13.9	18.3	11.3	0.0018	4.6
ANOVA										
			Pr > F[1]							
2003	P rate	ns	ns	ns	ns	ns	ns	ns	0.10	ns
	linear	ns	ns	ns	ns	ns	ns	ns	ns	ns
	quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns
2004	P rate	0.07	0.10	ns	ns	ns	ns	**0.0294**	0.10	ns
	linear	ns	ns	ns	ns	ns	ns	ns	**0.0319**	ns
	quadratic	0.07	**0.0345**	ns	ns	ns	0.06	**0.0271**	ns	0.07
2005										
	P rate	0.10	ns	ns	0.08	ns	**0.0064**	ns	ns	ns
	linear	**0.0186**	ns	ns	0.06	ns	**0.0017**	**0.0313**	ns	ns
	quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns
2006										
	P rate	ns	**0.0091**	ns	ns	ns	ns	0.06	ns	ns
	linear	ns	ns	0.08	ns	ns	ns	ns	ns	ns
	quadratic	ns	**0.0012**	ns	ns	ns	ns	**0.0199**	ns	ns

[1]ns indicates that the effect was not significant at P>0.10.

Table 4. Means of tuber quality parameters for irrigated Russet Burbank potato for four site-years in Manitoba (2003-2006)

Year	P fertilizer rate (kg P_2O_5 ha^{-1})	Greening	Rot		Fry colour							Hollow heart / brown centre	
					0	1	2	3	4	Sugar ends	Dark ends	Occurrence	Tare
		% by number	% by number	% by weight	----------------------% by number of tubers----------------------							-----% by weight-----	
2003	0	1	0	0	---	---	---	---	---	---	---	17.5	6.4
	34	0	0	0	---	---	---	---	---	---	---	10.5	0.7
	67	0	0	0	---	---	---	---	---	---	---	14.7	0.7
	100	0	0	0	---	---	---	---	---	---	---	18.1	5.1
2004	0	0	0	0	85	15	0	0	0	0	5	14.0	0.6
	34	0	0	0	81	13	5	1	0	0	1	14.3	2.1
	67	0	0	0	88	10	2	0	0	2	1	11.3	4.1
	100	0	0	0	86	13	1	0	0	0	4	20.9	2.7
2005	0	0	0	0	96	3	1	0	0	0	0	6.0	2.3
	34	0	0	0	97	3	0	0	0	1	1	4.2	0.0
	67	0	0	0	92	7	1	0	0	0	0	6.5	1.6
	100	0	1	0	96	4	0	0	0	0	0	21.4	0.0
2006	0	2	0	0	98	2	0	0	0	3	26	5.6	0.0
	34	4	0	0	100	0	0	0	0	6	43	0.0	0.0
	67	0	1	1	97	1	2	0	0	11	32	3.0	0.0
	100	0	0	0	100	0	0	0	0	2	26	0.0	0.0

Table 5. Effect of rate of P fertilizer application on soil test P level ($NaHCO_3$-extractable P, 0-15 cm) measured following tuber harvest for four site-years in Manitoba (2003-2006)

P rate (kg P_2O_5 ha^{-1})	Detailed sampling (10 cores/plot)				General sampling (2 cores/plot)			
	2003	**2004**	**2005**	**2006**	**2003**	**2004**	**2005**	**2006**
	kg $NaHCO_3$-extr. P ha^{-1}							
0	42	35	36	31	50	34	31	29
34	50	48	51	39	52	45	48	32
67	48	65	70	44	58	66	44	39
100	50	82	72	47	57	80	53	38
SE	2	4	4	3	4	5	3	3
	Pr > F[1]							
P rate								
Rep	0.06	ns	0.10	0.08	ns	ns	**0.0410**	**0.0041**
Treatment	**0.0518**	**0.0001**	**0.0006**	**0.0366**	ns	**0.0003**	**0.0051**	0.07
P rate								
Linear	**0.0284**	**0.00002**	**0.0001**	**0.0064**	ns	**0.00004**	**0.0018**	**0.0163**
Quadratic	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	8.3	15.0	15.0	16.2	14.4	16.9	14.6	15.0

[1]ns indicates that the effect was not significant at P>0.10