Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta (2005)

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INTRODUCTION

The 2005 season marked the second year of a three-year study sponsored by the Potato Growers of Alberta (PGA). The 2005 growing season in southern Alberta was remarkable for the record rainfall and cool temperatures. Many growers were forced to pump out portions of fields that were flooded and these saturated conditions can lead to nitrogen losses through runoff, deep drainage and microbial denitrification. Although the cool temperatures likely slowed denitrification, the potential for nitrogen losses was still present. Other nutrients can also be lost with water that is removed by pumping and through runoff and deep drainage. The potential for nutrient losses in 2005 make it difficult to be certain that the applied rates of fertilizer remained within the root zone of their designated plot sites.

Background

- Precise fertilizer application rates are critical for optimal potato production. Sufficient nutrients are necessary to maximize tuber yield, quality and uniformity, while issues of economy and environment make excess fertilizer undesirable.
- The analysis of potato petiole samples has been used to monitor the nutrient status of potato crops throughout the growing season. This can be a useful and timely technique for monitoring any crop deficiencies that may occur mid-season that were not identified in spring soil samples.
- Many of the current recommended petiole nutrient (N, P and K) concentrations have come from research conducted in the northwest United States (Schaupmeyer, 1999), where longer growing seasons and different soil conditions and climate prevail.
- Petiole analysis results from previous Russet Burbank studies in southern Alberta (McKenzie et al., 2002; Woods et al., 2002) indicated that the current recommendations may be high for potassium (K) and somewhat high for phosphorus (P), especially early in the growing season. Results also indicated that recommended nitrate nitrogen (N) concentrations may need fine-tuning to suit southern Alberta growing conditions.

Objectives

- Determine the optimal petiole nutrient concentrations for Russet Burbank potatoes, specific to southern Alberta.
- Determine the relationship, if any, between potato petiole nutrient concentrations and tuber specific gravity.
- Compare these relationships to those found in field-scale petiole data.

METHODS AND MATERIALS

Project Treatments and Layout

Ten rates (Table 1) of N, P and K fertilizers were surface applied (April 20-21/05) to strips in a small portion of a field of grower-managed Russet Burbank potatoes, approximately 5 km southwest of Taber, Alberta. The ten treatments were broken down into four different rates each of N (Treatments 1, 2, 3 and 4), P (Treatments 5, 6, 3 and 7) and K (Treatments 8, 9, 3 and 10) fertilizer, where the other nutrients were held constant. Each treatment plot was 8 rows wide (24 ft) x 115 ft long (Figure 1). All plots ran just west of the pivot road. There were a total of four randomized replications of the experiment and the plots covered a total area of 2.5 ac. Figure 1 shows the layout of the experimental site and its approximate location within the grower's field. Blue squares indicate the lowest rate for the individual nutrients and red the highest. The pink squares indicate the treatment (Treatment 3) that was common to all three (N, P and K) sub-trials. Note that the individual plot sizes are not shown to scale. Because of flooding in the study field, the cooperating grower was forced to plough out a low area of the south end of the field that included Rep 1, Treatments 1 and 6 and Rep 2, Treatments 9 and 7, so no petiole or yield data could be collected from those 4 plots (Figure 2). Late-season flooding also made an additional 4 low-lying plots inaccessible at harvest (Rep 3, Treatments 7 and 10 and Rep 4, Treatments 4 and 5) so yield data was not collected for these (Figure 1).

Figure 1. Plot layout, 2005.

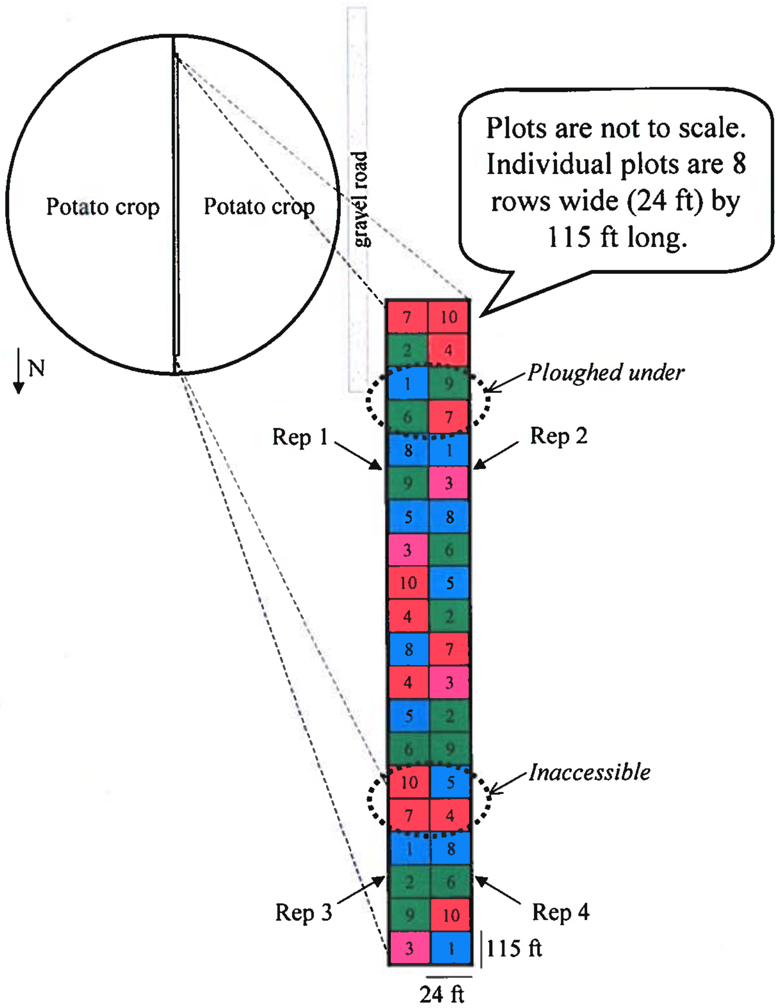
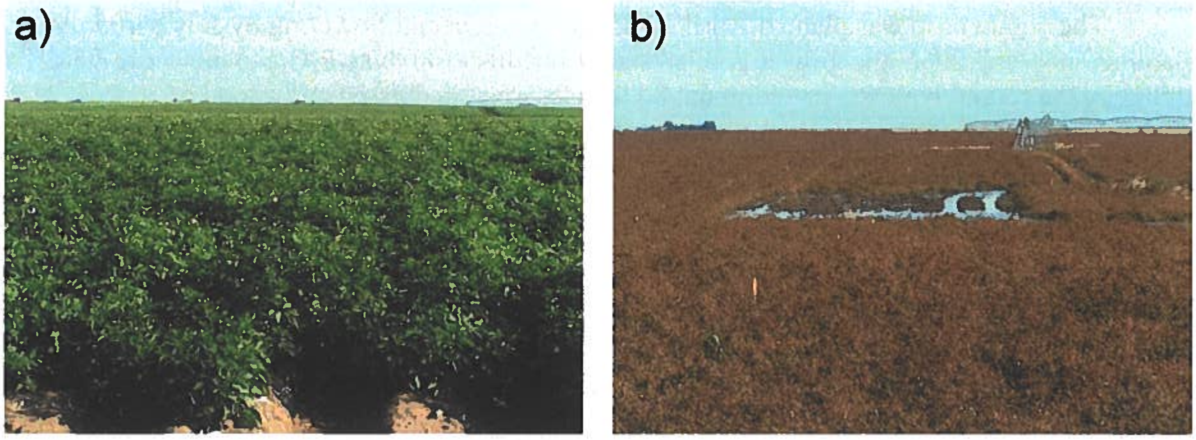


Figure 2. South end of research site looking north from edge of field, on a) July 20, 2005 and b) September 14, 2005, showing flooded portion of the field.



Fertilizer Schedule

In the fall of 2004, the field received a fertilizer application of 75 lb/ac N, 30 lb/ac P_2O_5 and 115 lb/ac K_2O. Soil samples taken April 22, 2005, after the grower applied fall fertilizer and just outside of the individual fertilized plots, indicated that there was a total of 297 lb nitrate N/ac, 145 lb P/ac and 1994 lb K/ac in the surface 2 feet of soil. The experimental rates of fertilizer were applied April 20-21, 2005. The fertilizer rates for the experimental treatments were chosen to create four increasing amounts of one nutrient, while holding the other two constant. So, for example, treatments 1, 2, 3 and 4 have increasing levels of N, while P and K were kept constant (Table 1).

Table 1. Fertilizer schedule (lb/ac) 2004-2005.

	Trtmt	Grower Applied 2004-2005						Experiment Amts			Total		
		Fall 2004			Planting	Top dressed	Fertigation	Apr 20/04					
		N	P_2O_5	K_2O	P_2O_5	N	N	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Nitrogen	1	75	30	115	60	80	30	**16**	69	22	**201**	159	137
	2	75	30	115	60	80	30	**77**	69	22	**262**	159	137
	3	75	30	115	60	80	30	**126**	69	22	**311**	159	137
	4	75	30	115	60	80	30	**177**	69	22	**362**	159	137
Phosphorus	5	75	30	115	60	80	30	127	**0**	22	312	**90**	137
	3	75	30	115	60	80	30	127	**69**	22	311	**159**	137
	6	75	30	115	60	80	30	126	**174**	22	312	**264**	137
	7	75	30	115	60	80	30	99	**258**	22	284	**348**	137
Potassium	8	75	30	115	60	80	30	126	69	**0**	311	159	**115**
	3	75	30	115	60	80	30	126	69	**22**	311	159	**137**
	9	75	30	115	60	80	30	126	69	**133**	311	159	**248**
	10	75	30	115	60	80	30	126	69	**234**	311	159	**349**

Whole Site was 2300 ft x 48 ft = 110400 sq ft = 2.5 ac
Each Individual Plot was 115 ft x 24 ft = 2760 sq ft = 0.0633 ac
Each Treatment was 0.0633 ac x 4 reps = 0.253 ac

Crop Timetable

The potato crop was planted April 22/05 and it had begun flowering by July 13/05. At planting, in spring 2005, the grower applied starter fertilizer (60 lb/ac P_2O_5) to the entire field, including the research plots. An additional 80 lb/ac N was top dressed and a total of 30 lb/ac N was applied through fertigation. Petioles were collected seven times throughout the growing season and tubers were harvested September 21-22/05.

Petiole Sampling

Petiole samples were collected and analyzed for each plot 7 times throughout the 2004 growing season, on June 30, July 6, 13, 20 and 27, and August 10 and 24. The 4th leaf stem (petiole) from the top of the main stem was taken and leaflets were removed in the field (Figure 3). Approximately 80 petioles were collected from each plot, at each sample date. Within each plot, approximately 40 petioles each were collected from the 2nd and 3rd potato rows and the 6th and 7th potato rows on alternating weeks (Figure 4). Staff were instructed to sample representative plants only, to avoid any unhealthy or overly advanced plants. Staff were instructed to only walk in furrows between the 2nd and 3rd rows and between the 6th and 7th rows, in order to leave the middle two rows (4th and 5th) undisturbed for tuber harvest. Field staff were also instructed to only walk between rows at the border between two plots, as indicated by footprints in Figure 4. In order to maintain consistency, whenever possible, the same person sampled the same plots at approximately the same time of day and in the same order. The outside two rows were designated guard rows and were not sampled. Petiole samples were kept in a cooler and then air dried overnight in a tobacco dryer (45-50 °C). Samples were ground and sent to a laboratory for analysis of nitrate nitrogen (NO_3-N), phosphorus (P) and potassium (K). Because of a problem with laboratory equipment, initial K results were too low and samples required re-analysis over the winter. Final results were received from the lab January 23/06.

Figure 3. Russet Burbank 4th leaf stem a) before and b) after removal of leaves (petiole shown in dashed circle).

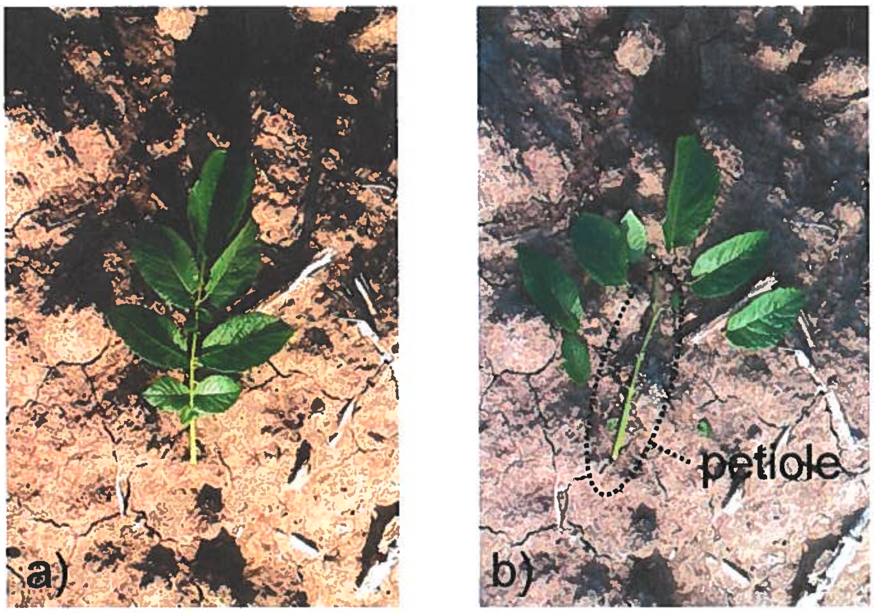
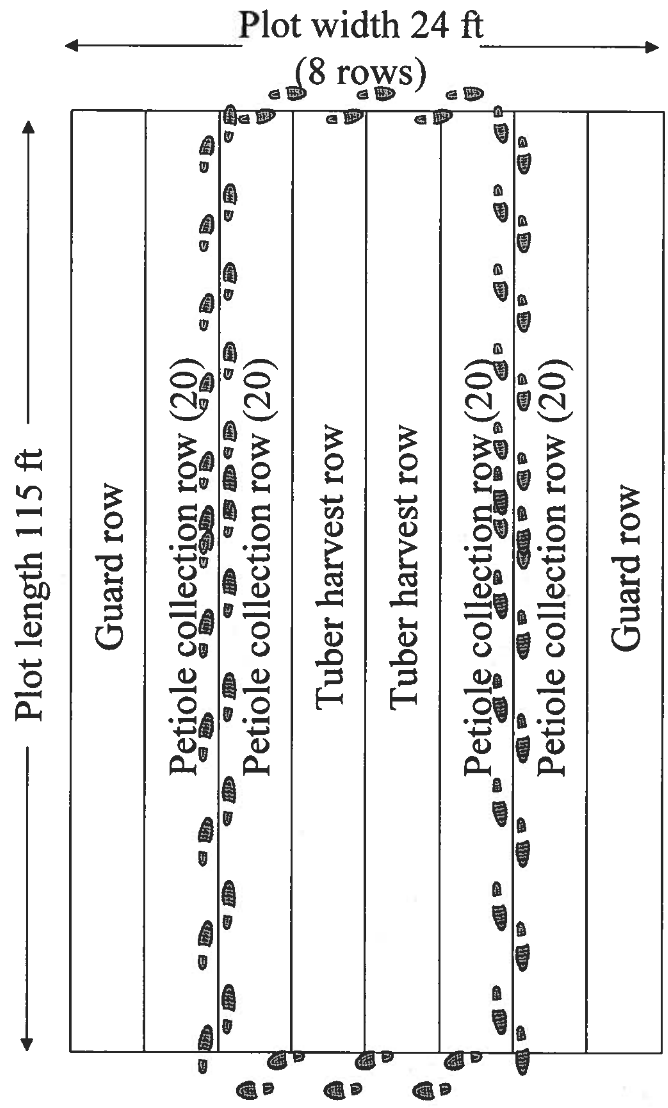


Figure 4. Map of individual 2005 plot, indicating guard rows, petiole collection rows, tuber harvest rows and staff walking paths.



Tuber Harvest

Tuber samples (2x25 ft strips) were collected on September 21 and 22/05. The harvest was done with the PGA two-row harvester (Figure 5) and field staff collected, bagged and labelled samples in the field. In the laboratory, samples were graded and weighed, in order to calculate total yield, marketable yield, mean tuber weight and % smalls. Grading categories used were small (<$1^7/_8$"), medium ($1^7/_8$ – 3½"), over-size (> 3½") and deformed. Weights and tuber numbers were recorded for each category and each sample and then converted to yield (short tons per acre) based on sample area (2 rows = 6 ft x 25 ft long = 150 sq ft). Marketable yield was defined as total yield minus yield of small (undersize) tubers. Specific gravity was calculated by the weight in air over weight in water method, on 25 medium tubers for each sample.

Figure 5. PGA plot combine with Crop Diversification Centre South staff collecting harvested tubers, 2005.

RESULTS AND DISCUSSION

Average Petiole Concentration Compared to Marketable Yield and Specific Gravity

Complete results for each of the ten treatments and four replications are indicated in Appendix 1 (petiole N), Appendix 2 (petiole P), Appendix 3 (petiole K) and Appendix 4 (tuber yield and specific gravity).

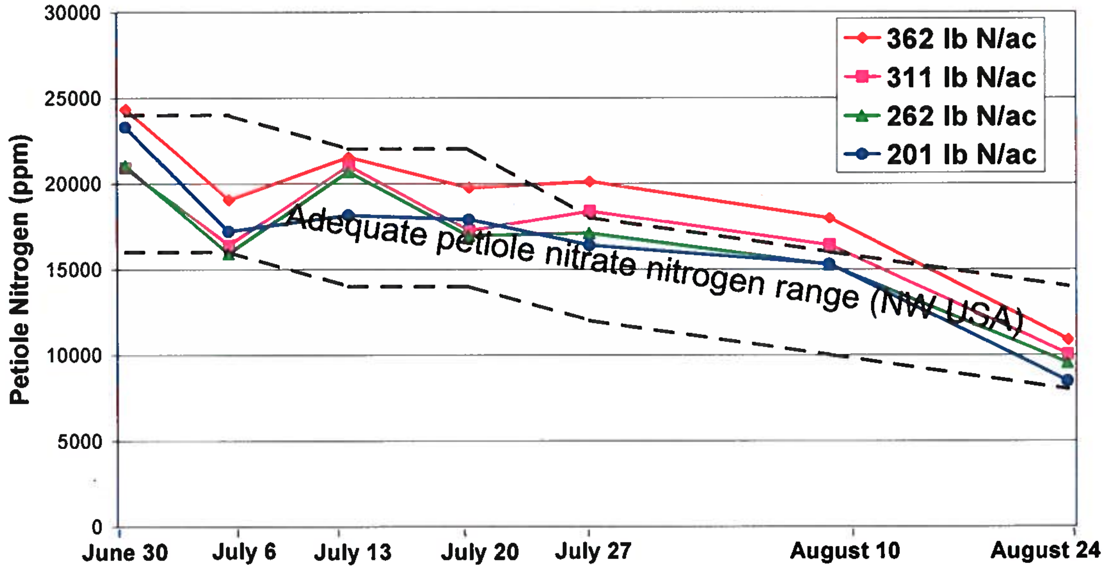
Averages for each of the treatments are summarized in Figures 6, 7 and 8, which are shown on the following three pages. On all graphs, the colour of lines and bars corresponds to the colours designated for fertilizer applications (Table 1). On the line graphs (petiole nutrient content as a function of date), the dashed black lines correspond to upper and lower suggested limits used in the northwest USA (Schaupmeyer, 1999). The error bars on the bar graphs (marketable yield and specific gravity) indicate the 95% confidence intervals. Differences between treatments for which error bars overlap are not statistically significant. In all cases, there were no statistically significant differences between treatments, in yield or specific gravity, however, there are some notable trends.

a) Nitrogen (N) Fertilizer Rates (Figure 6)

- The highest N rate (Treatment 4: 367 lb N/ac) consistently showed the highest petiole nitrate N (NO_3-N) concentration (Figure 6a) but not by a large margin. The lowest N rate (Treatment 1: 201 lb N/ac) actually had the second-highest average petiole N concentration for the first, second and fourth sampling dates (June 30, July 6 and 20). For the remainder of the sampling dates, it had the lowest average petiole NO_3-N. These inconsistencies may have resulted form N losses from the large amounts of rainfall in 2005. Despite the record rainfall, all petiole NO_3-N results were within or above the suggested adequate ranges for the northwest USA. Petiole NO_3-N initially decreased until 75 days after planting (DAP), increased dramatically at 82 DAP and then decreased for the remainder of the growing season. At the 2004 study site, the initial decrease lasted until 76 DAP, with the increase noted 83 DAP. It may be possible that the initial decline in petiole N coincides with the tuber initiation stage of growth, where rapid formation and growth of stems and leaves is taking place. The jump in petiole N may coincide with tuber bulking, where above-ground plant growth has stabilized and the plant root uptake of N is able to "catch-up" to optimal levels. It is at this stage that growers typically begin to monitor petiole nutrients. Results from the first two years of the study suggest that the recommendations for petiole NO_3-N ranges will not follow a single line but instead will have two stages; prior to and after the beginning of tuber bulking. The 2006 results will be necessary to confirm this finding.
- Treatment 2 (262 lb N/ac) had the highest overall yield, however, the treatments were not significantly different (Figure 6b). The yield data for this treatment was quite variable (Appendix 4).
- For fertilizer rates greater than 262 lb N/ac, there was a slight decrease in specific gravity (Figure 6c). Although it was not statistically significant, the trend does correspond to suggestions in the literature that excess nitrogen fertilizer can have the unwanted consequences of low specific gravity (Waterer and Heard, 2005). Because lowered specific gravity is a goal for some Alberta producers, further research into the link between specific gravity and amounts and timing of excess N fertilizer may be useful.

Figure 6. Potato petiole N, marketable yield and specific gravity for four different N fertilizer rates (2005).

a)



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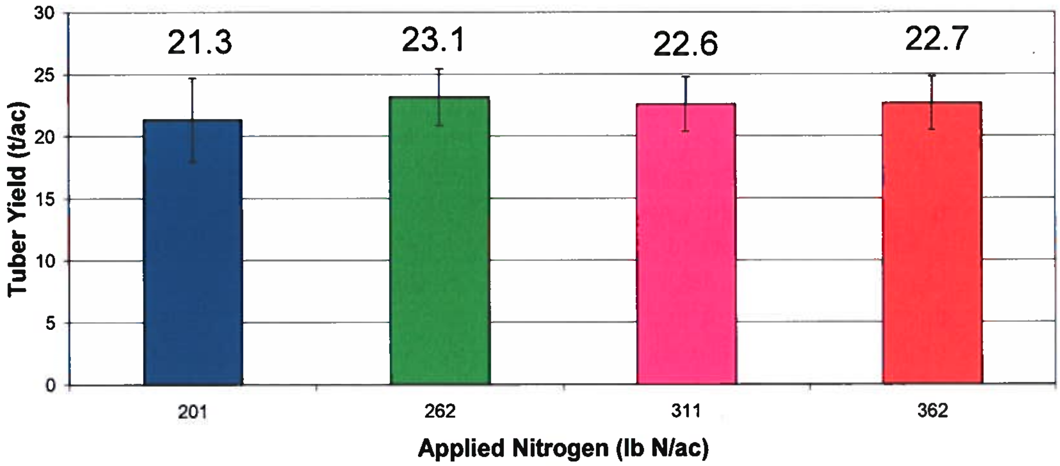
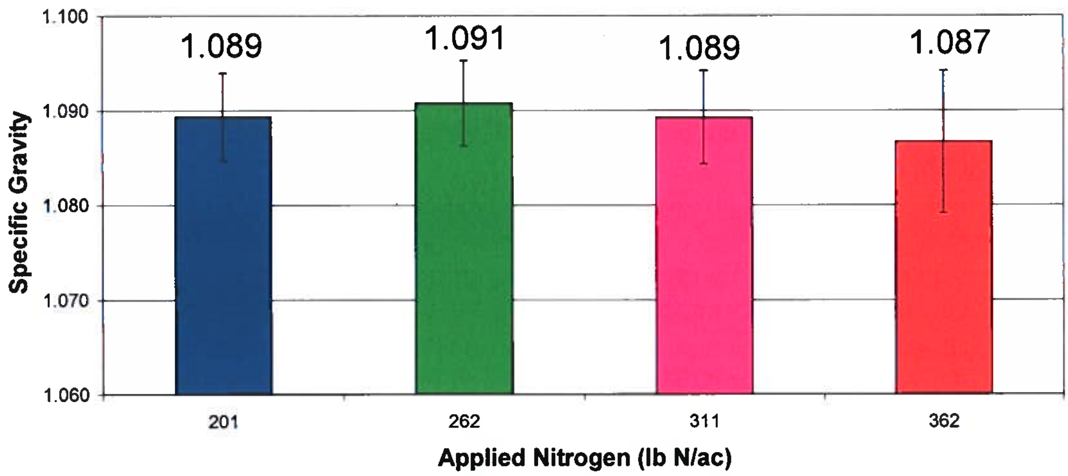


c)



b) Phosphorus (P) Fertilizer Rates (Figure 7)

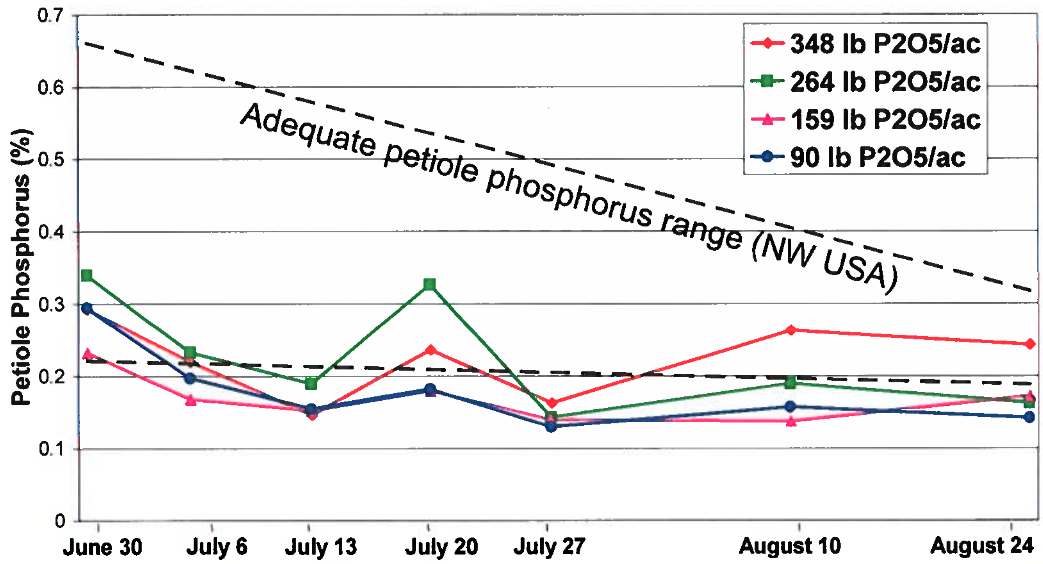
- In 2005 the two highest rates of fertilizer P gave higher amounts petiole P (Figure 7a). Overall, petiole P initially decreased, until 89 DAP, when it took a sharp increase (especially for the two highest fertilizer P rates). Petiole P then decreased at 96 DAP and levelled-off or increased slightly for the remainder of the growing season. All but a few points were beneath the lower limit for the adequate USA petiole P standard range, yet yields were not significantly impacted. This indicates that the lower limits for petiole P are likely too high for Alberta fields. Because soil P is not very mobile, it is unlikely that the heavy rains of 2005 led to significant leaching of P.
- The highest rate of fertilizer P (Treatment 7: 348 lb P_2O_5/ac) had a slightly greater yield than the other three rates of fertilizer P but results did not show statistically significant differences (Figure 7b). Incidentally, this treatment had a slightly lower amount of fertilizer N applied (99 lb N/ac) compared to the other three treatments (126-127 lb N/ac) because of limitations in the application rates of the fertilizer spreader used.
- The specific gravity was variable, did not show any statistically significant relationships and did not appear to be affected by fertilizer P (Figure 7c)

c) Potassium (K) Fertilizer Rates (Figure 8)

- Similar to 2004 results, the 2005 data showed that increasing rates of fertilizer K had no observable effect on petiole K (Figure 8a). This may be due to the already high soil potassium levels at the site, sampled on April 22/05 (1994 lb K/ac). Also, like the 2004 results, most average petiole K concentrations were above the USA standard ranges, at the 2005 site. Together, these results confirm those of previous unpublished studies (Konschuh, 2001 and McKenzie et al., 2002) that have shown no relationship between fertilizer K and petiole K. This may be a function of the potassium buffering effects of the soils found in southern Alberta. With the exception of very sandy soils, most soils found in southern Alberta have high levels of K, much of which (90-98%) is in an unavailable/nonexchangeable form within soil minerals. Over a period of years, this unavailable K can move into available forms and vice-versa, depending on crop use and fertilizer K rates. The exchangeable form of K can then rapidly move into the soil solution in response to depleted K levels, where it can be taken up by plant roots. This dynamic equilibrium creates a labile pool of K in the soil, which is capable of maintaining a constant supply of plant-available K and which is also capable of masking effects of different application rates of fertilizer K.
- There was a trend toward slightly increased yield with increasing fertilizer K up to 248 lb K_2O/ac with a small decrease for the highest rate (349 lb K_2O/ac) but results did not show statistically significant differences and were all within a narrow range, between 21.5 and 23.1 t/ac (Figure 8b).
- In 2005, there was a trend toward increasing specific gravity with increasing fertilizer K but differences were not statistically significant (Figure 8c). These results are contrary to those seen in 2004, where a trend toward decreasing specific gravity with increasing fertilizer K was observed. The 2005 results may call into question the notion that manipulation of fertilizer K can be used to lower tuber specific gravity.

Figure 7. Potato petiole P, marketable yield and specific gravity for four different P fertilizer rates (2005).

a)



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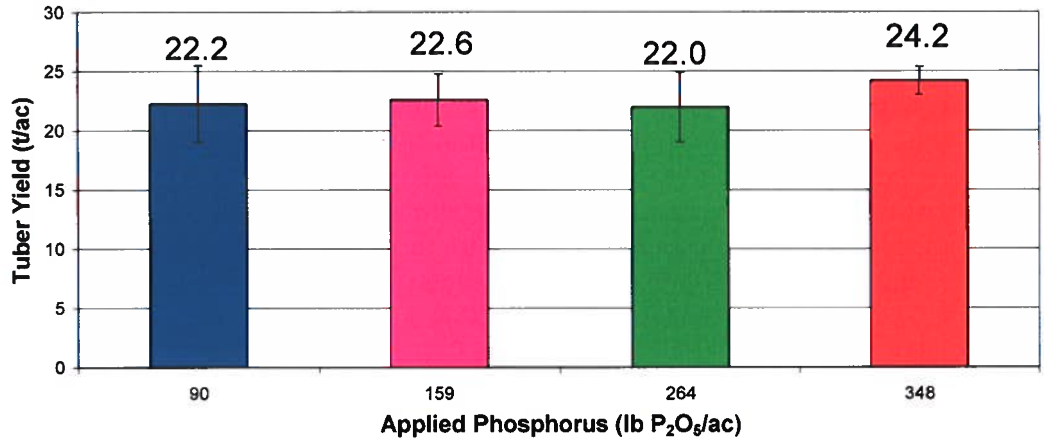

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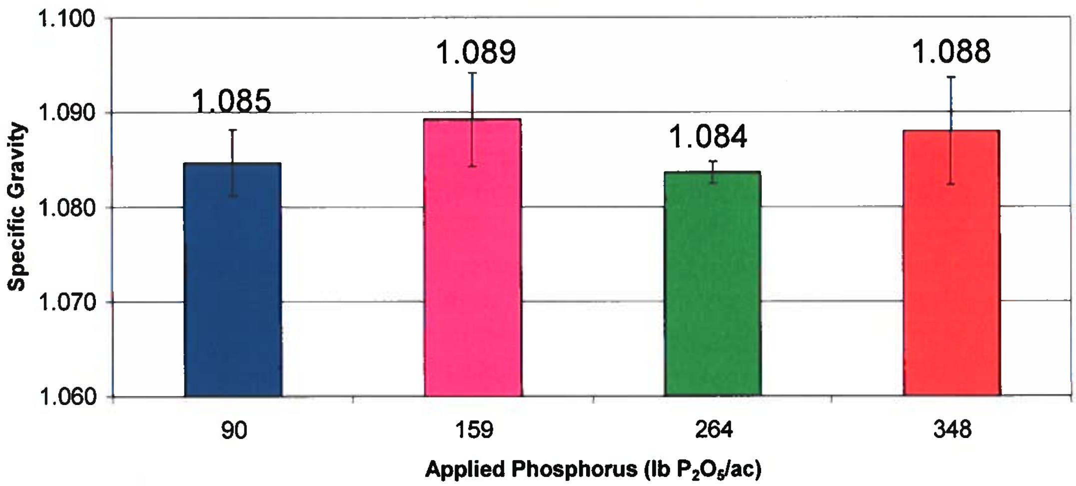
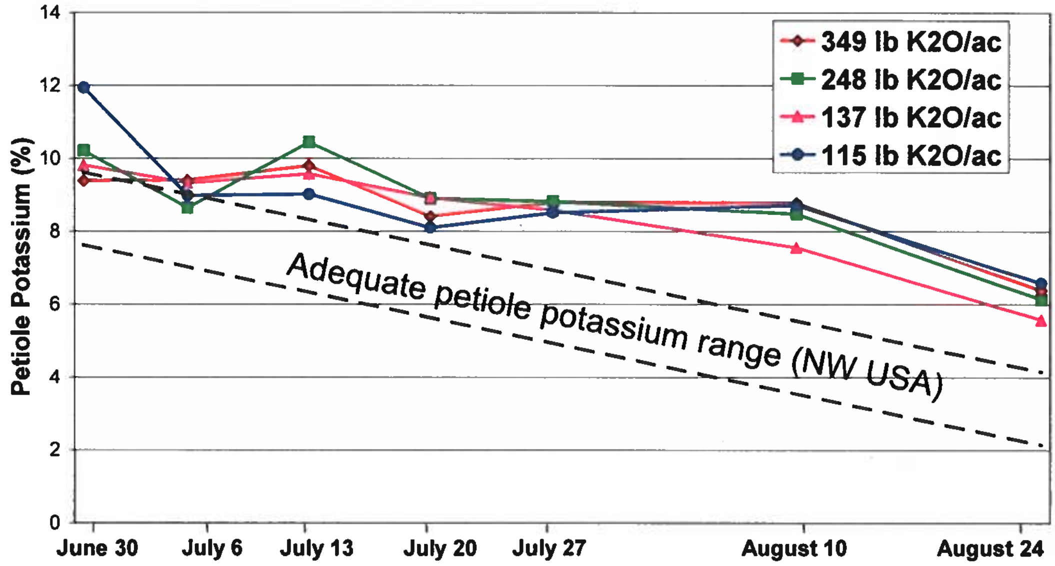


Figure 8. Potato petiole K, marketable yield and specific gravity for four different K fertilizer rates (2005).

a)



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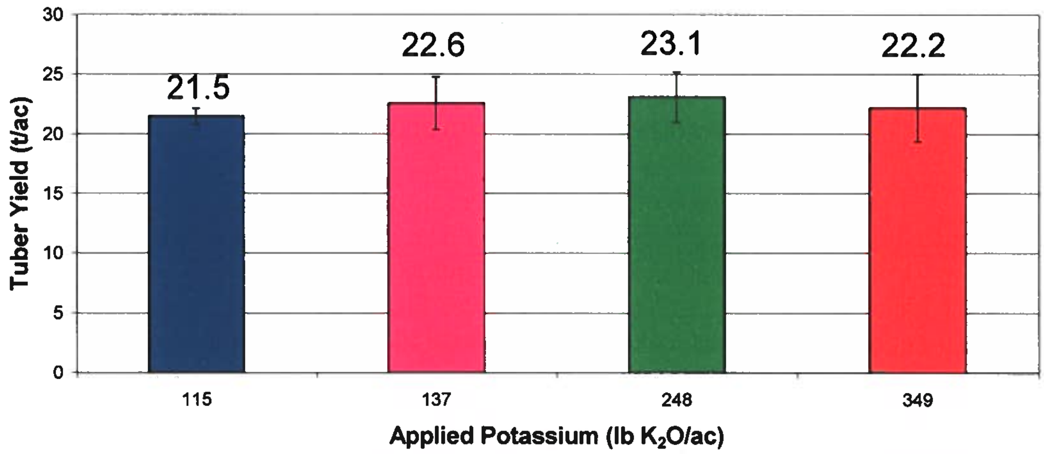

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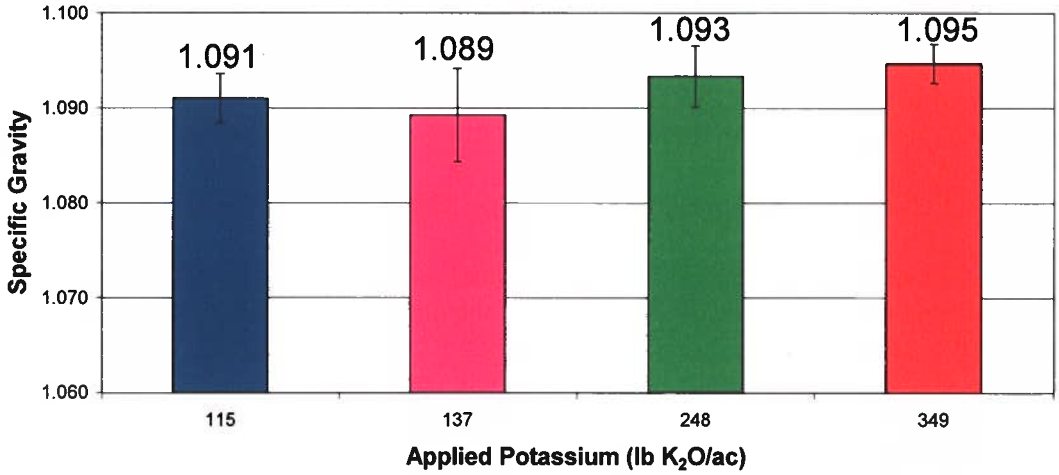


Optimal Petiole Concentration vs Days After Planting

Belanger et al. (2001 and 2003) proposed a technique for determining critical petiole nitrate nitrogen concentrations from experimental data. In addition to petiole nutrient concentrations, the Belanger technique requires several other measurements, such as shoot biomass and shoot nutrient concentration, that were not collected as part of this study due to cost constraints. The Belanger technique was adapted and applied to the data gathered in 2005. Only paired petiole and yield data were available so, rather than using a nitrogen nutrition index compared to yield as Belanger did, yield was compared to petiole nutrient concentration at each petiole sample date.

1. For the first step, a second order polynomial curve was fitted to the yield vs petiole nutrient relationship and the petiole concentration at the maximum yield value for the curve was recorded. This maximum occurred where the slope of the second order polynomial equalled zero. This was called the 100% relative yield (100%RY) petiole concentration. The maximum yield, designated as 100%RY, was multiplied by 0.9 to calculate the 90% relative yield (90%RY). Its corresponding petiole nutrient concentration was calculated for each petiole sampling date, from the formula for the second order polynomial best-fit line. For the seven petiole sampling dates in 2005, the chart showing data points, fitted curve and 100%RY and 90%RY values are shown for nitrogen (Figure 9), phosphorus (Figure 10) and potassium (Figure 11). The black circles indicate the actual data points and the "+" signs, along the best-fit curves, indicate the 90%RY and 100%RY values. The intercept of the best-fit lines was set to zero, in order to fix the shape of the second order polynomial as an inverted "U". This gives a relationship where yield increases with increasing petiole nutrient concentration to a point (100%RY), beyond which, yield actually decreases with increasing petiole nutrient concentration, as concentrations reach a level that is detrimental to tuber formation. The fit of these lines is highly variable ($r^2 = 0.070$ to 0.79 for NO_3-N; $r^2 = 0.10$ to 0.97 for P and $r^2 = 0.058$ to 0.87 for K).

2. For the second step of the adaptation of the Belanger procedure, the petiole nutrient concentrations at 100% and 90% relative yields are plotted as a function of the days after planting (DAP) for each corresponding date. In this study, there were seven petiole sampling dates, which corresponded to 69, 75, 82, 89, 96, 110 and 124 DAP. These graphs depict the optimal petiole nutrient concentration throughout the 2005 growing season (Figure 12), including the 100%RY (green circles) and 90%RY (blue squares) and their respective best-fit lines. Also shown on these graphs (dashed black lines) are the optimal ranges that have been suggested for the northwest USA (Schaupmeyer, 1999).

For the 2005 study site, the USA standard ranges are very similar for N, much higher for P and slightly lower for K. At the study site, for the 100%RY, the optimal petiole NO_3-N was nearly 24,000 ppm at 60 DAP and declined to 14,000 ppm by 125 DAP (Figure 12a). The following is the 2005 formula for the best-fit 100%RY relationship for NO_3-N, which holds for DAP = 69-124.

Petiole NO_3-N (ppm) = -153.7*DAP + 32826 **($r^2 = 0.43$)**

As discussed before, however, the actual relationship is more likely two lines, one for the tuber initiation growth stage (<80 DAP) and the other from the beginning of tuber bulking and onward (>80 DAP). Figure 13 shows the relationship, with both 2004 and 2005 (darker coloured markers) results. A difference in petiole nutrient concentrations has been noted in past studies between fields and between years (climate-effect) (Woods et al., 2004). This year-to-year difference is also noticeable in Figure 13 and will likely be apparent when the 2006 data is added. The following formulae are the best-fit 100%RY relationship for NO_3-N, in 2004 and 2005.

Petiole NO_3-N (ppm) = -363.7*DAP + 42884 **($r^2 = 0.49$) for DAP < 80**
Petiole NO_3-N (ppm) = -273.4*DAP + 44976 **($r^2 = 0.80$) for DAP > 80**

The 100%RY optimal P was approximately 0.24% at 60 DAP and declined a small amount to 0.21% by 125 DAP (Figure 12b). This relationship was nearly a flat line in 2005 and overall values are much smaller than in 2004, yet no negative impacts on yield were observed. For this reason, and because of corroborating data from past studies (Woods et al., 2004) it is felt that both the upper and lower limits for petiole P (as given by NW USA standards) is too high. Once the 2006 data is collected, a more precise estimate of this range will be calculated. The following formula is for the 2005 best-fit 100%RY relationship between petiole P and DAP, which hold for DAP = 69-124.

Petiole P (%) = -0.00021*DAP + 0.24 **($r^2 = 0.01$)**

The 100%RY optimal K was approximately 13.3% at 60 DAP and declined to 7.9% by 125 DAP (Figure 12c). The 2005 petiole K results are much higher than the 2004 results and than the adequate range from the NW USA. In 2005, the laboratory experienced problems with their equipment used for measuring K and results were re-analysed in January 2006. Results were adjusted to much higher than initial estimates. Results from previous studies (Konschuh 2001, McKenzie et al., 2002 and Woods et al., 2002) have indicated that a wider range for adequate petiole K will be more suitable in southern Alberta (Woods et al., 2004). Estimtes for this will be given after analysis of the final year (2006) of data. The following formula is for the 2005 best-fit 100%RY relationship between petiole K and DAP, which hold for DAP = 69-124.

Petiole K (%) = -0.0834*DAP + 18.3 **($r^2 = 0.17$)**

Similar to NO_3-N, petiole K optimal levels appear to follow two stages, one for prior to tuber bulking (<80 DAP) and the other from the beginning of tuber bulking and onward (>80 DAP) (Figure 12c). The 2006 results will be necessary to confirm this inference.

Figure 9. Russet Burbank potato tuber yield (t/ac) as a function of petiole nitrate nitrogen (ppm), showing data points, fitted second order curve and the 100%RY and 90%RY values, for seven 2005 petiole sampling dates.

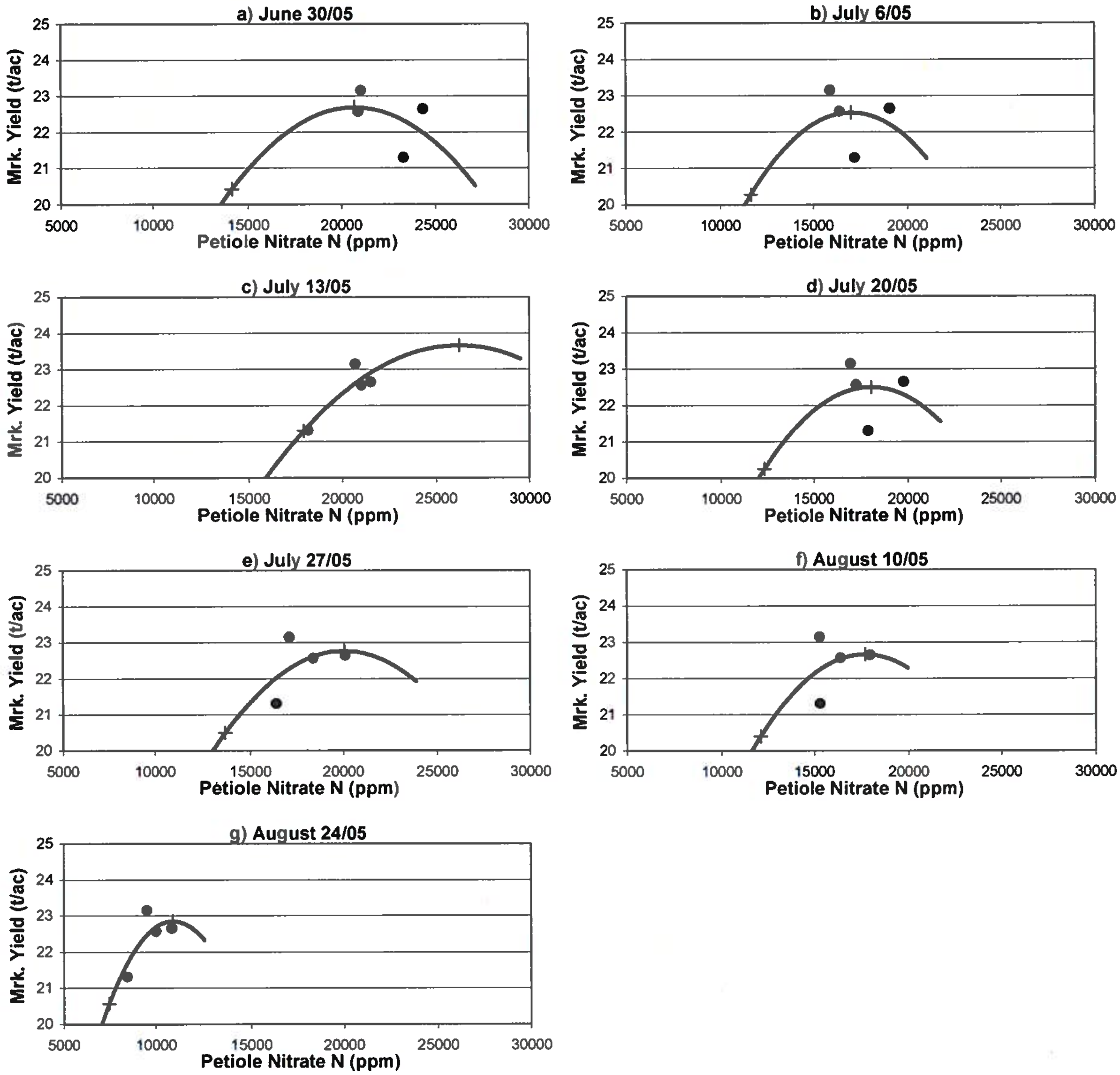


Figure 10. Russet Burbank potato tuber yield (t/ac) as a function of petiole phosphorus (%), showing data points, fitted second order curve and the 100%RY and 90%RY values, for seven 2005 petiole sampling dates.

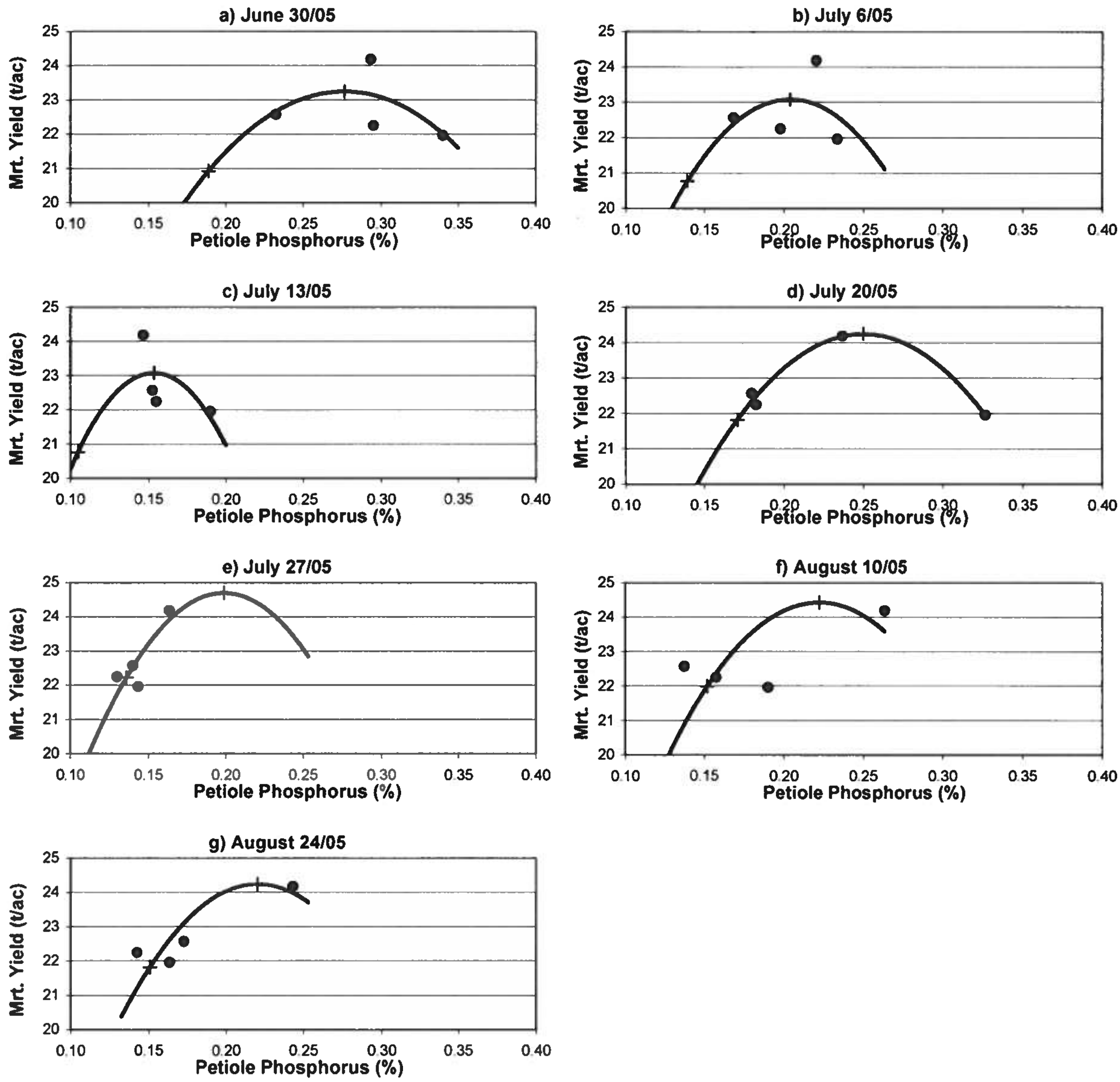


Figure 11. Russet Burbank potato tuber yield (t/ac) as a function of petiole potassium (%), showing data points, fitted second order curve and the 100%RY and 90%RY values, for seven 2005 petiole sampling dates.

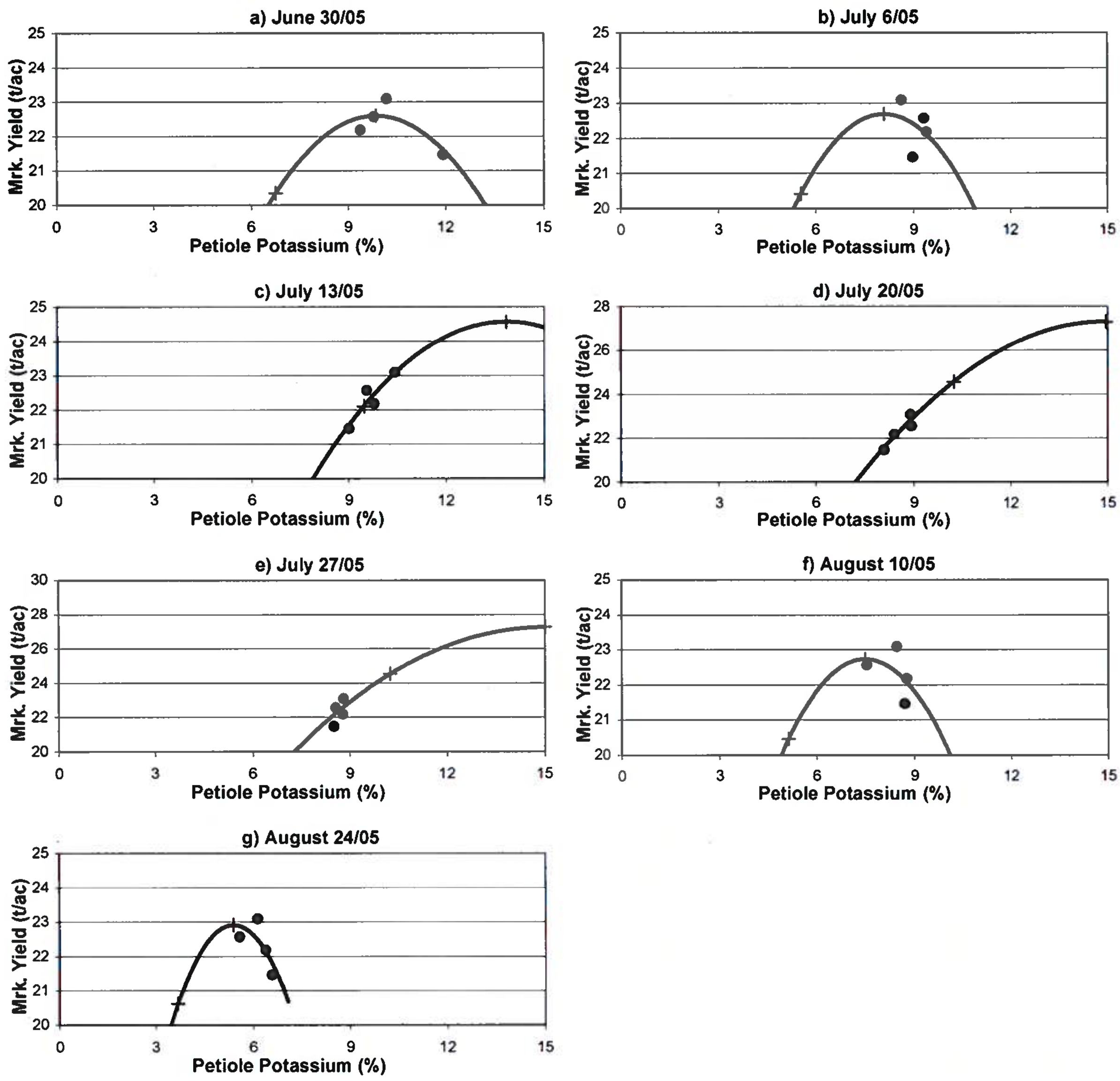
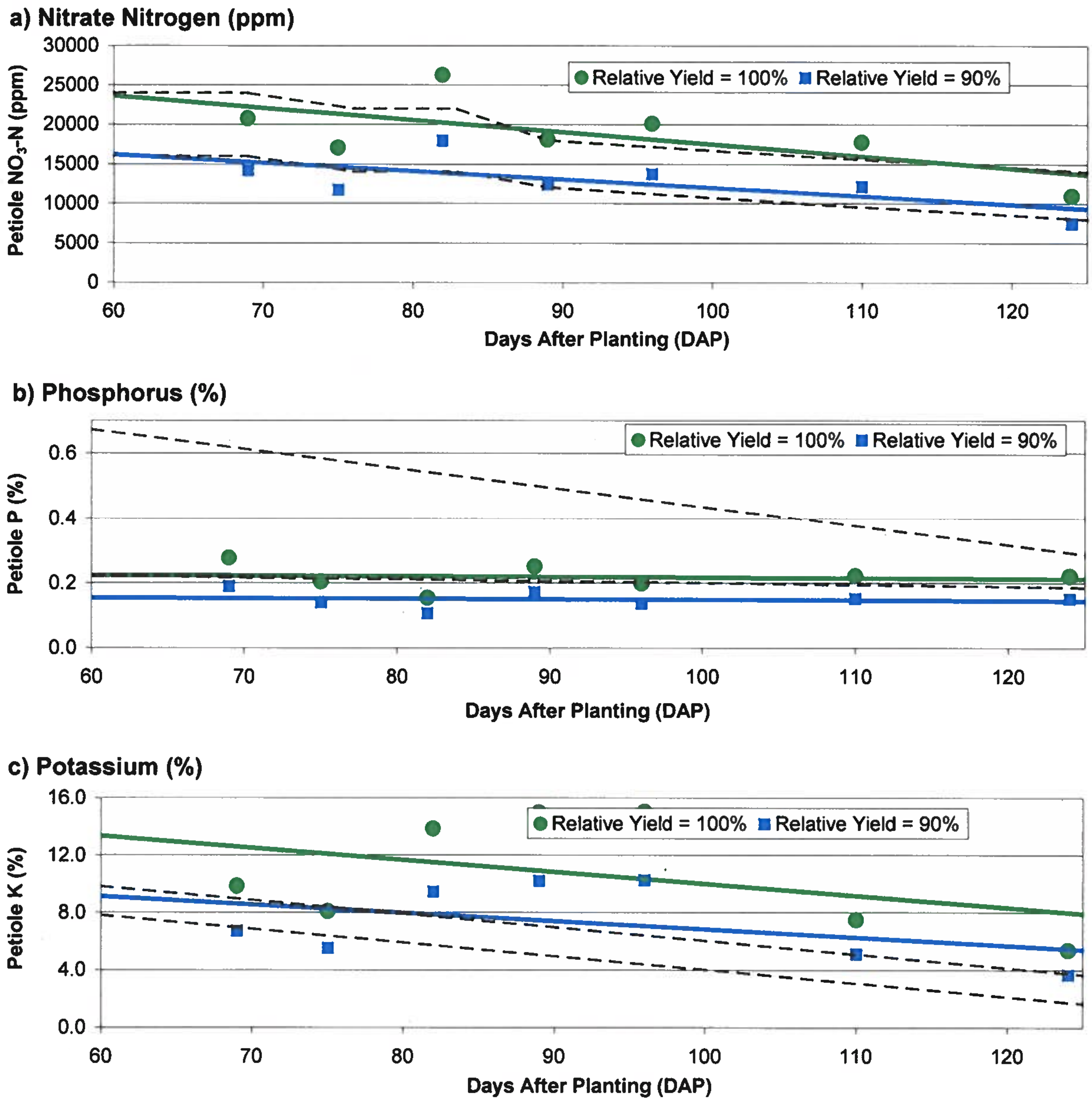
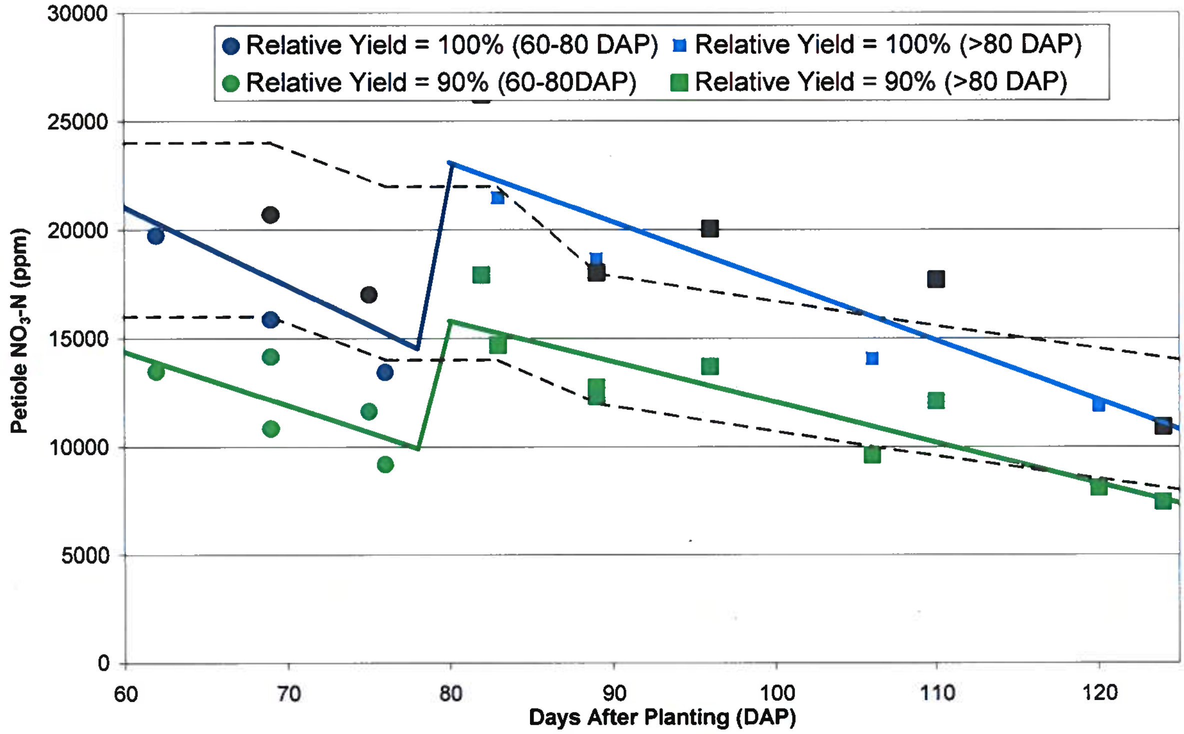


Figure 12. 100%RY and 90%RY petiole (a) nitrate nitrogen, (b) phosphorus and (c) potassium concentration as a function of days after planting, for the 2005 Taber site.





Summary

Petiole analysis results from 2005 corroborate previous studies, which have indicated that current recommendations may be high for phosphorus (P). Results also indicated that recommended nitrate nitrogen (N) and potassium (K) concentrations may need fine-tuning to suit southern Alberta growing conditions.

In the 2005 study, the relationships between petiole nutrient concentrations, tuber yield and specific gravity of Russet Burbank potatoes was examined. Although no statistical significance was found between treatments in yield and specific gravity results, there were some notable trends. For example, the highest N rate consistently showed the highest petiole N concentration. The highest rates of fertilizer P gave higher amounts of petiole P, throughout the growing season. Increasing rates of fertilizer K had no observable effect on petiole K. This year, there was a trend toward increasing specific gravity with increasing fertilizer K and decreasing specific gravity with increasing fertilizer N but differences were not statistically significant.

At the 2005 study site, the USA standard ranges were found to be somewhat high for P, slightly low for K and about right for NO_3-N. Results differed somewhat from the 2004 study and this highlights the fact that climatic differences also greatly impact petiole nutrient concentrations. The summer of 2005 will be remembered for its record rainfall and cool temperatures and this, no doubt had an effect on petiole nutrient concentrations. The results from the final year (2006) of this three-year study will be essential to estimate optimal petiole nutrient concentrations for southern Alberta.

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Appendix 1. Petiole nutrient N concentrations (ppm) for seven sample dates, ten treatments and four replications 2005.

		N (ppm)						
Trt	Rep	June 30	July 6	July 13	July 20	July 27	August 10	August 24
1	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1	2	21500	19200	16700	19800	16400	18200	10100
1	3	24000	16800	21900	19800	19200	16300	8400
1	4	24400	15600	15900	14100	13600	11400	6900
1	**Average**	**23300**	**17200**	**18167**	**17900**	**16400**	**15300**	**8467**
2	1	15500	17000	25300	15700	19600	15900	10500
2	2	21500	15300	18900	16500	14000	17900	10700
2	3	22800	16400	21000	20300	19600	15900	9300
2	4	24400	14900	17600	15300	15200	11400	7600
2	**Average**	**21050**	**15900**	**20700**	**16950**	**17100**	**15275**	**9525**
3	1	22400	16400	22300	17000	20400	18200	11000
3	2	26000	17200	21000	16500	18800	18200	11400
3	3	12100	15600	21900	19400	18000	14200	9100
3	4	23100	16400	18900	16100	16400	15000	8600
3	**Average**	**20900**	**16400**	**21025**	**17250**	**18400**	**16400**	**10025**
4	1	22000	16400	22700	17400	19200	18200	11000
4	2	23200	20700	21000	18600	19600	19500	11200
4	3	23600	17600	22700	21900	20800	16300	9100
4	4	28500	21500	19700	21100	20800	17900	12200
4	**Average**	**24325**	**19050**	**21525**	**19750**	**20100**	**17975**	**10875**
5	1	22000	15600	21900	17000	19200	18200	10700
5	2	25200	18400	18900	18200	18400	17100	9100
5	3	22800	16000	22300	17800	21200	14200	11000
5	4	25200	24600	18000	17400	18800	11800	8800
5	**Average**	**23800**	**18650**	**20275**	**17600**	**19400**	**15325**	**9900**
6	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6	2	24400	17200	18900	18200	18800	20300	11800
6	3	24800	19600	22300	21500	19600	16700	11800
6	4	26800	19200	18400	17400	18400	15900	13300
6	**Average**	**25333**	**18667**	**19867**	**19033**	**18933**	**17633**	**12300**
7	1	22000	16800	22700	15700	20000	16300	10700
7	2	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7	3	22400	19200	24000	18600	16000	21100	6300
7	4	22000	18000	18400	16100	16800	13000	10700
7	**Average**	**22133**	**18000**	**21700**	**16800**	**17600**	**16800**	**9233**
8	1	21500	17200	21400	15700	18800	18700	9900
8	2	26800	18800	17100	16500	17200	18200	12000
8	3	18300	16000	21400	19400	18400	15500	9500
8	4	26800	18400	16700	13600	17200	15000	11800
8	**Average**	**23350**	**17600**	**19150**	**16300**	**17900**	**16850**	**10800**
9	1	19100	16800	22300	17800	21200	17900	9100
9	2	n/a	n/a	n/a	n/a	n/a	n/a	n/a
9	3	22800	16400	19700	20300	17600	13800	12200
9	4	25200	16800	16700	18600	16800	12200	8800
9	**Average**	**22367**	**16667**	**19567**	**18900**	**18533**	**14633**	**10033**
10	1	22000	18400	24000	17800	19600	18200	10900
10	2	22800	16400	17600	14500	15200	18700	15200
10	3	22000	16400	22700	21900	21200	16300	12900
10	4	25200	16400	15000	14500	15200	11400	8400
10	**Average**	**23000**	**16900**	**19825**	**17175**	**17800**	**16150**	**11850**

Appendix 2. Petiole nutrient P concentrations (%) for seven sample dates, ten treatments and four replications 2005.

					P (%)			
Trt	**Rep**	**June 30**	**July 6**	**July 13**	**July 20**	**July 27**	**August 10**	**August 24**
1	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1	2	0.45	0.32	0.16	0.29	0.16	0.25	0.16
1	3	0.38	0.21	0.18	0.23	0.21	0.16	0.14
1	4	0.3	0.17	0.13	0.14	0.08	0.14	0.11
1	**Average**	**0.38**	**0.23**	**0.16**	**0.22**	**0.15**	**0.18**	**0.14**
2	1	0.25	0.18	0.15	0.29	0.13	0.22	0.22
2	2	0.29	0.21	0.15	0.13	0.15	0.19	0.16
2	3	0.25	0.16	0.18	0.26	0.18	0.14	0.16
2	4	0.25	0.18	0.15	0.16	0.1	0.14	0.25
2	**Average**	**0.26**	**0.18**	**0.16**	**0.21**	**0.14**	**0.17**	**0.20**
3	1	0.2	0.183	0.09	0.21	0.16	0.14	0.27
3	2	0.33	0.18	0.18	0.21	0.15	0.16	0.14
3	3	0.25	0.16	0.16	0.16	0.15	0.14	0.14
3	4	0.15	0.15	0.18	0.14	0.1	0.11	0.14
3	**Average**	**0.23**	**0.17**	**0.15**	**0.18**	**0.14**	**0.14**	**0.17**
4	1	0.25	0.16	0.11	0.21	0.13	0.16	0.14
4	2	0.3	0.21	0.16	0.18	0.21	0.27	0.16
4	3	0.3	0.18	0.13	0.18	0.15	0.16	0.14
4	4	0.38	0.29	0.26	0.16	0.13	0.22	0.19
4	**Average**	**0.31**	**0.21**	**0.17**	**0.18**	**0.16**	**0.20**	**0.16**
5	1	0.18	0.16	0.09	0.23	0.11	0.19	0.14
5	2	0.3	0.18	0.16	0.18	0.15	0.11	0.08
5	3	0.3	0.17	0.13	0.18	0.13	0.14	0.16
5	4	0.4	0.28	0.24	0.14	0.13	0.19	0.19
5	**Average**	**0.30**	**0.20**	**0.16**	**0.18**	**0.13**	**0.16**	**0.14**
6	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6	2	0.25	0.2	0.18	0.54	0.15	0.19	0.14
6	3	0.39	0.25	0.18	0.22	0.18	0.22	0.19
6	4	0.38	0.25	0.21	0.22	0.1	0.16	0.16
6	**Average**	**0.34**	**0.23**	**0.19**	**0.33**	**0.14**	**0.19**	**0.16**
7	1	0.25	0.16	0.13	0.23	0.13	0.25	0.19
7	2	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7	3	0.4	0.29	0.13	0.25	0.21	0.35	0.38
7	4	0.23	0.21	0.18	0.23	0.15	0.19	0.16
7	**Average**	**0.29**	**0.22**	**0.15**	**0.24**	**0.16**	**0.26**	**0.24**
8	1	0.2	0.18	0.09	0.18	0.08	0.19	0.16
8	2	0.28	0.16	0.15	0.13	0.13	0.16	0.11
8	3	0.37	0.26	0.24	0.16	0.13	0.19	0.14
8	4	0.43	0.24	0.26	0.11	0.13	0.19	0.14
8	**Average**	**0.32**	**0.21**	**0.19**	**0.15**	**0.12**	**0.18**	**0.14**
9	1	0.28	0.2	0.11	0.26	0.13	0.14	0.14
9	2	n/a	n/a	n/a	n/a	n/a	n/a	n/a
9	3	0.25	0.16	0.29	0.18	0.13	0.14	0.14
9	4	0.35	0.21	0.18	0.19	0.13	0.15	0.14
9	**Average**	**0.29**	**0.19**	**0.19**	**0.21**	**0.13**	**0.14**	**0.14**
10	1	0.27	0.21	0.13	0.21	0.11	0.16	0.15
10	2	0.37	0.21	0.16	0.18	0.13	0.19	0.16
10	3	0.4	0.24	0.16	0.22	0.18	0.22	0.23
10	4	0.3	0.18	0.16	0.1	0.1	0.08	0.1
10	**Average**	**0.34**	**0.21**	**0.15**	**0.18**	**0.13**	**0.16**	**0.16**

Appendix 3. Petiole nutrient K concentrations (%) for seven sample dates, ten treatments and four replications 2005.

		K (%)						
Trt	**Rep**	**June 30**	**July 6**	**July 13**	**July 20**	**July 27**	**August 10**	**August 24**
1	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1	2	10.38	9.92	8.02	13.78	6.84	6.76	6.17
1	3	10.76	10.14	8.6	8.54	9.96	8.06	6.19
1	4	12.1	9.24	7.16	6.8	5.5	5.22	3.14
1	**Average**	**11.08**	**9.77**	**7.93**	**9.71**	**7.43**	**6.68**	**5.17**
2	1	10.6	15.96	8.58	8.4	8.3	7.12	6.52
2	2	8.74	10.52	7.24	9.34	6.54	9.04	6.46
2	3	9.54	10.98	10.76	9.1	8.7	7.44	5.9
2	4	9.1	8.38	8.86	11.32	7.78	6.45	4.46
2	**Average**	**9.50**	**11.46**	**8.86**	**9.54**	**7.83**	**7.51**	**5.84**
3	1	10.9	9.3	10.08	10.1	9.28	7.64	7.23
3	2	11.36	9.38	8.58	8.74	8.82	9.26	5.46
3	3	7.64	9.2	10.86	8.24	8.34	6.78	4.81
3	4	9.28	9.38	8.7	8.62	7.82	6.53	4.79
3	**Average**	**9.80**	**9.32**	**9.56**	**8.93**	**8.57**	**7.55**	**5.57**
4	1	9.82	9.16	9.76	11.04	8.24	10.48	7.01
4	2	7.78	8.68	7.98	8.56	7.44	11.4	6.26
4	3	15.9	9.3	10.38	8.84	10.26	6.92	6.01
4	4	14.12	11.28	10.46	7.16	10.68	8.64	6.44
4	**Average**	**11.91**	**9.61**	**9.65**	**8.90**	**9.16**	**9.36**	**6.43**
5	1	9.07	10.74	7.06	9.46	9.06	7.5	6.41
5	2	8.76	10.08	8.54	8.38	8.84	7.22	4.78
5	3	10.34	9.34	8.04	8.12	11.56	8.45	6.18
5	4	15.4	12.56	12	10.88	12.08	8.37	8.49
5	**Average**	**10.89**	**10.68**	**8.91**	**9.21**	**10.39**	**7.89**	**6.47**
6	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6	2	8.52	14.24	8.68	10.14	6.86	10.26	8.14
6	3	16.03	10.01	9.2	13.14	8.56	9.5	6.89
6	4	7.12	8.38	8.32	7.64	7.42	6.22	4.65
6	**Average**	**10.56**	**10.88**	**8.73**	**10.31**	**7.61**	**8.66**	**6.56**
7	1	11.5	10.1	7.16	7.32	7.06	8.44	5.92
7	2	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7	3	10.28	9.84	10.7	8.1	10.94	10.21	7.98
7	4	9.12	6.96	7.9	8.34	6.94	6.37	5.47
7	**Average**	**10.30**	**8.97**	**8.59**	**7.92**	**8.31**	**8.34**	**6.46**
8	1	10.14	11.56	9.94	9.38	7.86	10.14	6.51
8	2	10.36	7.64	8.75	8.5	7	8.74	7.82
8	3	16.24	9.14	9.56	9.72	11.54	8.25	7.03
8	4	10.96	7.56	7.76	4.76	7.6	7.7	4.9
8	**Average**	**11.93**	**8.98**	**9.00**	**8.09**	**8.50**	**8.71**	**6.57**
9	1	11.7	7.84	11.62	8.86	7.02	10.46	6.67
9	2	n/a	n/a	n/a	n/a	n/a	n/a	n/a
9	3	9.44	9.06	8.74	7.88	11.68	5.87	6.02
9	4	9.44	8.98	10.94	9.94	7.74	9.07	5.66
9	**Average**	**10.19**	**8.63**	**10.43**	**8.89**	**8.81**	**8.47**	**6.12**
10	1	9.1	9.8	8.56	8.94	8.62	9.4	6.5
10	2	9.02	11.8	10.08	9.08	7.2	10.08	6.69
10	3	9.88	7.58	12.82	8.12	13.04	10.08	8.6
10	4	9.5	8.38	7.7	7.46	6.28	5.51	3.69
10	**Average**	**9.38**	**9.39**	**9.79**	**8.40**	**8.79**	**8.77**	**6.37**

Appendix 4. Potato marketable yield (t/ac), mean tuber weight of marketable potatoes (g), % smalls by weight and specific gravity 2005.

Trt	Rep	Marketable Tubers Yield(t/ac)	MTW (g)	% Smalls by Weight	Specific Gravity
1	1	n/a	n/a	n/a	n/a
1	2	20.7	254	17	1.092
1	3	25.0	285	15	1.084
1	4	18.3	254	23	1.092
1	**Average**	**21.3**	**264**	**18**	**1.089**
2	1	25.3	273	16	1.093
2	2	21.0	280	17	1.084
2	3	25.0	303	13	1.093
2	4	21.4	290	17	1.093
2	**Average**	**23.2**	**286**	**16**	**1.091**
3	1	23.7	295	13	1.095
3	2	23.6	271	14	1.083
3	3	23.7	296	14	1.090
3	4	19.3	271	18	1.089
3	**Average**	**22.6**	**283**	**15**	**1.089**
4	1	24.4	280	14	1.094
4	2	20.2	287	17	1.079
4	3	23.4	315	14	1.087
4	4	n/a	n/a	n/a	n/a
4	**Average**	**22.7**	**294**	**15**	**1.087**
5	1	24.9	298	13	1.088
5	2	23.3	312	13	1.085
5	3	18.7	283	16	1.081
5	4	n/a	n/a	n/a	n/a
5	**Average**	**22.3**	**297**	**14**	**1.085**
6	1	n/a	n/a	n/a	n/a
6	2	20.5	328	15	1.083
6	3	25.4	310	12	1.083
6	4	20.1	287	15	1.085
6	**Average**	**22.0**	**309**	**14**	**1.084**
7	1	25.0	291	15	1.092
7	2	n/a	n/a	n/a	n/a
7	3	n/a	n/a	n/a	n/a
7	4	23.4	274	11	1.084
7	**Average**	**24.2**	**283**	**13**	**1.088**
8	1	20.8	305	11	1.088
8	2	22.0	274	16	1.092
8	3	22.1	294	12	1.090
8	4	21.0	265	14	1.094
8	**Average**	**21.5**	**284**	**13**	**1.091**
9	1	25.4	293	12	1.092
9	2	n/a	n/a	n/a	n/a
9	3	22.5	352	16	1.097
9	4	21.4	280	15	1.091
9	**Average**	**23.1**	**308**	**14**	**1.093**
10	1	24.8	287	13	1.093
10	2	22.5	387	13	1.094
10	3	n/a	n/a	n/a	n/a
10	4	19.2	261	19	1.097
10	**Average**	**22.2**	**312**	**15**	**1.095**