Petiole Nutrient Recommendations for Russet Burbank Potatoes Grown in Southern Alberta (2004-2007)

Shelley Woods[1], Len Hingley[2], and Michele Konschuh[3]

[1] Soil and Water Research Scientist, Irrigation and Farm Water Division, ARD. Lethbridge, Alberta.
[2] Soil and Water Technologist, Irrigation and Farm Water Division, ARD. Brooks, Alberta.
[3] Potato Research Scientist, Crop Diversification Centre South, ARD. Brooks, Alberta.

Alberta Agriculture and Rural Development
Lethbridge, Alberta
shelley.a.woods@gov.ab.ca

2008

Citation
Woods, S. A., Hingley, L. E., and Konschuh, M. N. 2008. Petiole nutrient recommendations for Russet Burbank potatoes grown in southern Alberta (2004-2007). Alberta Agriculture and Rural Development, Lethbridge, Alberta, Canada. 40 pp.

Published by
Alberta Agriculture and Rural Development
Lethbridge, Alberta, Canada

Printed in Canada

Copies of this report are available from
Alberta Agriculture and Rural Development
Agriculture Centre
100, 5401 – 1 Avenue South
Lethbridge, Alberta
Canada, T1J 4V6
Phone (403) 381-5140

ABSTRACT

A 3-yr project was conducted by Alberta Agriculture and Rural Development (ARD) staff, with financial support from the Potato Growers of Alberta (PGA). The goals of the project were: to determine the optimal petiole nutrient concentrations for Russet Burbank potatoes in southern Alberta; to determine the relationship, if any, between potato petiole nutrient concentrations and tuber specific gravity; and to compare these relationships to those found in previously-collected, field-scale petiole data. The collection and analysis of potato petiole samples are used to monitor the nutrient status of potato crops throughout the growing season. This can be a useful and timely technique for identifying any crop deficiencies that may occur mid-season; however, the currently-recommended petiole nutrient concentrations have come from research conducted in the northwest USA and previous studies in southern Alberta have indicated that these recommendations may be high for potassium (K) and somewhat high for phosphorus (P), especially early in the growing season. Based on results from this study, new optimal petiole nutrient ranges have been proposed and the suggested petiole nitrate nitrogen (NO_3-N) range is slightly lower than the northwest USA standards at the beginning of the growing season (Days After Planting (DAP) < 80) and late in the growing season (DAP > 105). The proposed optimal petiole phosphorus ranges are substantially less than the northwest USA standards. The proposed petiole potassium ranges are broader than the northwest USA standards overall, are similar early in the growing season (DAP < 80), and the upper limits are greater later in the growing season. The proposed petiole nutrient recommendations were compared to previously-collected data and gave reasonable results for P and K. There was a great deal of scatter in the previously-collected NO_3-N data, as petiole nitrate nitrogen can be affected by many factors in addition to available soil nitrogen, such as climate (temperature and precipitation), soil texture, weed competition, insects, petiole sampling technique, location of samples within the field, and laboratory analysis techniques. Potassium fertilizer did not have a consistent impact on specific gravity. Petiole nutrient concentrations should be considered on a field-specific basis. Spatial variability exists across any field, even if the entire field receives identical fertilizer application, so care must be taken to choose petioles from benchmark locations that are representative of the field, in terms of location and plant appearance. The proposed petiole nutrient recommendations drawn from this study are based on three years of experimental data and it is suggested that the potato industry continue to refine these recommendations.

ACKNOWLEDGEMENTS

This project was made possible with the financial support of the Potato Growers of Alberta (PGA) and Alberta Agriculture and Rural Development (ARD). The PGA also provided equipment, manpower, and expertise to assist with the tuber harvest. McCain Foods provided funding to allow an additional petiole sampling to be added each year of the study. Sandberg Laboratories Ltd. provided a discounted analysis rate. Jerry Zeinstra, Greg Nakamura, and Tony Bos are kindly acknowledged for hosting the trials. Numerous staff assisted with the collection and processing of petiole and tuber samples: Simone Dalpe, Sarah Williams, Shauna Pow, Linda Wenger, Alfonso Parra, Wendy Frank, Nicole Seto, Pamela Moeller, Lucinda Noronha, Corrine Thiessen-Hepner, Brent Nicol, Jonathan Peters, Darren Peterson, Rod Bennett, Jeff Bronsch, Mitchell Froyman, Miranda Mathies, Ryan Moeller, and Ralaina Virostek.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

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 (NO_3-N, P, and K) concentrations have come from research conducted in the northwest United States (Schaupmeyer *pers. commun.*), 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 (NO_3-N) concentrations may need fine-tuning to suit southern Alberta growing conditions. This was the impetus behind a project to determine petiole nutrient recommendations for Russet Burbank potatoes grown in southern Alberta.

Objectives

A three-year research project was initiated by Alberta Agriculture and Rural Development (ARD), in 2004, with the support of the Potato Growers of Alberta (PGA) to address the discrepancies between current petiole recommendations and previous data. The main objective was to determine the optimal petiole nutrient concentrations for Russet Burbank potatoes in southern Alberta. Another objective was to determine the relationship, if any, between potato petiole nutrient concentrations and tuber specific gravity. The third objective was to compare these relationships to those found in field-scale petiole data.

METHODS AND MATERIALS

Site Selection

Cooperating growers were chosen based on their willingness to participate in the project and allow a small potion of their field to be reserved for differential fertilizer applications. Preference was given to sites where spring nitrogen applications had not yet been applied. The 2004 site was approximately 15 km east of Taber, Alberta (Fig. 1), on a coarse-textured Orthic Brown Chernozemic soil. In 2005, the project was conducted on a field 10 km south of Taber, Alberta (Fig. 1), on a medium-textured Orthic Brown Chernozemic soil. In 2006, a suitable field was not located, so the final year of the study was completed in 2007, on a field approximately 10 km northeast of Coaldale, Alberta (Fig. 1), on a medium-textured Orthic Dark Brown Chernozemic soil.

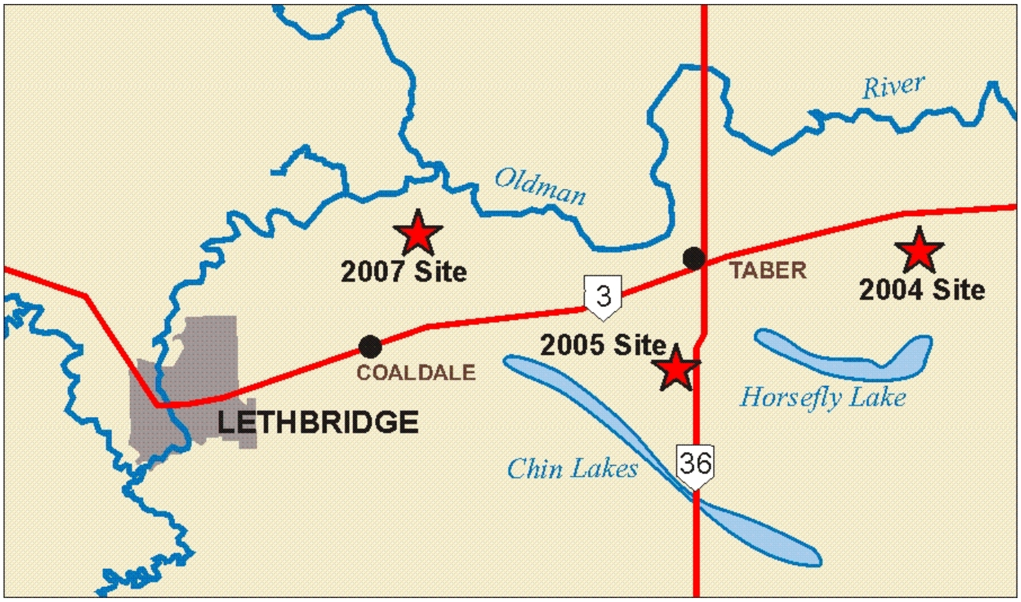


Figure 1. Petiole study site (map courtesy of Brian Coffey, ARD).

Current Petiole Standards

Information on current recommendations for petiole nutrient concentrations is difficult to find and the northwest USA standards used for comparison in this study were collected and kindly supplied by Clive Schaupmeyer in his former capacity as potato specialist with Alberta Agriculture and Rural Development (Table 1).

Table 1. Current petiole nutrient (NO_3-N, P, and K) recommendations based on information from the northwest United States (NW USA) (Schaupmeyer *pers. commun.*).

Days After Planting (DAP)	NW USA minimum	NW USA maximum
	Nitrate Nitrogen (ppm)	
60	16000	24000
69	16000	24000
76	14000	22000
83	14000	22000
89	12000	18000
106	10000	16000
	Phosphorus (%)	
69	0.62	0.22
89	0.5	0.2
106	0.4	0.2
	Potassium (%)	
69	9	7
89	7	5
106	5.5	3.5

Experimental Design

Ten rates of N, P, and K fertilizers were surface applied on April 20, 2004 (Table 2), April 20-21, 2005 (Table 3), and April 17, 2007 (Table 4), to strips in a small portion of fields of grower-managed Russet Burbank potatoes in southern Alberta (Fig. 1). The 10 treatments consisted of four different rates each of N, P, and K fertilizer, where the other nutrients were held constant. In 2004 and 2005, each treatment plot was eight rows wide (24 ft) and 115 ft long. In 2007, each treatment plot was six rows wide (18 ft) and 115 ft long. All plots ran adjacent to a pivot road. There were a total of four randomized replications of the experiment and the plots covered a total area of 2.5 ac in 2004 and 2005, and 1.9 ac in 2007.

Because of flooding in the study field in 2005, 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 four plots. Late-season flooding also made an additional four low-lying plots inaccessible at harvest (Rep 3, Treatments 7 and 10 and Rep 4, Treatments 4 and 5), so yield data were not collected for them.

Due to an error in the application rate of K on several plots in Rep 2, data from four plots were not used in results calculations. On August 10, 2007, the crop was damaged by a hail storm that swept through southern Alberta. Crop damage was slightly worse on the north half of the field than the south half. The hail likely had a detrimental effect on overall yields; however, the methodology used in this experiment compares the relative differences in yield between fertilizer treatments, not absolute yield values. Therefore, the hail should not have a detrimental effect on the veracity of the experimental results.

Fertilizer Applications

Taber 2004. In the fall of 2003, the field received a fertilizer application of 130 lb/ac N and 50 lb/ac K_2O. Soil samples taken on April 5, 2004, after the grower applied fall fertilizer and just prior to the individual plot fertilization, indicated that there was a total of 192 lb NO_3-N /ac, 144 lb P/ac, and 1647 lb K/ac in the surface 2 ft of soil.

The experimental rates of fertilizer were applied on April 20, 2004. The fertilizer rates for the experimental treatments were chosen to create four increasing amounts of one nutrient, while holding the other two nutrients constant. Treatments 1, 2, 3, and 4 had increasing levels of N, while P and K were kept the same; Treatments 5, 6, 3, and 7 received increasing amounts of fertilizer P, while N and K remained the same; and Treatments 8, 9, 3, and 10 received increasing amounts of fertilizer K, while N and P applications were the same (Table 2). These increasing amounts are shown in colour and correspond to the colours used in subsequent figures. At hilling in the spring of 2004, starter fertilizer (34 lb/ac N and 10 lb/ac P_2O_5) was applied to the entire field, including the research plot. The plot also received three applications of fertigation and one application of foliar feed (Table 2).

Table 2. Fertilizer schedule (lb/ac) in 2003-2004.

Treatments		Grower Applied 2003-2004										Experiment Amts			Total		
		Fall 2003 (130-0-50) Oct 18/03		Hilling (34-0-0) +P		Foliar Feed (20-20-20) July 9/04			Fertigation (20-0-0)			Apr 20/04					
									Jn 25	Jl 5	Jl 15						
		N	K_2O	N	P_2O_5	N	P_2O_5	K_2O	N	N	N	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Nitrogen	**1**	130	50	34	10	5	5	5	15	15	15	**29**	122	62	**243**	137	117
	2	130	50	34	10	5	5	5	15	15	15	**41**	122	62	**255**	137	117
	3	130	50	34	10	5	5	5	15	15	15	**58**	122	62	**272**	137	117
	4	130	50	34	10	5	5	5	15	15	15	**153**	122	62	**367**	137	117
Phosphorus	**5**	130	50	34	10	5	5	5	15	15	15	60	**0**	62	274	**15**	117
	6	130	50	34	10	5	5	5	15	15	15	58	**57**	62	272	**72**	117
	3	130	50	34	10	5	5	5	15	15	15	58	**122**	62	272	**137**	117
	7	130	50	34	10	5	5	5	15	15	15	54	**231**	62	268	**246**	117
Potassium	**8**	130	50	34	10	5	5	5	15	15	15	58	122	**0**	272	137	**55**
	9	130	50	34	10	5	5	5	15	15	15	58	122	**29**	272	137	**85**
	3	130	50	34	10	5	5	5	15	15	15	58	122	**62**	272	137	**117**
	10	130	50	34	10	5	5	5	15	15	15	58	122	**183**	272	137	**238**

Taber 2005. 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 there was a total of 297 lb NO_3-N/ac, 145 lb P/ac, and 1994 lb K/ac in the surface 2 ft of soil. The experimental rates of fertilizer were applied on April 20-21, 2005. The fertilizer rates for the treatments were chosen to create four increasing amounts of one nutrient, while holding the other two constant (Table 3).

Table 3. Fertilizer schedule (lb/ac) in 2004-2005.

Trtmt		Grower Applied 2004-2005						Experiment Amts			Total		
		Fall 2004			Planting	Top dressed	Fertigation	Apr 20-21/05					
		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**

Coaldale 2007. In the fall of 2006, the entire field received an application of composted manure. Fall 2006 and spring 2007 applications of mineral fertilizer were not applied to the area where the experiment was conducted. Soil samples taken on September 18, 2006, indicated there was a total of 32 lb NO_3-N/ac in the surface 2 ft and 21 lb P/ac and 1123 lb K/ac in the surface foot of soil.

The experimental rates of fertilizer were applied on April 17, 2007. The fertilizer rates for the experimental treatments were chosen to create four increasing amounts of one nutrient, while holding the other two constant (Table 4). These increasing amounts are shown in colour and correspond to the colours used in subsequent figures. The field also received eight applications of fertigation between June 15 and August 18, 2007 (Table 4).

Table 4. Fertilizer schedule (lb/ac) in 2006-2007.

	Trtmt	**Grower Applied 2006-2007***					**Experiment Amts**			**Total**		
		Fall 2006 Compost			**Fertigation**		**Apr 17/07**					
		N	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**N**	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**K_2O**
Nitrogen	**1**	50	60	105	101	17	**24**	101	75	**175**	178	180
	2	50	60	105	101	17	**151**	101	75	**302**	178	180
	3	50	60	105	101	17	**200**	101	75	**351**	178	180
	4	50	60	105	101	17	**250**	101	75	**401**	178	180
Phosphorus	**5**	50	60	105	101	17	200	**0**	75	351	**77**	180
	3	50	60	105	101	17	200	**101**	75	351	**178**	180
	6	50	60	105	101	17	201	**151**	75	352	**228**	180
	7	50	60	105	101	17	200	**201**	75	351	**278**	180
Potassium	**8**	50	60	105	101	17	200	101	**0**	351	178	**105**
	3	50	60	105	101	17	200	101	**75**	351	178	**180**
	9	50	60	105	101	17	200	101	**152**	351	178	**257**
	10	50	60	105	101	17	200	101	**206**	351	178	**311**

Petiole Sampling

Petiole samples were collected and analyzed for each plot on June 29, July 6, 13, 20, and 25, and August 12 and 26, 2004; on June 30, July 6, 13, 20, and 27, and August 10 and 24, 2005; and on June 27, July 4, 11, 18, and 25, and August 8 and 22, 2007. The fourth leaf stem (petiole) from the top of the main stem was taken and leaflets were removed in the field (Fig. 2). Approximately 80 petioles were collected from each plot, at each sampling date.

Within each plot, approximately 20 petioles were collected from the second, third, sixth, and seventh potato rows in 2004 and 2005 and from either the second or the sixth rows on alternating weeks in 2007. Unlike previous years, the 2007 plots consisted of six rows instead of eight. This was because the cooperating grower utilized a six-row harvester, so this size of plot was most suitable. Staff were instructed to sample representative plants only and to avoid any unhealthy or overly advanced plants. Staff were instructed to only walk in furrows between the second and third rows and between the sixth and seventh rows in 2004 and 2005 and between the first and second or the fifth and sixth in 2007, in order to preserve the middle two rows for tuber harvest. Field staff were also instructed to only walk between rows at the border between two plots. 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 in 2005, initial K results were low and samples required re-analysis during the winter.

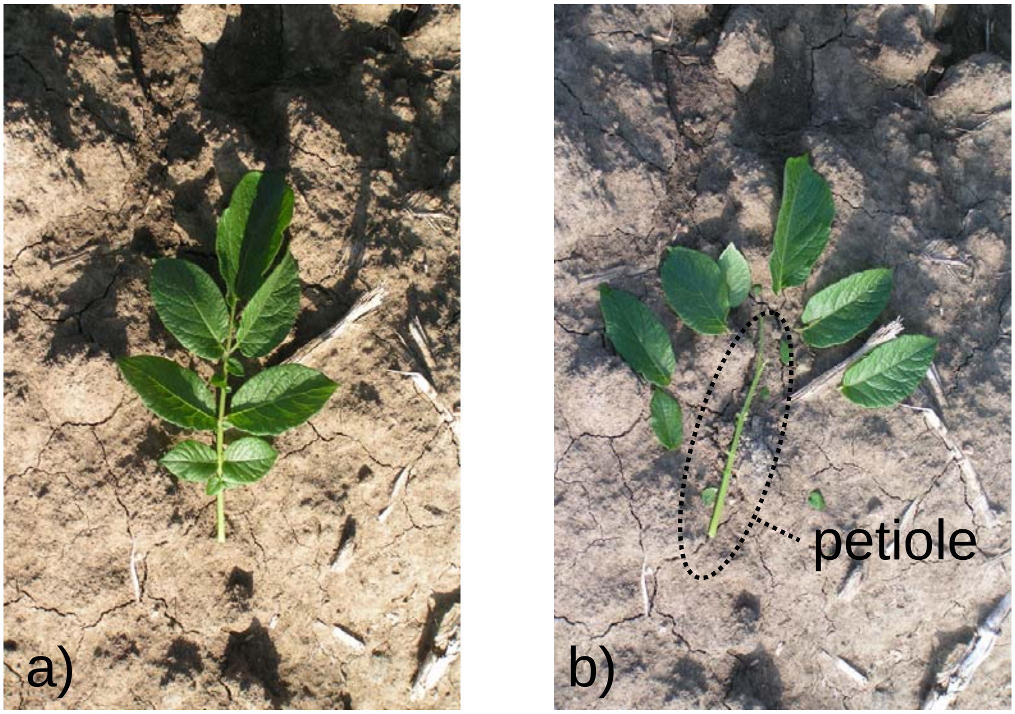


Figure 2. Russet Burbank fourth leaf stem a) before and b) after removal of leaves (petiole shown in dashed circle).

Tuber Harvest

Tuber samples (2 x 25 ft strips) were collected on September 22 and 23, 2004; September 21 and 22, 2005; and September 13 and 14, 2007. The harvest was conducted with the PGA two-row harvester. Field staff collected, bagged, and labelled samples in the field. In the laboratory, samples were washed, graded, and weighed to calculate total yield, marketable yield, mean tuber weight, and percent smalls. Grading categories used were small (<$1^{7}/_{8}$ in), medium ($1^{7}/_{8}$ – 3½ in), over-size (> 3½ in), and deformed. Clean 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 as the weight in air divided by weight in water method (Schippers 1976) on 25 medium tubers for each sample.

Data Analysis

Results were analyzed as a randomized complete block design, with six treatments and four replicates, using an analysis of variance (ANOVA) procedure (SAS Institute Inc. 2004). The Student-Newman-Keuls multiple range test ($P < 0.05$) was used to determine if differences existed among treatments.

Critical Petiole Nutrient Concentrations

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 project data. 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 sampling date.

1. For the first step, a second order polynomial curve was fitted to the yield *versus* 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). The corresponding petiole nutrient concentration was calculated for each petiole sampling date, from the formula for the second order polynomial best-fit line. 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.

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 sampling date. These plots indicate the optimal ranges for petiole nutrients throughout the growing season.

RESULTS AND DISCUSSION

Meteorological Observations

Early in the first growing season of the study (2004), just as flowering initiated (July 7), the potato crop was damaged by hail but recovered well. Overall, 2004 temperature and rainfall were similar to long-term (1950-2000) averages (Table 5).

The 2005 growing season in southern Alberta was remarkable for the record rainfalls in June and September (Table 5). Many growers were forced to pump out portions of fields that were flooded. 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 made it difficult to be certain that the applied rates of fertilizer remained within the root zone of their designated plot sites. Additionally, eight of the 40 plots were not harvested due to the wet conditions.

Overall, growing season (May to August) temperatures in 2007 were somewhat higher than long-term averages and total precipitation was close to the long-term average (Table 5). June and July 2007 were hotter and drier than long-term averages with no precipitation falling in July. On August 10, 2007, the crop was damaged by hail.

Table 5. Monthly average temperature and rainfall at Taber in 2004, 2005, and 2007 compared to long-term (1950-2000) averages (Environment Canada, 2008).

	Average Temperatures (°C)				Total Precipitation (mm)			
Month	**2004**	**2005**	**2007**	**1950-2000 Average**	**2004**	**2005**	**2007**	**1950-2000 Average**
April	8.1	7.6	4.6	5.7	25.6	26.3	83.6	31.6
May	10.3	12.5	12.8	11.7	78.4	17.4	89.4	44.0
June	15.3	15.0	17.0	15.8	57.8	198.4	34.3	69.9
July	19.6	19.3	23.5	18.7	51.8	5.0	0.0	37.9
August	17.9	15.8	18.7	18.0	76.9	58.8	47.6	38.5
September	12.8	12.4	11.5	12.8	8.2	116.4	36.4	34.5
Average/Total	14.0	13.8	14.7	13.8	298.7	422.3	291.3	256.4

Crop Growth and Development

Taber 2004. The potato crop was planted on April 28, 2004, and it was flowering on July 7, 2004, the same date a hailstorm damaged the field. The grower responded to the hail with a foliar feed application of 20-20-20 on July 9, 2004, which was in addition to three scheduled fertigation applications of 20-0-0 (June 25, July 5, and July 15, 2004).

Taber 2005. The potato crop was planted on April 22, 2005, and it had begun flowering by July 13, 2005. At planting in the spring of 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.

Coaldale 2007. The crop was planted on April 22, 2007, and it had begun flowering by July 11, 2007. The plot area was avoided by the grower during the spring and planting fertilizer applications. A total of 101 lb/ac N and 17 lb/ac P_2O_5 were applied through fertigation. The field was impacted by a hail storm on August 10, 2007. Crop damage was more extensive on the north half of the field.

Average Petiole Nitrate Nitrogen Compared to Marketable Yield and Specific Gravity

Average petiole nitrate nitrogen (NO_3-N), marketable yield, and specific gravity for each of the variable nitrogen treatments for 2004, 2005, and 2007 are summarized in Fig. 3, 4, and 5. On all graphs, the colour of lines and bars corresponds to the colours designated for treatments in the fertilizer schedules (Tables 2, 3, and 4). In all cases, there were no statistically significant differences among treatments, in marketable yield or specific gravity; however, there are some notable trends.

Petiole Nitrate Nitrogen. There was an increasing concentration of petiole NO_3-N with increasing fertilizer N and this was seen in all three years of the study. Throughout 2004, the highest N rate (367 lb N/ac) consistently showed the greatest petiole NO_3-N concentration (Fig. 3a). Early in the growing season, petiole NO_3-N concentration in all but the greatest N treatment fell below the USA standard range, yet this did not have a detrimental effect on yield for the 272 lb N/ac treatment. Petiole NO_3-N initially decreased for the first three sample dates until 76 days after planting (DAP), with a large increase noted on the fourth petiole sampling date (83 DAP). The initial decline in petiole NO_3-N possibly coincided with the tuber initiation stage of growth, where rapid formation and growth of stems and leaves was taking place. The jump in petiole NO_3-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. Growers typically begin to monitor petiole nutrients at this stage.

The greatest N rate (Treatment 4: 362 lb N/ac) in 2005 consistently showed the greatest petiole NO_3-N concentration (Fig. 3b), but not by a large margin. The lowest N rate (Treatment 1: 201 lb N/ac) actually had the second-greatest average petiole NO_3-N concentration for the first, second, and fourth sampling dates (June 30, July 6, and 20). For the remainder of the sampling dates, Treatment 1 had the lowest average petiole NO_3-N concentration. These inconsistencies may have resulted from 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 DAP, increased dramatically at 82 DAP, and then decreased for the remainder of the growing season.

In 2007, all but the lowest N fertilizer treatment (Treatment 1: 175 lb N/ac) fell within the USA standards (Fig. 3c). The three highest N treatments had very similar petiole NO_3-N concentrations, despite representing a range in fertilizer N (302 to 401 lb N/ac). Overall petiole NO_3-N initially decreased and then levelled-off between 73 and 94 DAP, then decreased for the final two petiole samplings in August 2007. The sharp increase in petiole NO_3-N seen at 83 DAP in 2004 and 82 DAP in 2005, respectively, was not seen. This may be due to crop stress due to the extreme heat and lack of precipitation seen in July 2007 (Table 5). The hail storm on August 10, 2007, did not seem to have an effect on the petiole NO_3-N concentrations for the subsequent sampling date (August 22, 2007) (Fig. 3c) and petiole NO_3-N concentrations followed a similar declining pattern that was observed in August of previous years (Fig. 3a and 3b).

Marketable Yield. In 2004, Treatment 3 (272 lb N/ac) had the greatest overall yield; however, the treatments were not significantly different (Fig. 4a). Treatment 3 was designed to approximate the typical grower-applied rate of fertilizer. In 2005, Treatment 2 (262 lb N/ac) had the greatest overall yield; however, the treatments were not significantly different (Fig. 4b). Yield data for this treatment were quite variable.

In 2007 on Reps 1 and 2 (north half of the field), plots that received the lowest N fertilizer rates (Treatment 1) were visibly different (lighter green) than all of the surrounding treatments. Fig. 6 shows the Treatment 1, Rep 1 plot just next to the Treatment 9 Rep 2 plot. Treatment 3 was meant to approximate the grower fertilizer rates and gave the greatest yield of all 10 treatments in 2007 (Fig. 4c).There was no significant yield difference among treatments;

however, there was a trend to increasing yield with increased fertilizer (Fig. 4c), with a decreased yield at the highest rate of N.

Tuber Specific Gravity. In 2004, the two higher rates of N fertilizer (Treatments 3 and 4) had slightly greater specific gravities (Fig. 5a). This result is contrary to the findings of Waterer and Heard (2005) who stated that excess fertilizer N may lead to low specific gravity. In 2005, a slight decrease in specific gravity was found for fertilizer rates greater than 262 lb N/ac (Fig. 5b). In 2007, there was also a slight trend to decreasing specific gravity with increased fertilizer N (Fig. 5c). Although these results were not statistically significant, this observation is similar to other findings wherein 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.

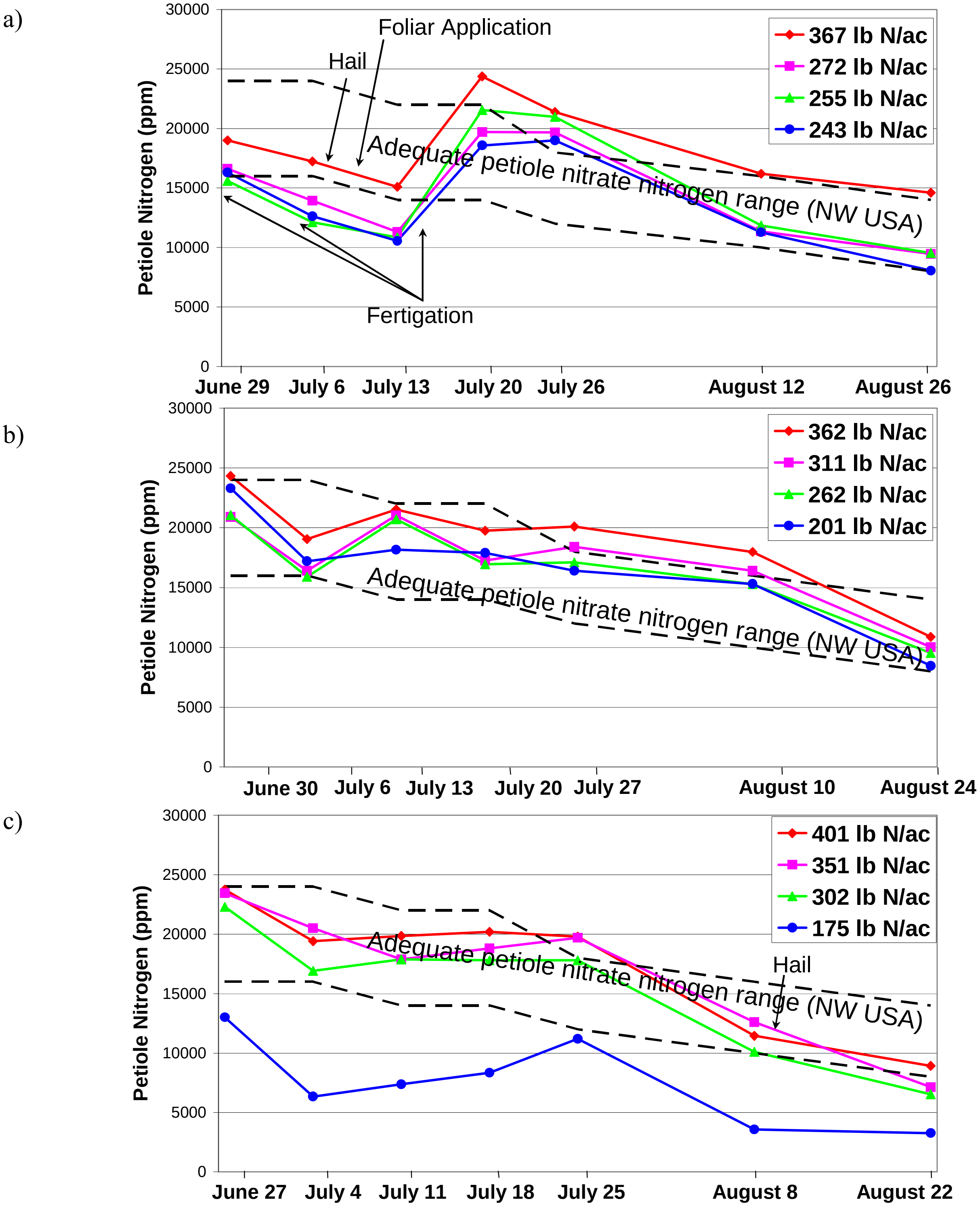


Figure 3. Russet Burbank potato petiole nitrate nitrogen (NO_3-N) concentrations (ppm) for four different N fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Dashed black lines correspond to upper and lower suggested limits used in the northwest USA.

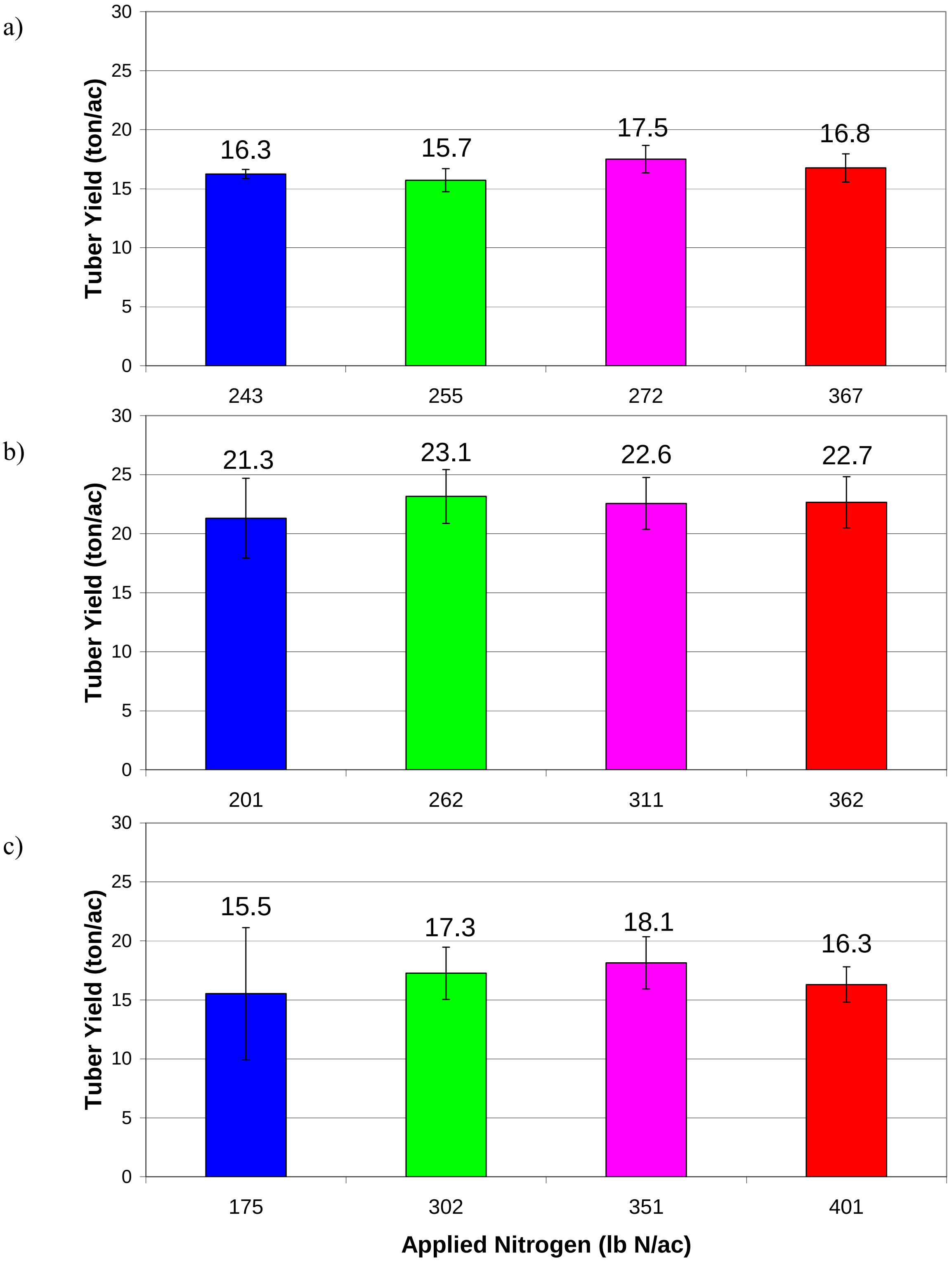


Figure 4. Russet Burbank potato marketable yield (ton/ac) for four different N fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Error bars indicate standard deviations. Differences among treatments for which error bars overlap are not statistically significant.

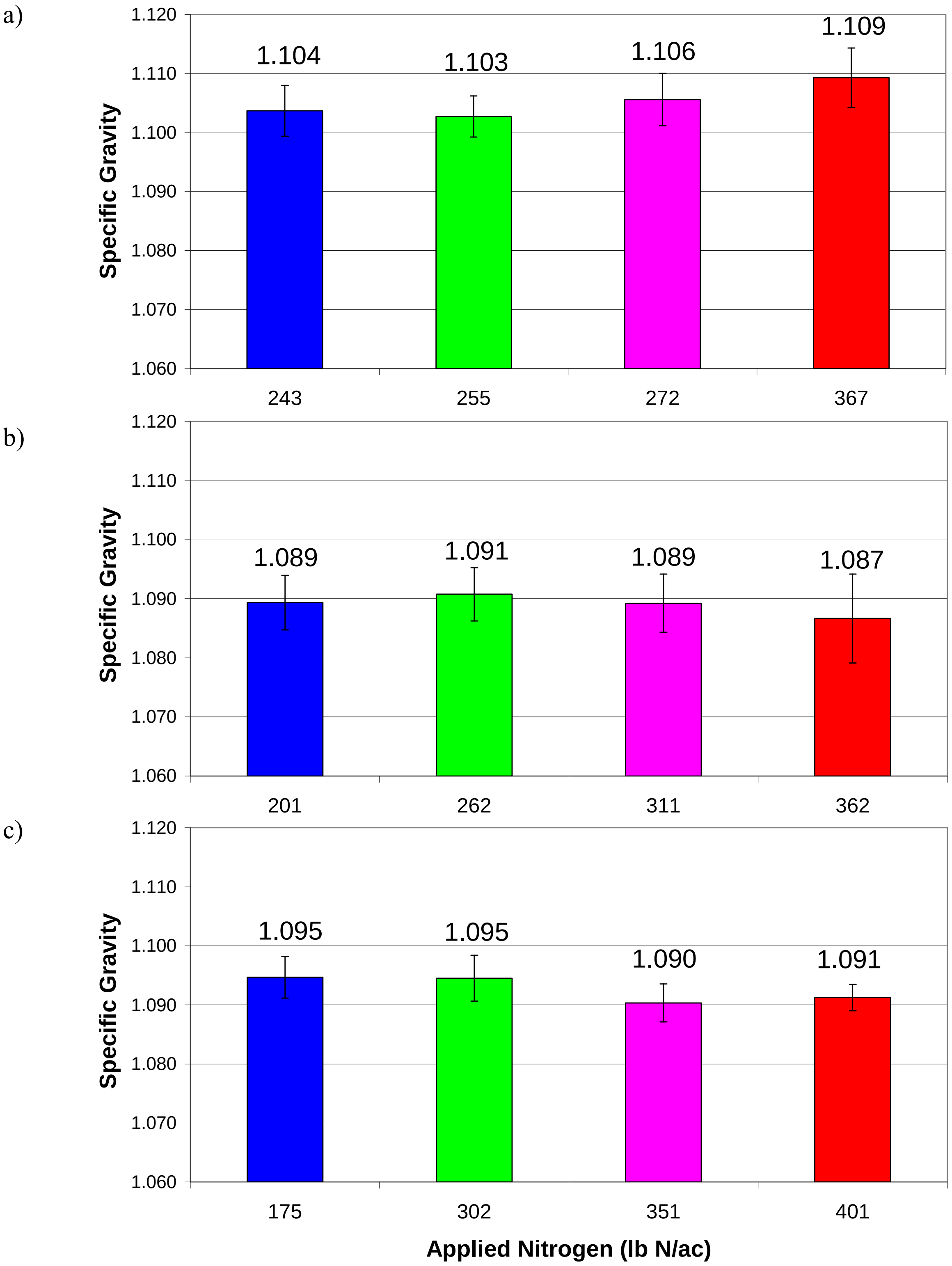


Figure 5. Russet Burbank potato tuber specific gravity for four different N fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Error bars indicate standard deviations. Differences among treatments for which error bars overlap are not statistically significant.

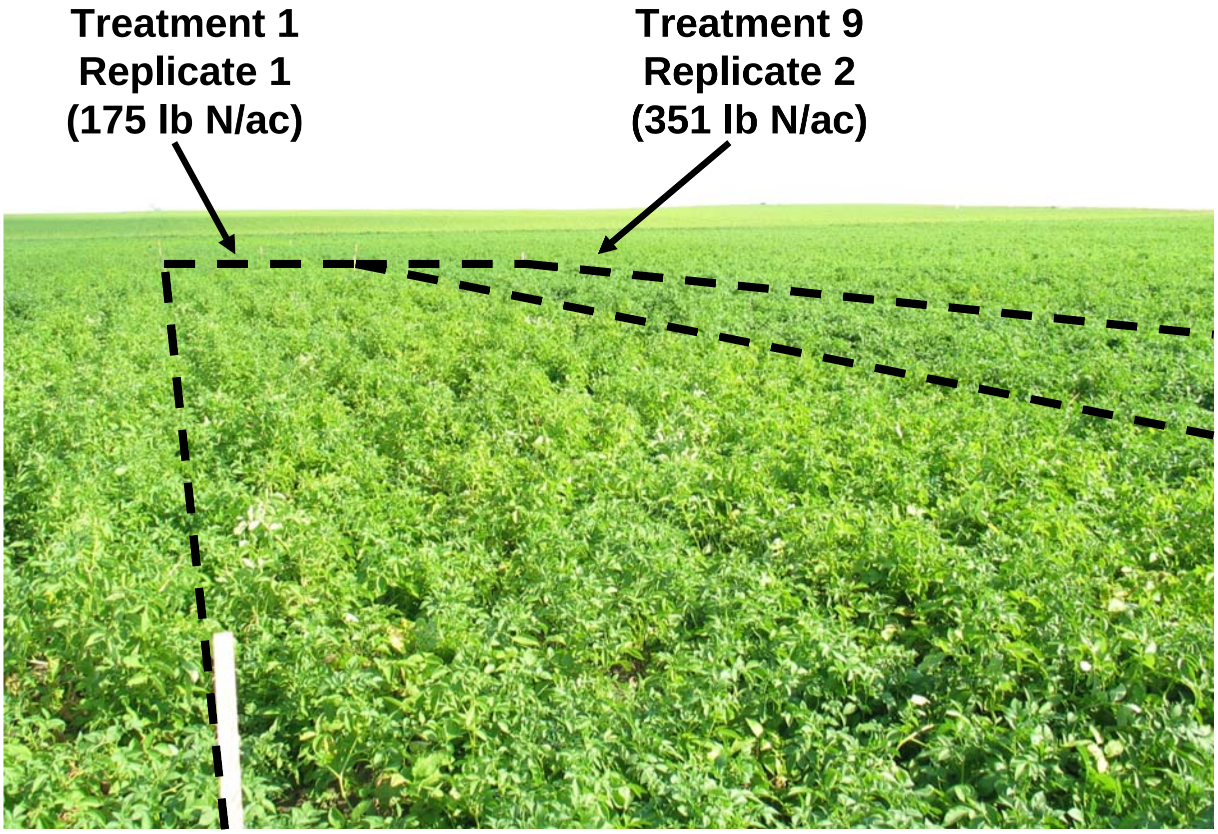


Figure 6. Visible difference in colour of Treatment 1, Rep 1 (175 lb/ac N fertilizer, including 24 lb/ac N added on April 17, 2007) compared to Treatment 9, Rep 2 (351 lb/ac N fertilizer, including 200 lb/ac N added on April 17, 2007), looking north on August 8, 2007 (photo courtesy of Gary Larson, AAFC).

Average Petiole Phosphorus Compared to Marketable Yield and Specific Gravity

Average petiole phosphorus, marketable yield, and specific gravity for each of the phosphorus (P) treatments are summarized in Fig. 7, 8, and 9. As with the N treatments, there were no statistically significant differences among P treatments, in yield or specific gravity; however, there are some notable trends.

Petiole Phosphorus. In 2004, increasing rates of fertilizer P gave increasing amounts of petiole P (Fig. 7a). This held true throughout the growing season, with the exception of the petiole samples taken immediately following the hail. This may be because of a spatially variable impact of the hail. The lower rates of P fertilizer gave petiole P concentrations in the lower half of the USA standard range, yet yields were not significantly impacted. In 2005, the two highest rates of fertilizer P gave greater amounts of petiole P (Fig. 7b). 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. In 2007, all petiole P results were in the low range, within and slightly below the USA standards (Fig. 7c). The lowest fertilizer P rate had the lowest petiole P content until 108 DAP (August 8, 2007); however, on most petiole sample dates, the highest rate of fertilizer P gave the second-lowest petiole P content and the lowest on the last sampling date (Fig. 7c).

Marketable Yield. In 2004, the two highest rates of fertilizer P (137 and 246 lb P_2O_5/ac) had a slightly greater yield than the two lower rates of fertilizer P (15 and 72 lb P_2O_5/ac), but results were not significantly different (Fig. 8a). In 2005, 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 were not significantly different (Fig. 8b). Incidentally, this treatment had a slightly lower amount of fertilizer N applied (99 lb N/ac) on April 20-21, 2005 (Table 3), compared to the other three treatments (126-127 lb N/ac) because of limitations in the application rates of the fertilizer spreader used. Treatment 7 had 258 lb P_2O_5/ac applied on April 20-21, 2005, as 506 lb/ac of monoammonium phosphate (12-51-0), which also provided 61 lb N/ac. This left 65 lb N/ac (188 lb/ac product) to be applied as ammonium nitrate (34.5-0-0) to give a total application of 126 lb N/ac. The nearest to this amount that the chain settings on the fertilizer spreader could achieve was 111 lb/ac product or 38 lb N/ac, which gave a total of 99 lb N/ac for Treatment 7, applied April 20-21, 2005 (Table 3). In 2007, the greatest tuber yield was found on the plots that received the second-lowest P fertilizer rate (Treatment 3: 178 lb P_2O_5/ac) (Fig. 8c).

Tuber Specific Gravity. There was no discernible trend in tuber specific gravity in relation to fertilizer P rates in 2004 (Fig. 9a). In 2005, the specific gravity was variable, did not show any statistically significant relationships, and did not appear to be affected by fertilizer P (Fig. 9b). In 2007, there was virtually no difference in the specific gravity for the different P rates (Fig. 9c).

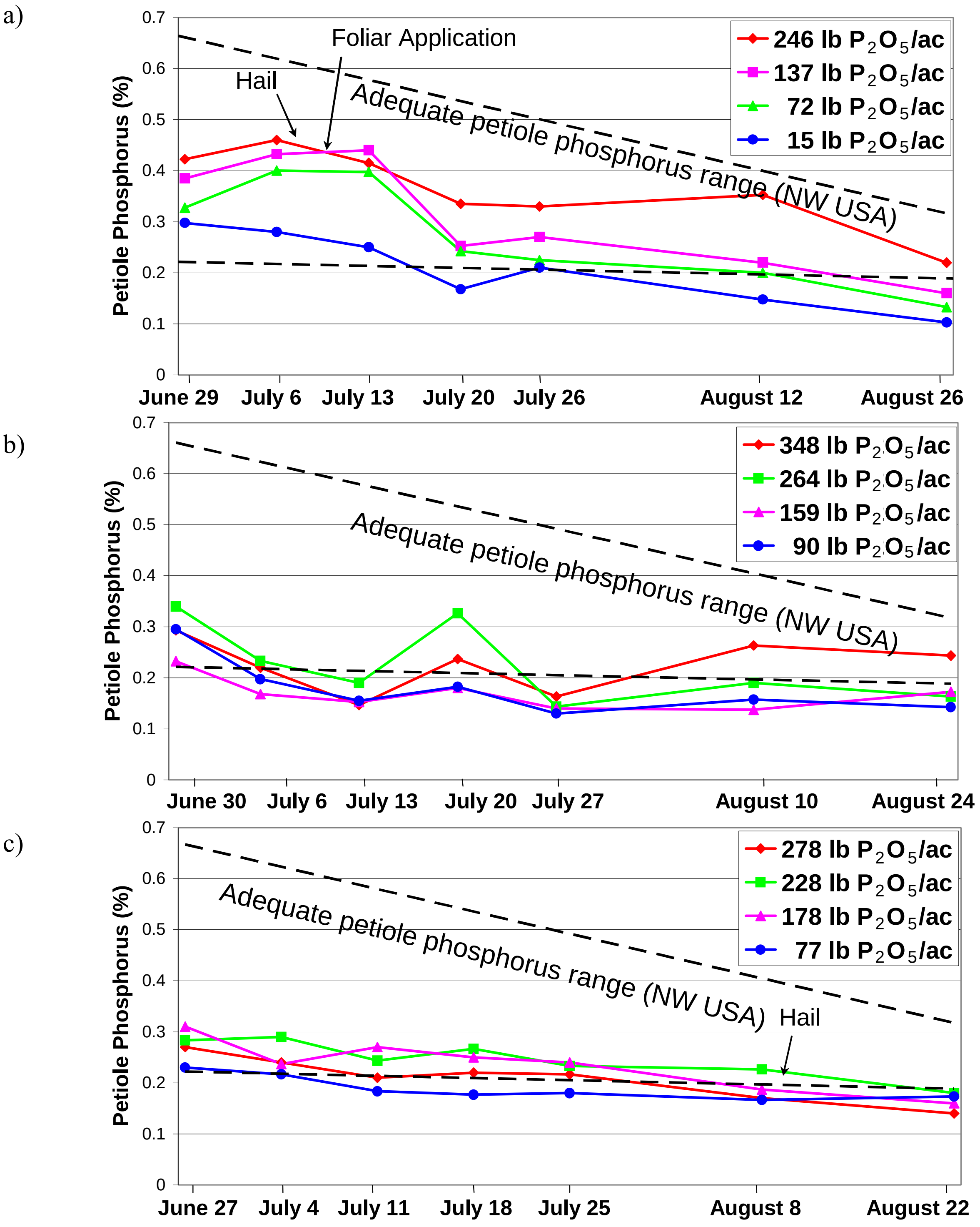


Figure 7. Russet Burbank potato petiole phosphorus concentrations (%) for four different P_2O_5 fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Dashed black lines correspond to upper and lower suggested limits used in the northwest USA.

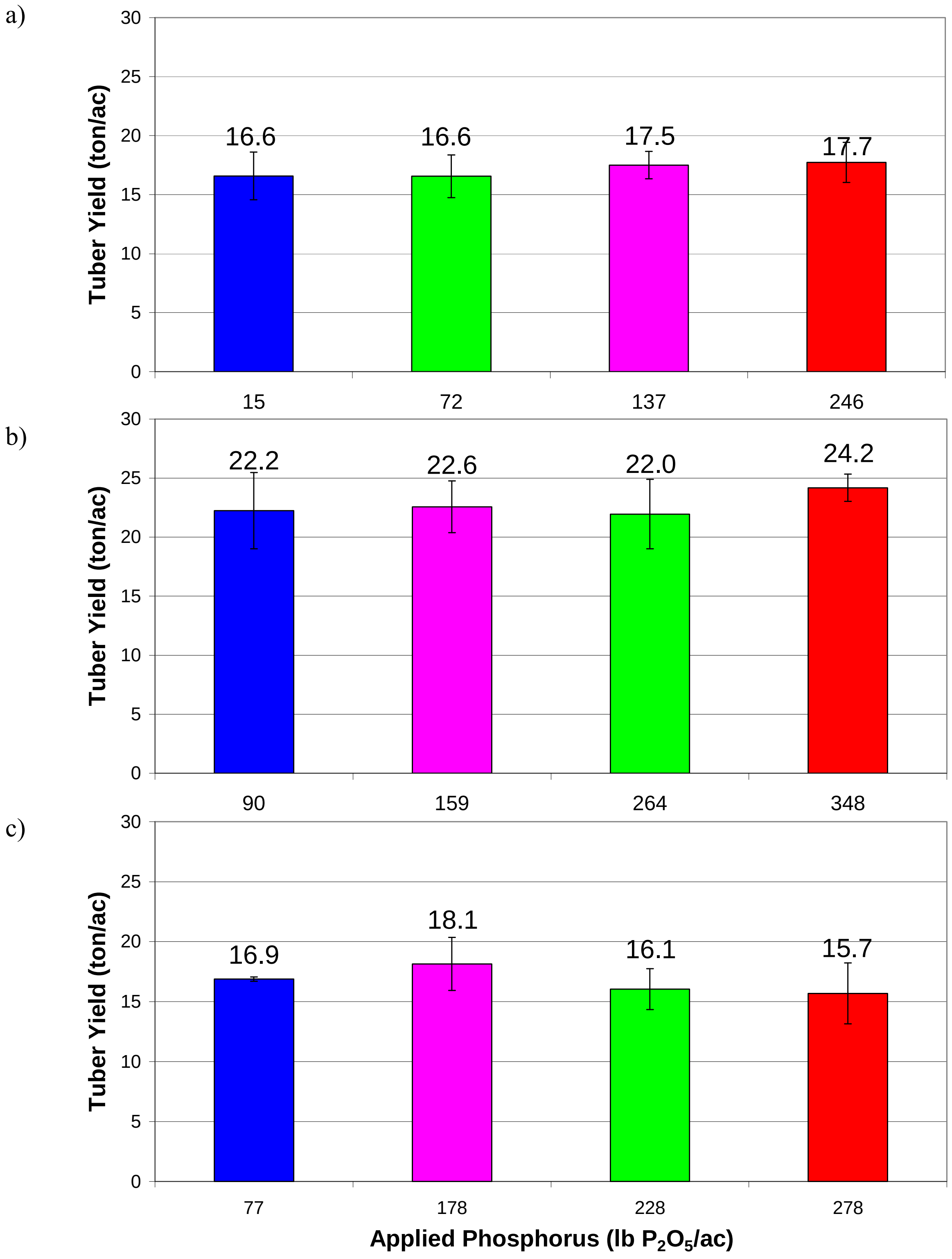


Figure 8. Russet Burbank potato marketable yield (ton/ac) for four different P_2O_5 fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Error bars indicate standard deviations. Differences among treatments for which error bars overlap are not statistically significant.

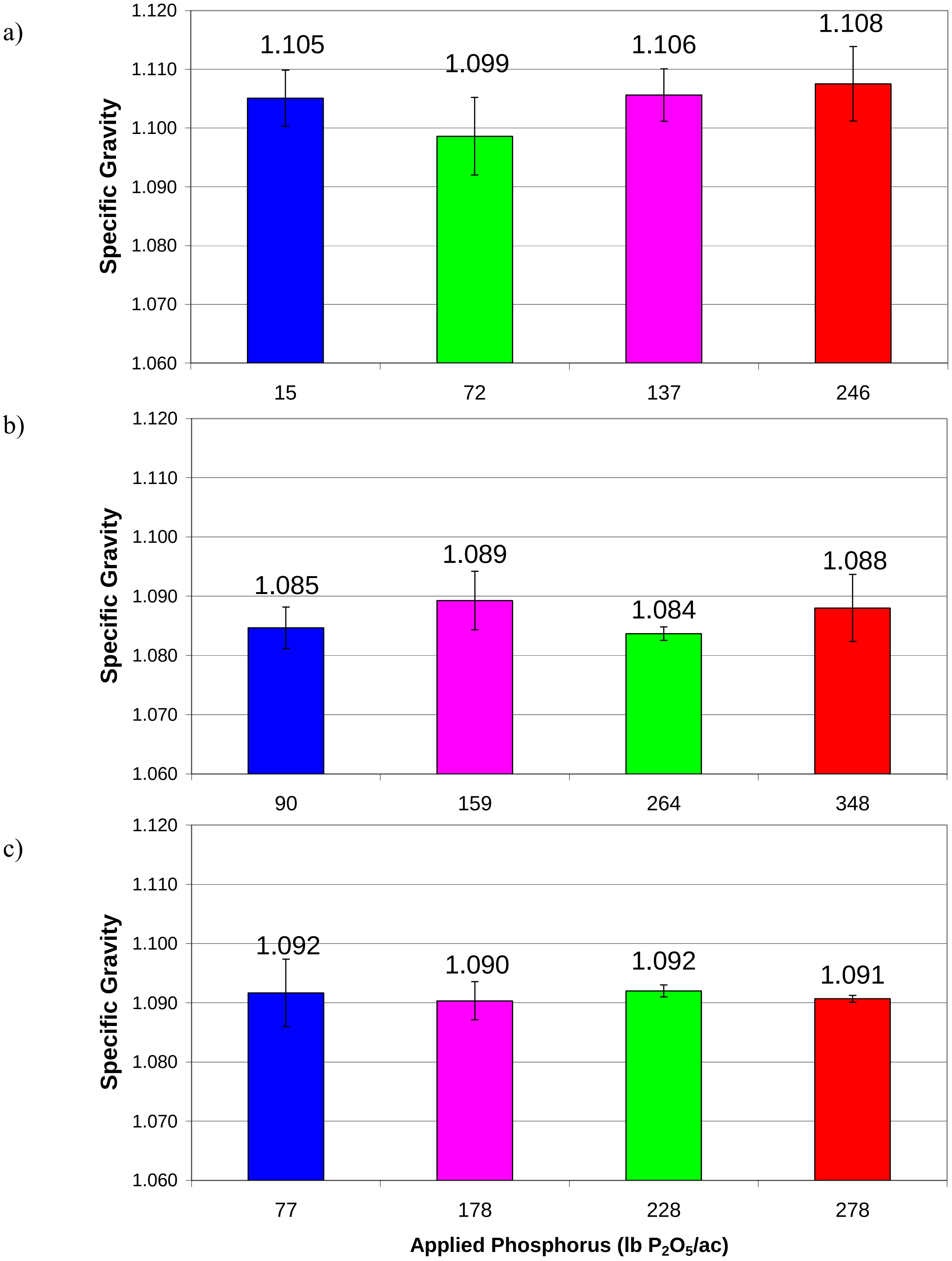


Figure 9. Russet Burbank potato tuber specific gravity for four different P_2O_5 fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Error bars indicate standard deviations. Differences among treatments for which error bars overlap are not statistically significant.

Average Petiole Potassium Compared to Marketable Yield and Specific Gravity

Average petiole potassium, marketable yield, and specific gravity for each of the potassium (K) treatments are summarized in Fig. 10, 11, and 12. As with the N and P treatments, there were no statistically significant differences among K treatments, in yield or specific gravity; however, there are some notable trends.

Petiole Potassium. In 2004, increasing rates of fertilizer K had no observable effect on petiole K concentration (Fig. 10a). Most average petiole K concentrations were above the USA standard ranges at this site. Similar to 2004 results, the 2005 data showed that increasing rates of fertilizer K had no observable effect on petiole K (Fig. 10b). Also, like the 2004 results, most average petiole K concentrations were above the USA standard ranges at the 2005 site. Similar to previous years, petiole K results in 2007 were above the USA adequate range and there was no relationship between fertilizer K and petiole K (Fig. 10c). Together, these results confirm those of previous published (Dubetz and Bole 1975; Mackay and Carefoot 1987; and Mackay et al. 1989) and unpublished studies (Konschuh 2001 and McKenzie et al. 2002) that have shown no relationship between fertilizer K, yield, 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 (Dubetz and Dudas 1981). During 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 (Brady and Weil 1999). 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 the effects of different application rates of fertilizer K.

Marketable Yield. In 2004, there was a trend toward slightly increased yield with increasing fertilizer K up to 117 lb K_2O/ac, with a small decrease for the highest rate (238 lb K_2O/ac), but results were not significantly different (Fig. 11a). In 2005, 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 were not significantly different and were all within a narrow range between 21.5 and 23.1 ton/ac (Fig. 11b). In 2007, there was no relationship between yield and fertilizer K (Fig. 11c).

Tuber Specific Gravity. There was a slight trend toward decreasing specific gravity with increasing fertilizer K in 2004, but differences were not statistically significant (Fig. 12a), even at the highest rate of fertilizer K. In 2005, there was a trend toward increasing specific gravity with increasing fertilizer K, but differences were not statistically significant (Fig. 12b). These results are contrary to those seen in 2004, where a trend toward decreasing specific gravity with increasing fertilizer K was observed. In 2007, there was no statistically significant trend in specific gravity with increasing fertilizer K (Fig. 12c); however, specific gravity decreased slightly for the highest rate of fertilizer K (311 lb K_2O/ac).

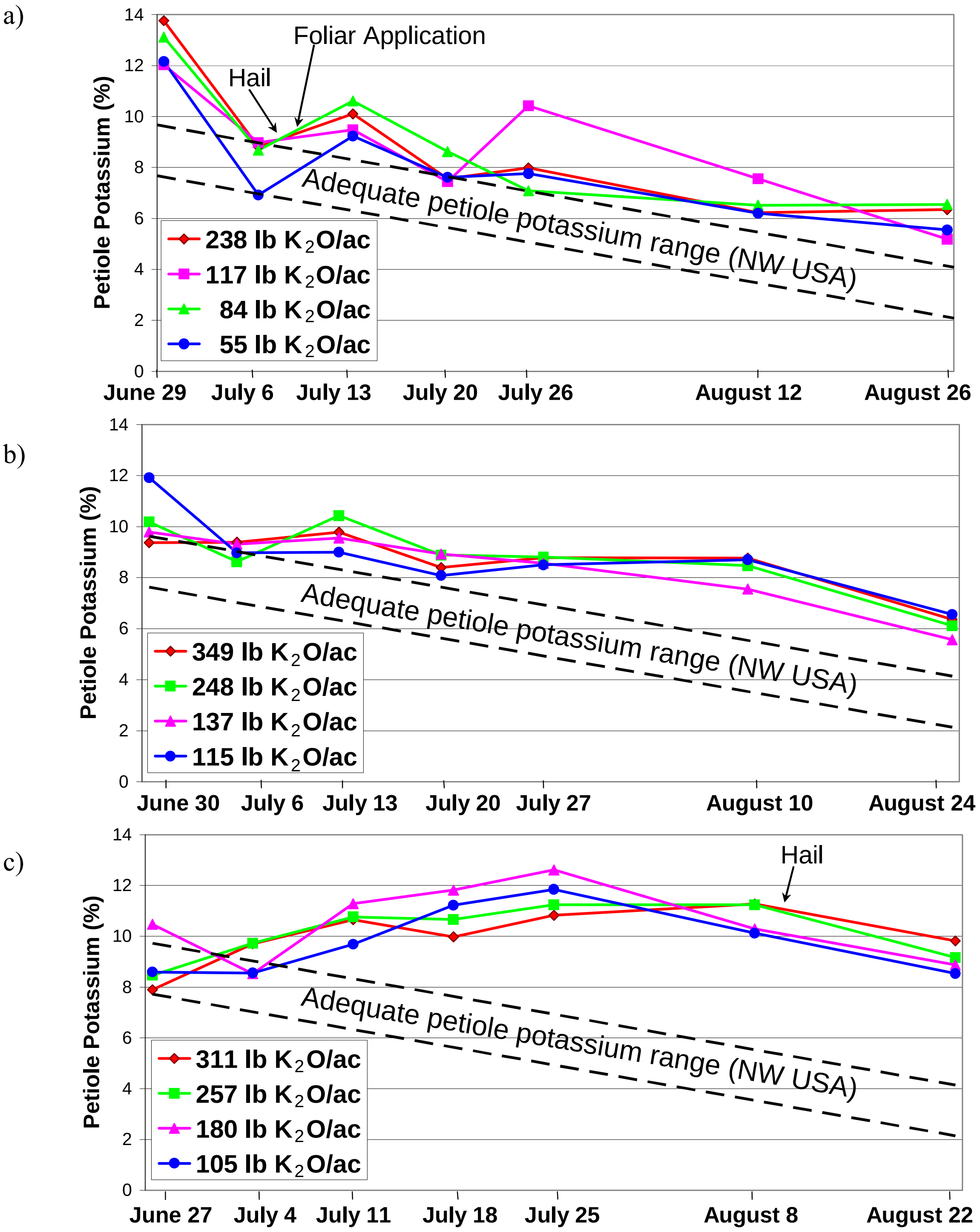


Figure 10. Russet Burbank potato petiole potassium concentrations (%) for four different K2O fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Dashed black lines correspond to upper and lower suggested limits used in the northwest USA.

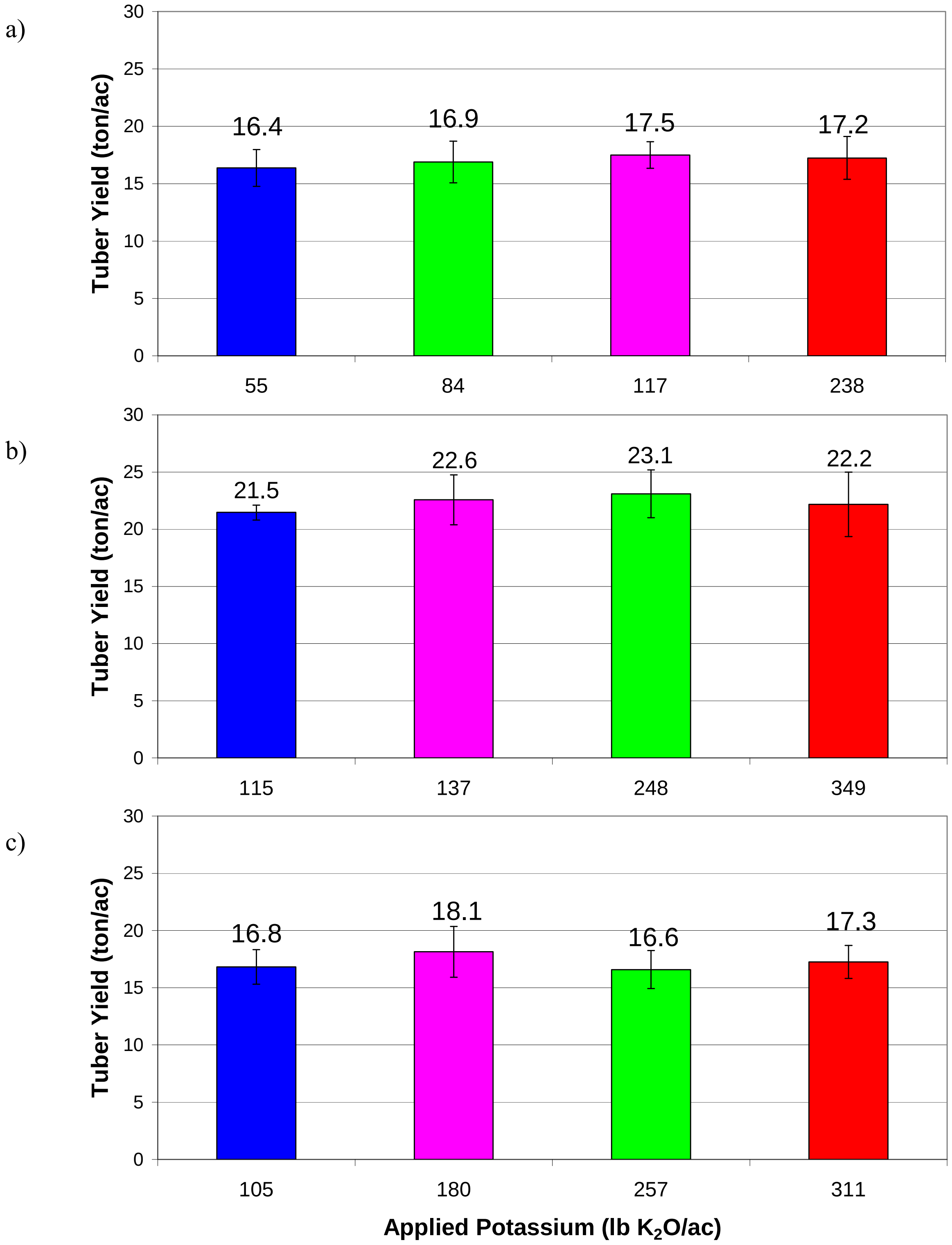


Figure 11. Russet Burbank potato marketable yield (ton/ac) for four different K_2O fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Error bars indicate standard deviations. Differences among treatments for which error bars overlap are not statistically significant.

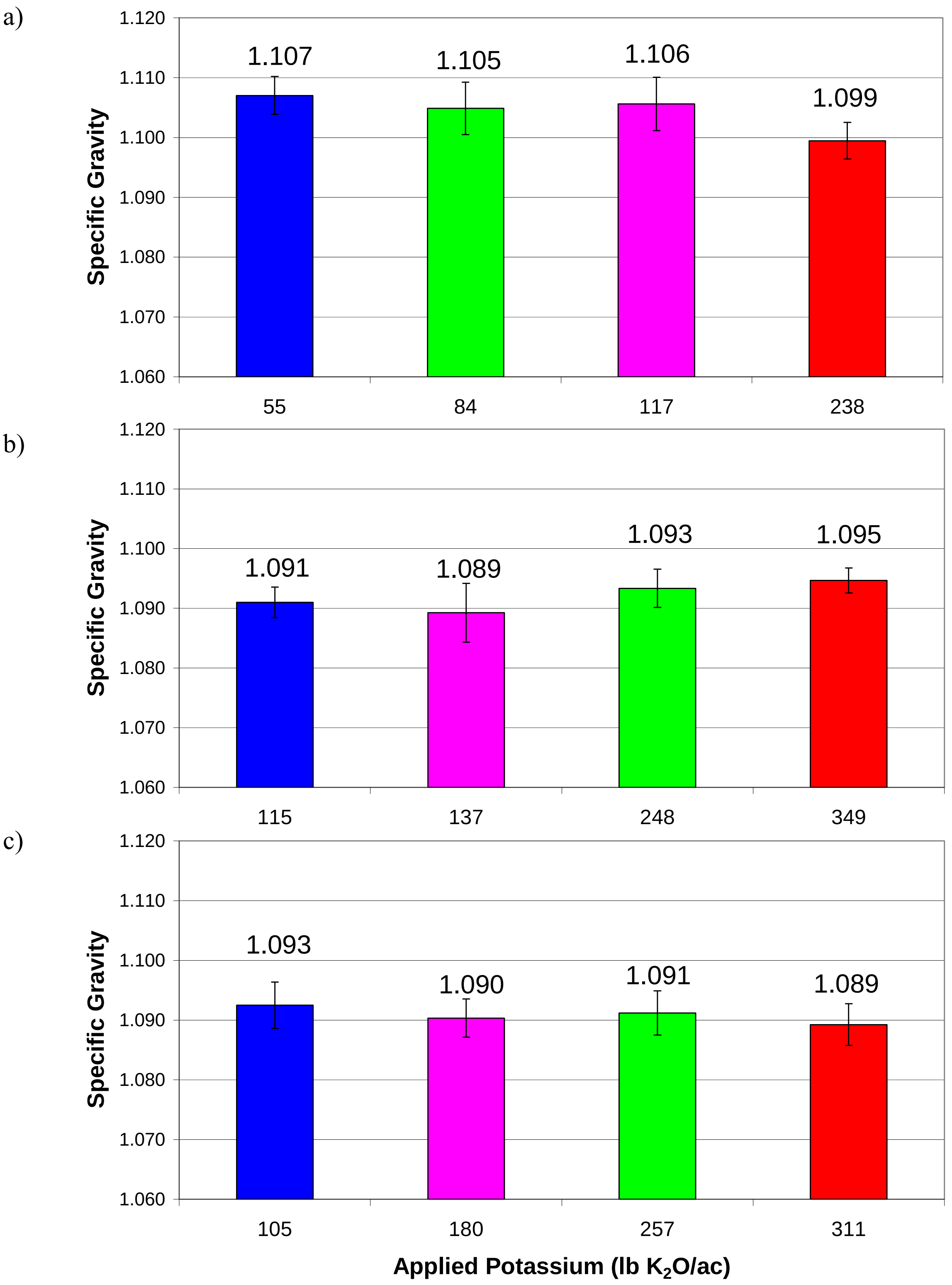


Figure 12. Russet Burbank potato tuber specific gravity for four different K_2O fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Error bars indicate standard deviations. Differences among treatments for which error bars overlap are not statistically significant.

Critical Petiole Nutrient Concentrations

As described in the Methods and Materials section, a second order polynomial curve was fitted to the yield *versus* petiole nutrient relationship (Belanger et al. 2001, 2003). Examples of these graphs are shown in Fig. 13 for the petiole phosphorus on seven petiole sampling dates in 2005. The fit of these lines was highly variable.

The 100%RY and 90%RY values were plotted as a function of DAP and these graphs depict the optimal petiole nutrient concentration throughout the growing seasons (Fig. 14 to 16), including the 100%RY and 90%RY and their respective best-fit lines. Also shown on these graphs are the optimal ranges that have been suggested for the northwest USA (Schaupmeyer, *pers. commun.*).

Petiole Nitrate Nitrogen. The USA standard ranges are greater than the 2004 optimal petiole NO_3-N concentrations. For the 100%RY, the optimal petiole NO_3-N was approximately 19,000 ppm at 60 DAP and declined to 13,000 ppm by 120 DAP (Fig. 14a). The data appear to follow two linear trends, one for the tuber initiation growth stage (<80 DAP) and the other from the beginning of tuber bulking and onward (>80 DAP).

The USA standard ranges are very similar to the 2005 optimal petiole NO_3-N concentrations. 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 (Fig. 14b). As discussed before, however, the actual relationship is more likely two lines, one for the tuber initiation growth stage and the other from the beginning of tuber bulking and onward.

The USA standard ranges are somewhat high compared to the 2007 optimal petiole NO_3-N concentrations (Fig. 14c). For the 100%RY, the optimal petiole NO_3-N was nearly 19,700 ppm at 60 DAP and declined to approximately 6,400 ppm by 125 DAP (Fig. 14c). In 2007, there was not a dramatic increase in petiole NO_3-N at around 80 DAP. Instead, the petiole NO_3-N concentration increased gradually between 80 and 94 DAP and then decreased until 122 DAP (Fig. 14c). 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 Fig. 14.

The following are the formulae for the linear best-fit 100%RY relationships between petiole NO_3-N and DAP, which hold for approximately DAP = 60-125.

2004 Petiole NO_3-N (ppm) = -98.7*DAP + 24982 ($r^2 = 0.32$)
2005 Petiole NO_3-N (ppm) = -153.7*DAP + 32826 ($r^2 = 0.43$)
2007 Petiole NO_3-N (ppm) = -204.4*DAP + 31955 ($r^2 = 0.73$)

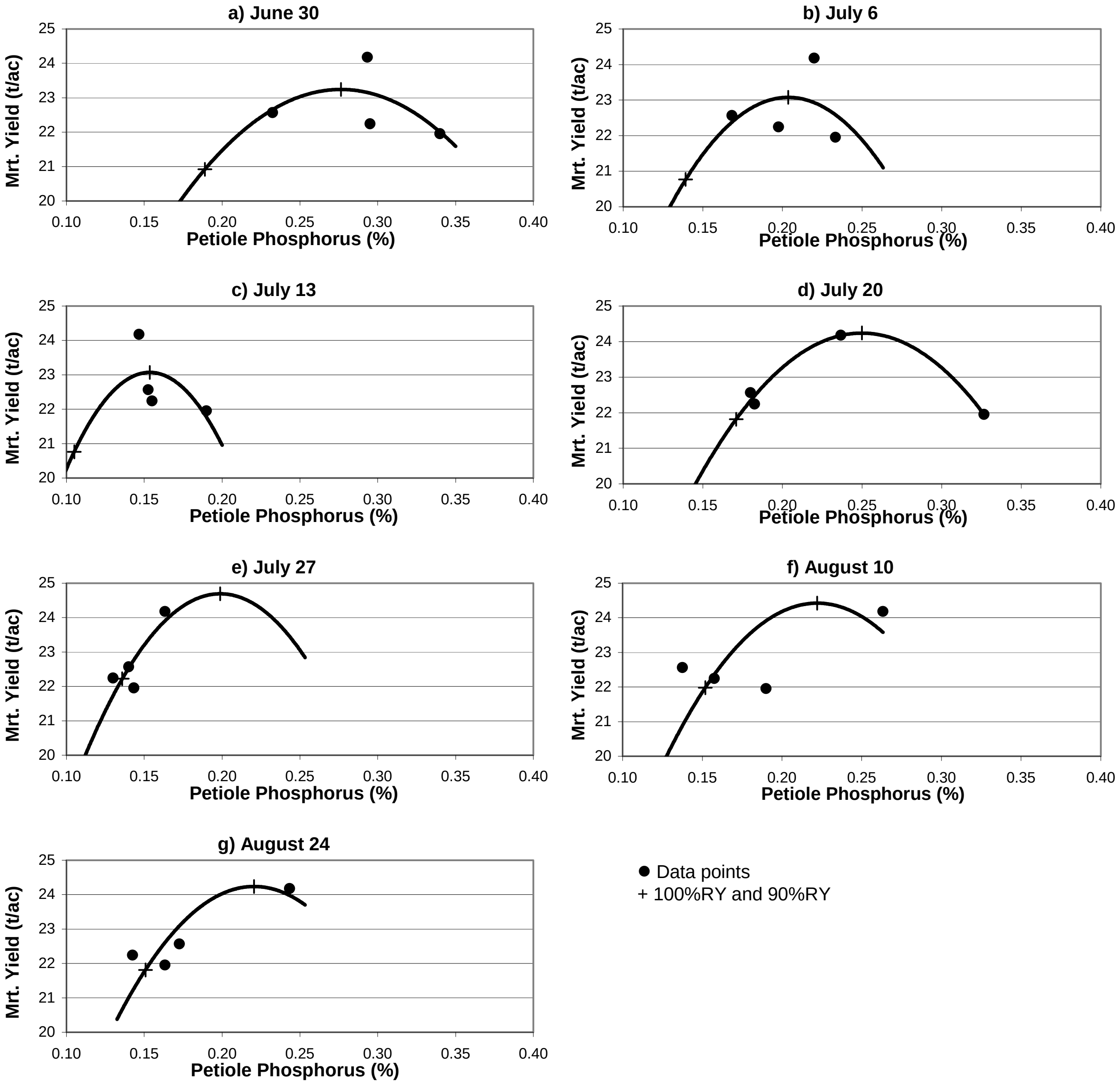


Figure 13. Russet Burbank potato tuber yield (ton/ac) as a function of petiole phosphorus (%), showing actual data points, the fitted second order curve, and the 100% relative yield (100%RY) and 90% relative yield (90%RY) values for seven petiole sampling dates in 2005.

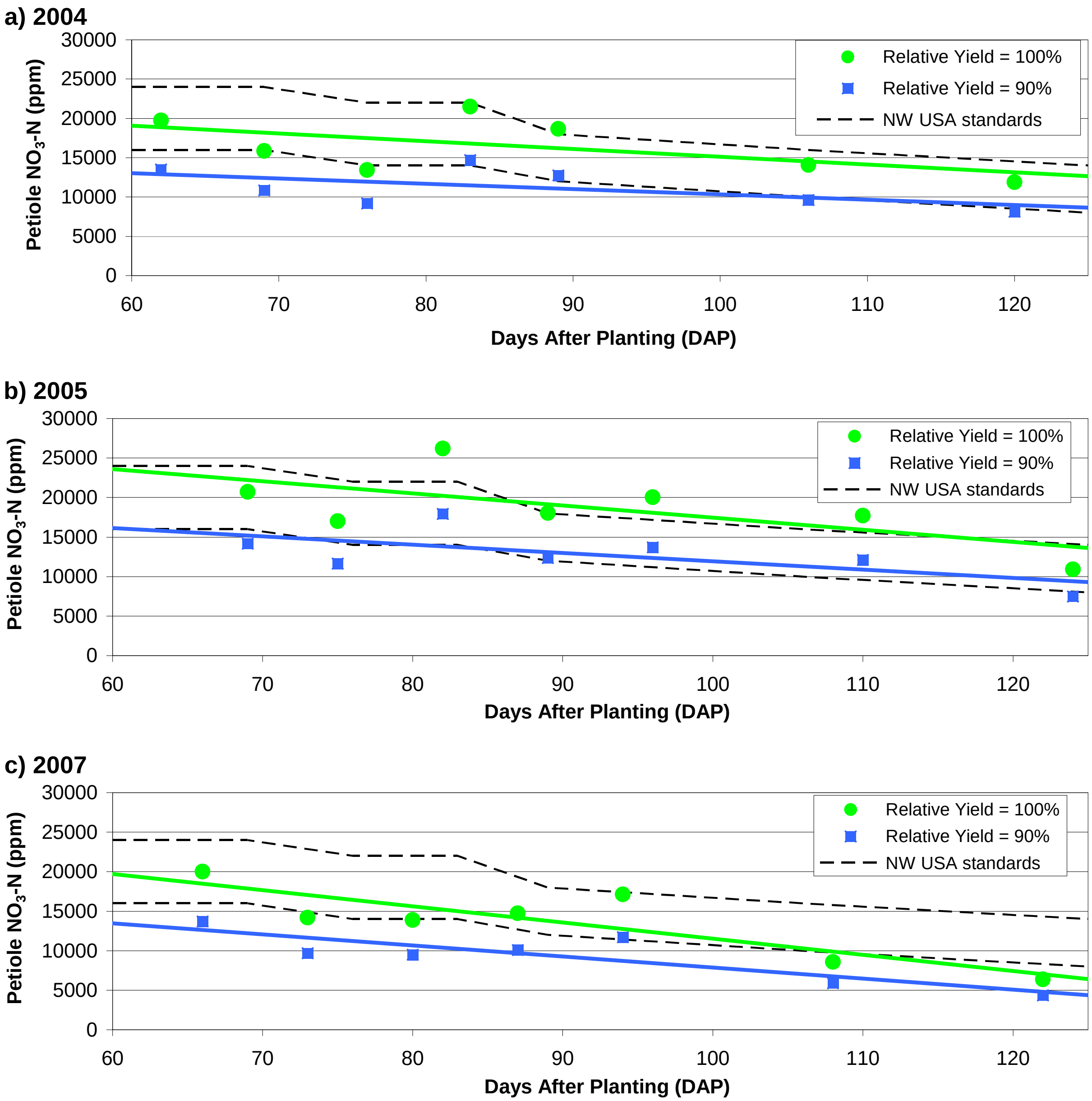
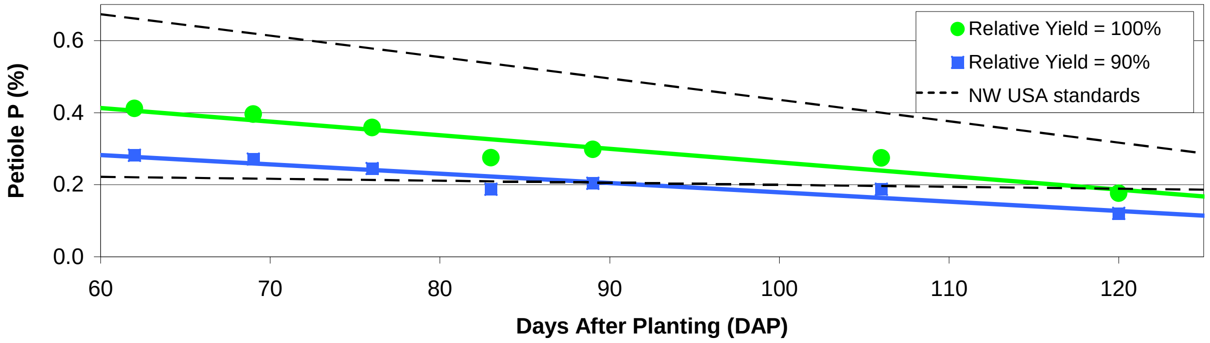
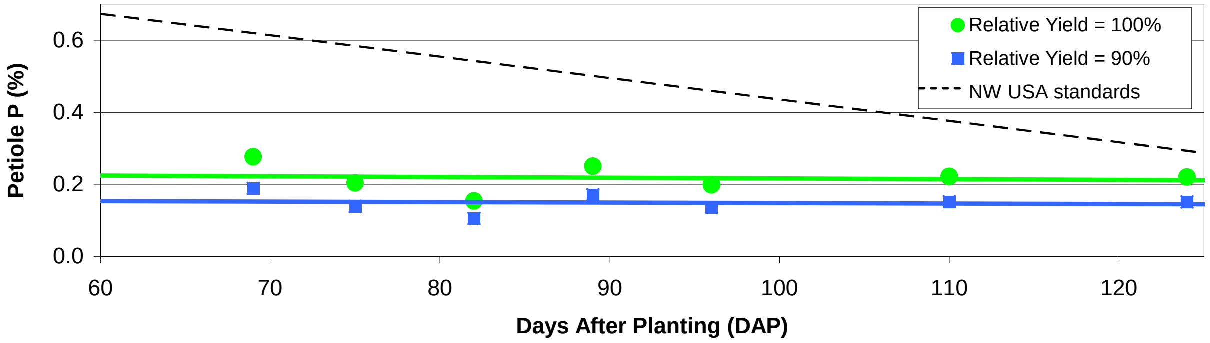


Figure 14. 100% relative yield (RY) and 90% relative yield petiole nitrate nitrogen (NO_3-N) concentration as a function of days after planting in (a) 2004, (b) 2005, and (c) 2007.

a) 2004



b) 2005



c) 2007

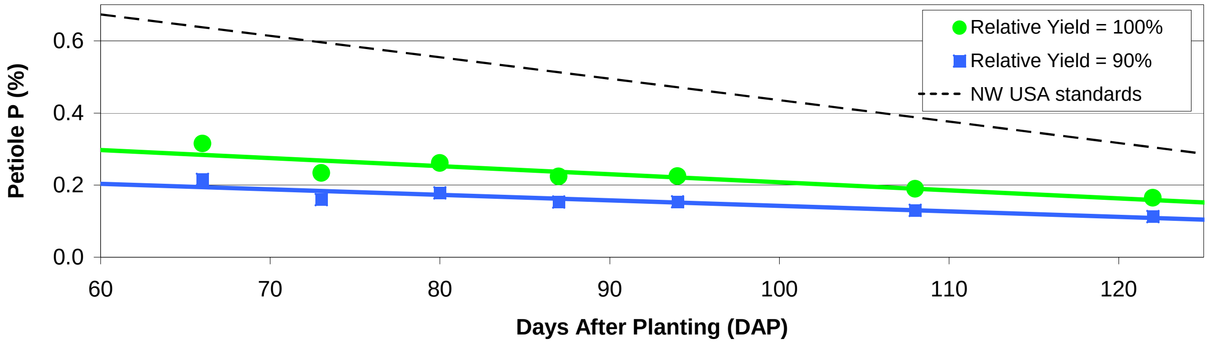
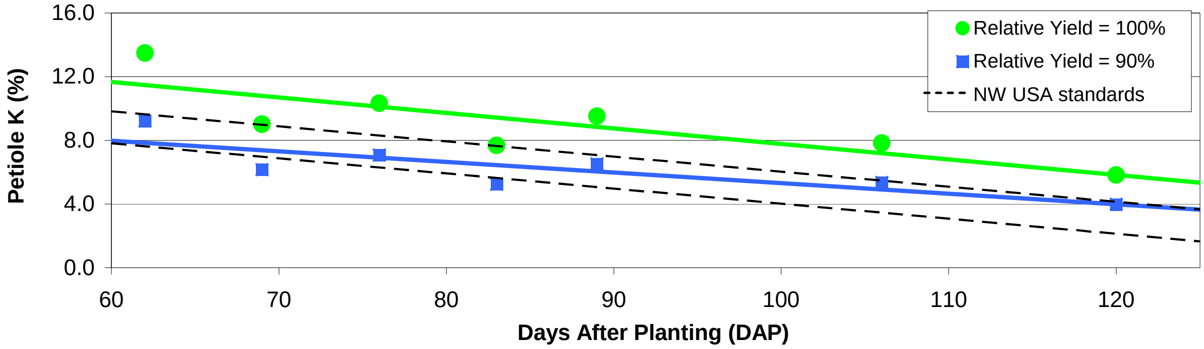
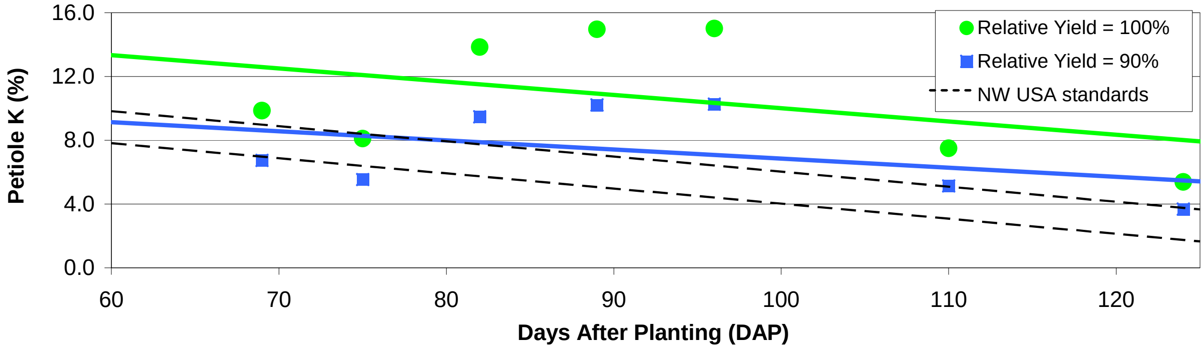


Figure 15. 100% relative yield (RY) and 90% relative yield petiole phosphorus concentration as a function of days after planting in (a) 2004, (b) 2005, and (c) 2007.

a) 2004



b) 2005



c) 2007

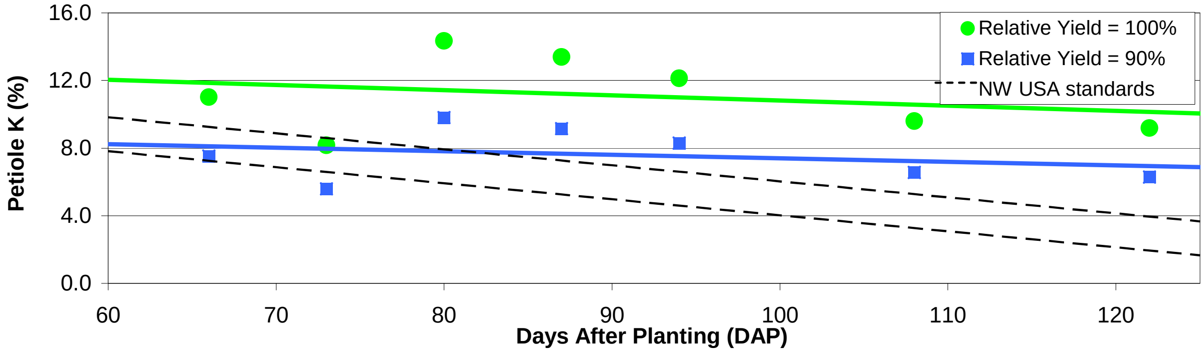


Figure 16. 100% relative yield (RY) and 90% relative yield petiole potassium concentration as a function of days after planting in (a) 2004, (b) 2005, and (c) 2007.

Petiole Phosphorus. The USA standard ranges are higher than the 2004 optimal petiole P concentrations. The 100%RY optimal P was approximately 0.42% at 60 DAP and declined to 0.18% by 120 DAP (Fig. 15a).

The USA standard ranges are much higher than the 2005 optimal petiole P concentrations. The 100%RY optimal P was approximately 0.24% at 60 DAP and declined a small amount to 0.21% by 125 DAP (Fig. 15b). This relationship was nearly a flat line in 2005 and overall values were much smaller than in 2004, yet no negative impacts on yield were observed.

The USA standard ranges are much higher than the 2007 optimal petiole P concentrations (Fig. 15c). The 100%RY optimal P was approximately 0.30% at 60 DAP and declined a small amount to 0.16% by 125 DAP (Fig. 15c). The optimal petiole P values in 2007 were similar to the 2005 results and are at the lowest end of the range of adequate NW USA standards, 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 the upper and lower limits for petiole P (as given by NW USA standards) are too high.

The following formulae are for the linear best-fit 100%RY relationship between petiole P and DAP, which hold for approximately DAP = 60-125.

2004 Petiole P (%) = -0.0038*DAP + 0.64 ($r^2 = 0.89$)
2005 Petiole P (%) = -0.00021*DAP + 0.24 ($r^2 = 0.01$)
2007 Petiole P (%) = -0.0022*DAP + 0.43 ($r^2 = 0.83$)

Petiole Potassium. The USA standard ranges are slightly lower than the 2004 optimal petiole K concentrations. The 100%RY optimal K was approximately 11.5% at 60 DAP and declined to 5.5% by 120 DAP (Fig. 16a).

The USA standard ranges are slightly lower than the 2005 optimal petiole K concentrations. The 100%RY optimal K was approximately 13.3% at 60 DAP and declined to 7.9% by 125 DAP (Fig. 16b). The 2005 petiole K results were 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. Similar to NO_3-N, 2005 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) (Fig. 16b).

The USA standard ranges are slightly lower than the 2007 optimal petiole K concentrations (Fig. 16c). The 100%RY optimal K was approximately 12.0% at 60 DAP and declined to 10.1% by 125 DAP (Fig. 16c). Similar to NO_3-N, petiole K optimal levels appear to follow two stages, one prior to tuber bulking (<80 DAP) and the other from the beginning of tuber bulking and onward (≥80 DAP) (Fig. 16c). The 2007 petiole K results are higher than the adequate range from the NW USA, especially after 80 DAP. 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 would be more suitable in southern Alberta (Woods et al. 2004).

The following formulae are for the linear best-fit 100%RY relationship between petiole K and DAP, which hold for approximately DAP = 60-125.

2004 Petiole K (%) = -0.0973*DAP + 17.5 ($r^2 = 0.32$)
2005 Petiole K (%) = -0.0834*DAP + 18.3 ($r^2 = 0.17$)
2007 Petiole K (%) = -0.0307*DAP + 13.9 ($r^2 = 0.07$)

Optimal Petiole Nutrient Concentrations for Southern Alberta

The study was conducted during a growing season with temperature and precipitation close to long-term averages (2004), a growing season that was cool and wet (2005), and a growing season that was hot and dry (2007). When the values of 100%RY and 90%RY were compared to DAP for all three years combined, they were used to determine optimal petiole nutrient concentrations specific for southern Alberta. Fig. 17 shows the three years of project data compared to the current NW USA standards and the suggested optimal petiole NO_3-N (Fig. 17a), P (Fig. 17b), and K (Fig. 17c) concentrations during the southern Alberta growing season. It is important to remember that these upper and lower limits are for optimal yield (90-100% of relative yield) of Russet Burbank potatoes and are merely guidelines. Actual petiole nutrient concentrations will be affected by genotype, climate, irrigation amount, soil type, planting date, petiole sample collection technique, and laboratory analysis (Doll et al. 1971; MacKay and Carefoot 1987, Westcott et al. 1991; and Lewis and Love 1994).

Nitrate Nitrogen (NO_3-N). The suggested optimal petiole NO_3-N concentrations are quite similar to the current NW USA standards, especially for greater than 80 DAP (Fig. 17a). It is suggested that there should be two sets of ranges, one set for prior to and including approximately 80 DAP and another set for after approximately 80 DAP. The following formulae can be used to calculate the ranges for NO_3-N in units of parts per million (ppm) from the known DAP.

Prior to 80 DAP Petiole NO_3-N (ppm) = -290*DAP + 38800 for 100%RY
Prior to 80 DAP Petiole NO_3-N (ppm) = -290*DAP + 30400 for 90%RY

After 80 DAP Petiole NO_3-N (ppm) = -244*DAP + 41156 for 100%RY
After 80 DAP Petiole NO_3-N (ppm) = -244*DAP + 33756 for 90%RY

Another way to compare petiole NO_3-N to the suggested optimal ranges is to refer to the ranges given in Table 6, which gives the 100%RY and 90%RY values that correspond to between 60 and 125 DAP.

Phosphorus (P). The suggested optimal petiole P concentrations are substantially lower than the current NW USA standards, particularly early in the growing season (Fig. 17b). The following formulae can be used to calculate the Alberta-specific optimal ranges for P in units of percent (%) as a function of DAP.

Petiole P (%) = -0.00308*DAP + 0.485 for 100%RY
Petiole P (%) = -0.00077*DAP + 0.196 for 90%RY

Sample values for optimal petiole P are also given in Table 6 for between 60 and 125 DAP.

Potassium (K). The suggested optimal petiole K concentrations have a wider range than the current NW USA standards (Fig. 17c). Similar to NO_3-N, it is suggested that there be two sets of ranges of petiole K concentrations, one set for prior to approximately 80 DAP and another set for after approximately 80 DAP. The following formulae can be used to calculate the Alberta-specific optimal ranges for K in units of percent (%), as a function of DAP.

Prior to 80 DAP Petiole K (%) = -0.17*DAP + 22.6 for 100%RY
Prior to 80 DAP Petiole K (%) = -0.14*DAP + 15.7 for 90%RY

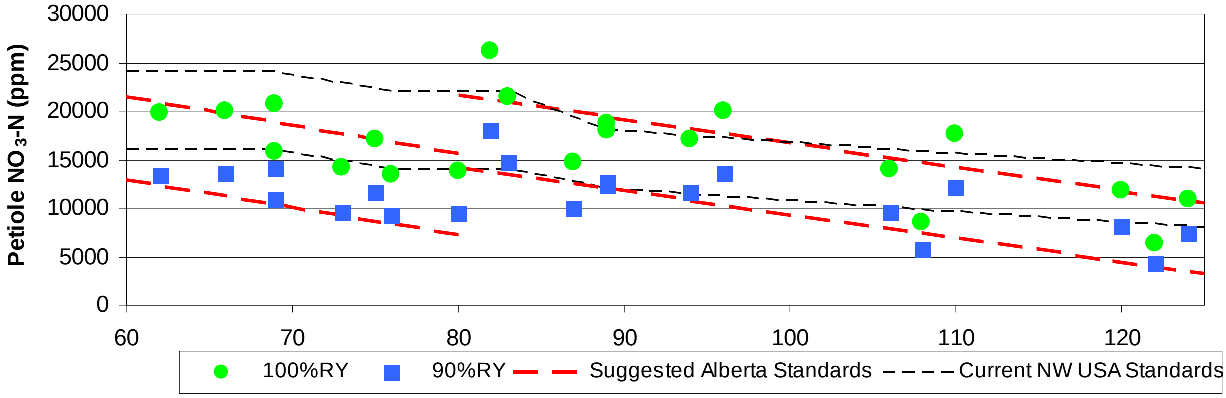
After 80 DAP Petiole K (%) = -0.18*DAP + 29.0 for 100%RY
After 80 DAP Petiole K (%) = -0.17*DAP + 23.1 for 90%RY

Sample values for optimal petiole K are also given in Table 6 for between 60 and 125 DAP.

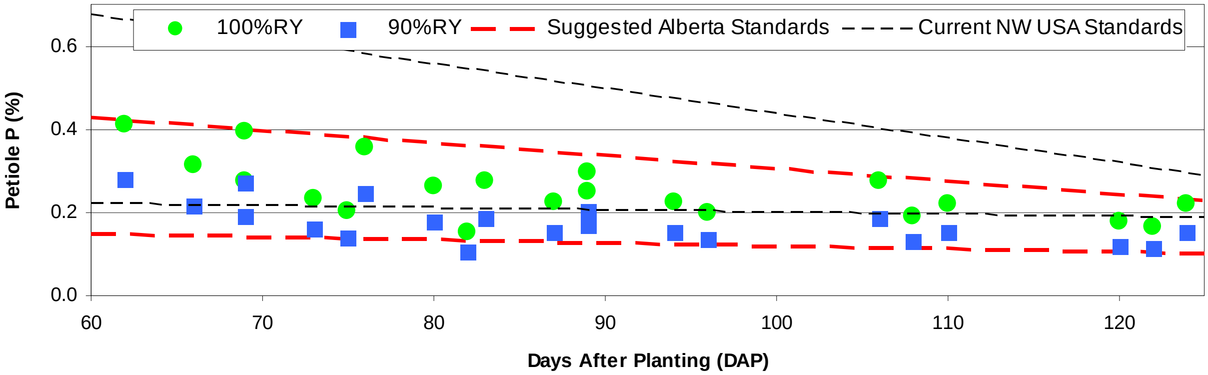
Table 6. Suggested optimal Russet Burbank petiole nutrient (NO_3-N, P, and K) contents based on information from southern Alberta (2004, 2005, and 2007).

Days After Planting (DAP)	Optimal Petiole Nutrient Concentrations					
	NO3-N (ppm)		P (%)		K (%)	
	90%RY	100%RY	90%RY	100%RY	90%RY	100%RY
60	13000	21400	0.15	0.30	7.3	12.4
65	11550	19950	0.15	0.28	6.6	11.6
70	10100	18500	0.14	0.27	5.9	10.7
75	8650	17050	0.14	0.25	5.2	9.9
80	7200	15600	0.13	0.24	4.5	9.0
85	12978	20378	0.13	0.22	8.8	14.1
90	11756	19156	0.13	0.21	7.9	13.2
95	10533	17933	0.12	0.19	7.1	12.4
100	9311	16711	0.12	0.18	6.2	11.5
105	8089	15489	0.12	0.16	5.4	10.6
110	6867	14267	0.11	0.15	4.5	9.7
115	5644	13044	0.11	0.13	3.7	8.9
120	4422	11822	0.10	0.12	2.8	8.0
125	3200	10600	0.10	0.10	2.0	7.1

a) Nitrate Nitrogen (ppm)



b) Phosphorus (%)



c) Potassium (%)

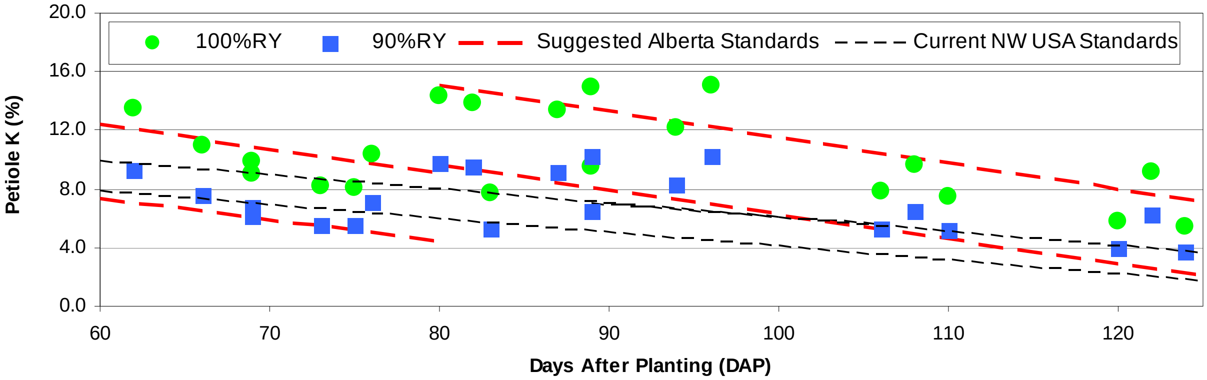


Figure 17. Suggested optimal petiole NO$_3$-N, P, and K concentrations for southern Alberta compared to current northwest USA recommendations and to the 100%RY and 90%RY data collected in 2004, 2005, and 2007.

Comparison to Previously Collected Data

The Belanger technique was adapted and applied to existing data sets accumulated from previous PGA-sponsored studies, where plot-scale petiole and corresponding yield and specific gravity data were available. These studies included projects on the precision farming of potatoes (McKenzie et al. 2002), effects of phosphorus and compost on Russet Burbank potatoes (Woods et al. 2002), and the effects of potassium on Russet Burbank potatoes (Konschuh 2001).

None of these studies consisted of variable rates of fertilizer N. In all cases, N was held constant for all treatments; therefore, results were inconclusive for N. The precision farming study demonstrated that spatial variability exists across any field, even if the entire field receives identical fertilizer application (McKenzie et al. 2002). The phosphorus and compost study (Woods et al. 2002) had variable rates of P, so the results of this study were used for P assessment. For this study, six experiments were conducted during three years (1999-2001). In all cases, P fertilizer rates were varied while other nutrients were held constant. Fig. 18 shows the 100%RY and 90%RY petiole P concentration as a function of days after planting for these six sites. There was variability in the results, but overall the new standards seem to fit quite well, especially early in the growing season.

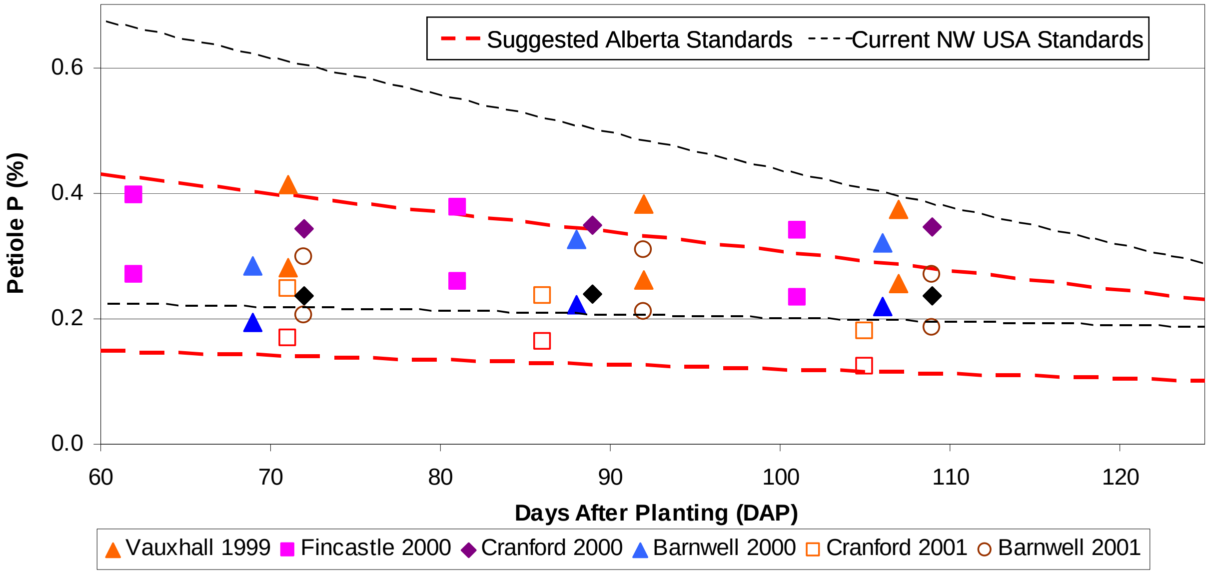


Figure 18. 100% relative yield (RY) phosphorus concentration as a function of days after planting for six previously-completed PGA-sponsored studies.

Results for several previous studies were unsuitable for the Belanger technique, as a second degree polynomial could not be fit to the data. Because this was the case, a simplified process was applied to these data (Konschuh 2001; Woods et al. 2002). For each site, the average petiole nutrient (NO_3-N, P, and K) concentrations for the treatment with the highest average marketable yield were taken as the optimal (Stark, *pers. commun.*). This eliminated the need to fit a polynomial to the data. NO_3-N, P, and K results shown are from the P and compost project (1999-2001) and the K results also include data from the K study (Konschuh 2001).

The NO_3-N results show (Fig. 19a) a great deal of scatter and that the suggested Alberta optimal range is about in the middle of the data points. Again, the N fertilizer rates were held constant for all of these studies, so results from these data and this simplified technique are uncertain.

The P results for this simplified method (Fig. 19b) support the previous results, using the Belanger technique, and fit within the suggested Alberta optimal range for petiole P quite well.

The K results for the simplified method (Fig. 19c) indicate that the suggested Alberta optimal range for petiole K may be too high for data from the P project.

One point to bear in mind regarding Fig. 19 is that this simplified technique for determining optimal petiole concentrations only takes into account the actual rates used in the study and does not "fill-in the blanks" for concentrations between the tested rates. So if one of the treatments did not achieve the exact optimal concentration-yield combination, it may have over or under estimated the optimal concentration and yield by just choosing the best one. The Belanger technique fits a curve to the data to determine the precise point at which the optimal yield should occur.

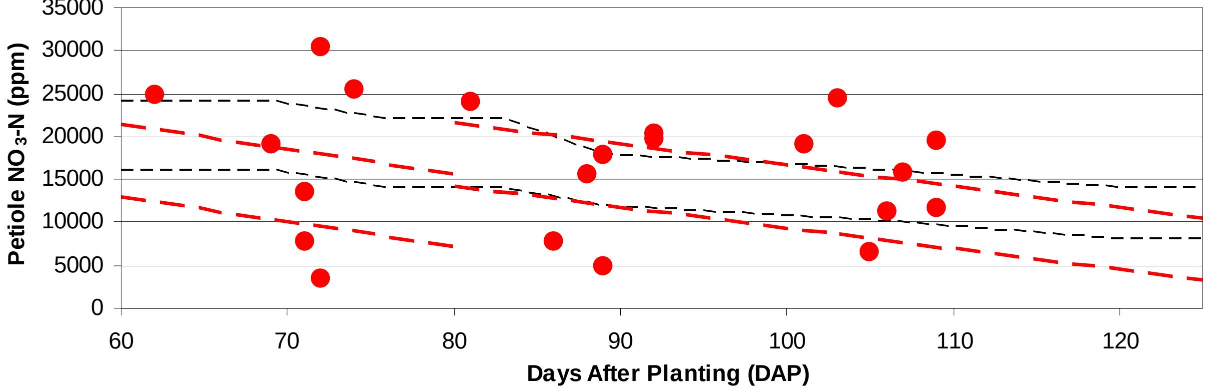
Effects of Climate

Although it was not a part of the initial objectives of the project, the effects of climate were examined using data from previously-completed PGA-sponsored studies done between 1997 and 2001 and using data from this study (2004, 2005, and 2007). The petiole NO_3-N data as a function of DAP were fit to a single linear regression equation, for each individual year. The intercept and slope of the best-fit line were then compared to temperature and precipitation data for the entire growing season and for various combinations of months during the growing season. Although the results of this analysis were not highly significant, there were some overall trends that were notable. Fig. 20 shows the results compared to average temperatures of June and July. The 40-yr mean temperature (1950-1990) for June and July was 17.4 °C and only the 2005 average was below this value.

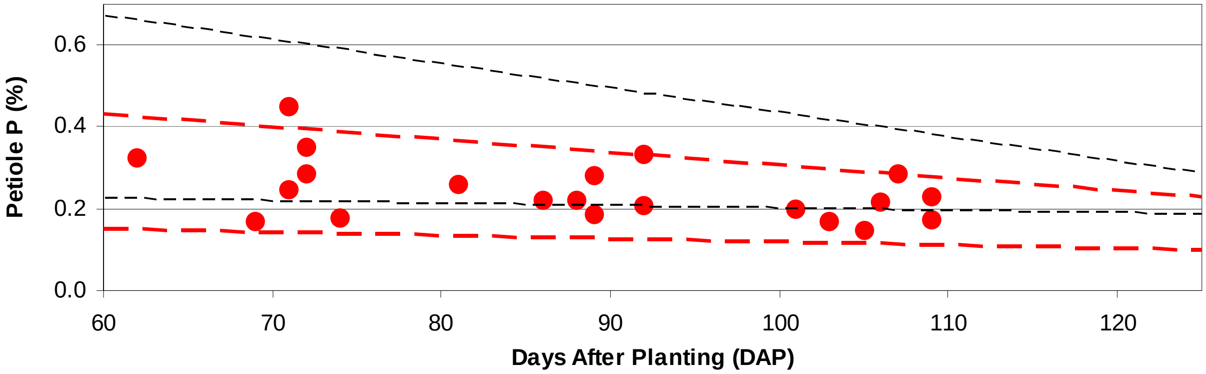
In years when June and July are hotter than average, petiole NO_3-N concentrations may be greater than usual at the start of the measuring dates, as indicated by a greater intercept (Fig. 20a) from the petiole NO_3-N *versus* DAP best-fit line. Comparison of the slope of the petiole NO_3-N *versus* DAP best-fit line to temperature (Fig. 20b) indicates that petiole NO_3-N concentrations may decrease at a greater rate in hotter than average years than in cooler years. This may be due to the plant growing faster in hotter June-July weather and being unable to sustain sufficient rates of nitrogen uptake or it may be an artefact of heat-stress. Regardless, these trends hint at the impact of climate on petiole nitrate nitrogen concentrations.

Temperature effects could possibly be seen in other petiole nutrients. Only a cursory analysis of the effects of climate data was done here and it is recommended that the effects of climate on petiole nutrients be examined in more detail.

a) Nitrate Nitrogen (ppm)



b) Phosphorus (%)



c) Potassium (%)

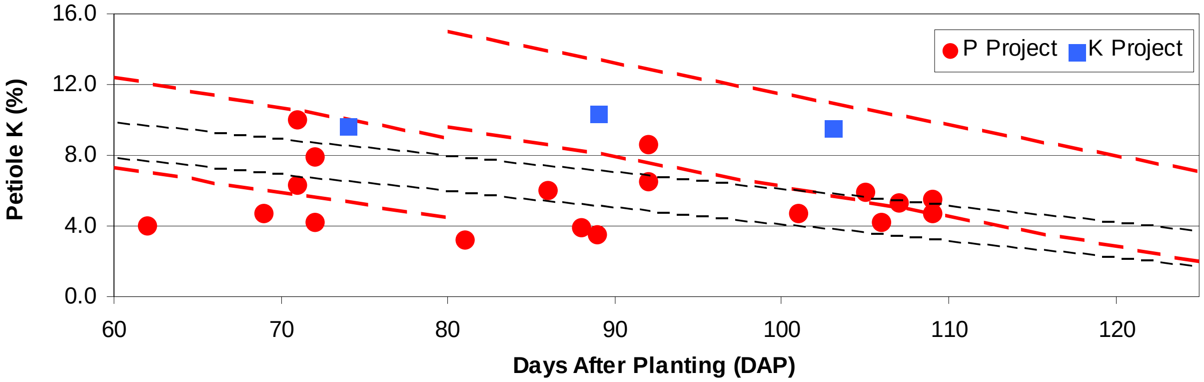


Figure 19. Petiole (a) nitrate nitrogen, (b) phosphorus, and (c) potassium concentration for treatment with highest yield as a function of days after planting for previously-completed PGA-sponsored studies.

The potential effects of climate reinforce the notion that petiole nutrient recommendations should only be treated as guidelines that will be impacted by climate, soil, and other environmental factors, as well as human factors.

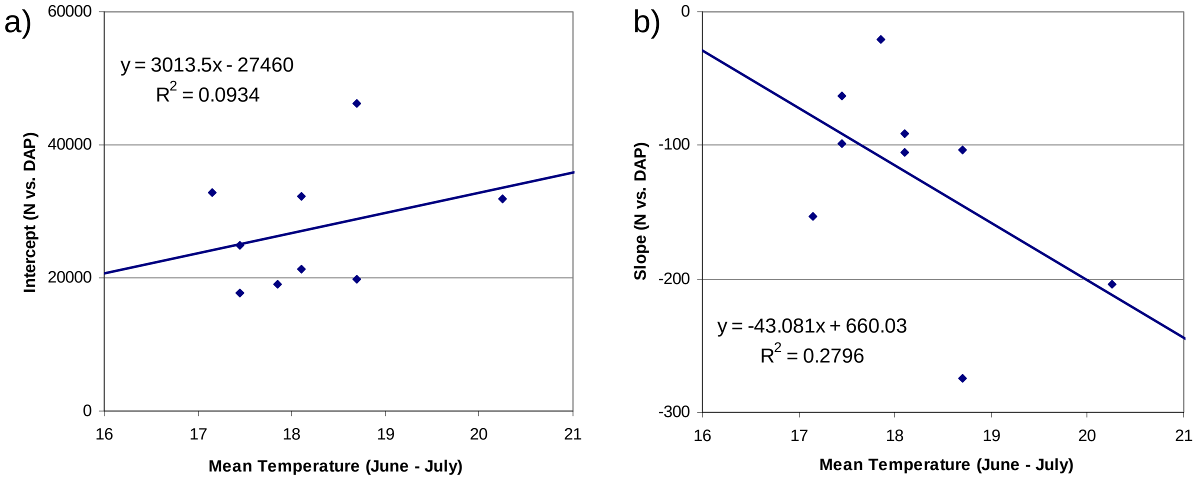
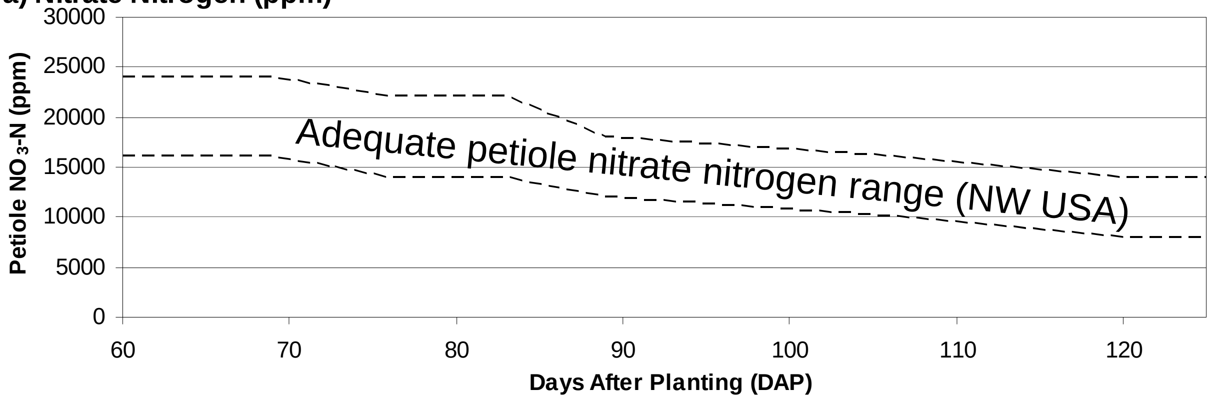


Figure 20. Climate effects on petiole nitrate nitrogen as exhibited by the relationship between the (a) intercept and (b) slope of the NO_3-N *versus* DAP best-fit lines as a function of mean temperatures in June and July for each year that data were available.

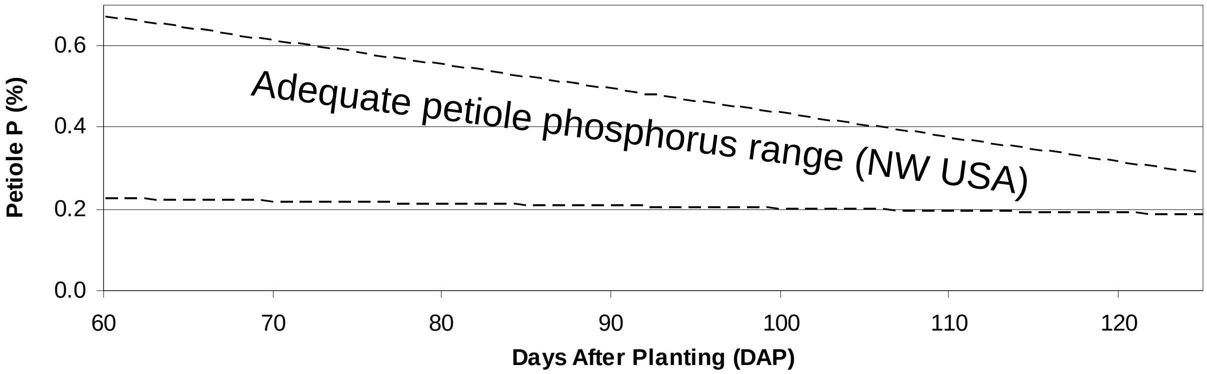
Petiole Nutrient Concentration Recommendations

Current Alberta Russet Burbank potato petiole NO_3-N, P, and K recommendations are based on information from the northwest United States (Table 1; Fig. 21). A technique for determining critical petiole nitrate nitrogen concentrations from experimental data (Belanger et al. 2001 and 2003) was applied to three years of data collected in southern Alberta in 2004, 2005, and 2007. Based on these data, new petiole nutrient concentration ranges have been proposed (Fig. 22). When these suggested petiole nutrient recommendations were compared to previously-collected data, they gave reasonable results for P and K. There was a great deal of scatter in the previously-collected N data, as petiole NO_3-N can be affected by many factors.

a) Nitrate Nitrogen (ppm)



b) Phosphorus (%)



c) Potassium (%)

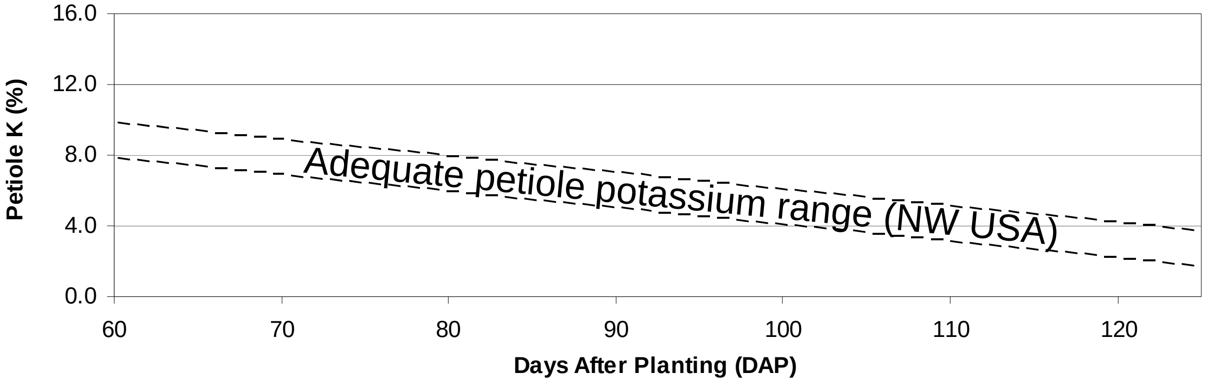
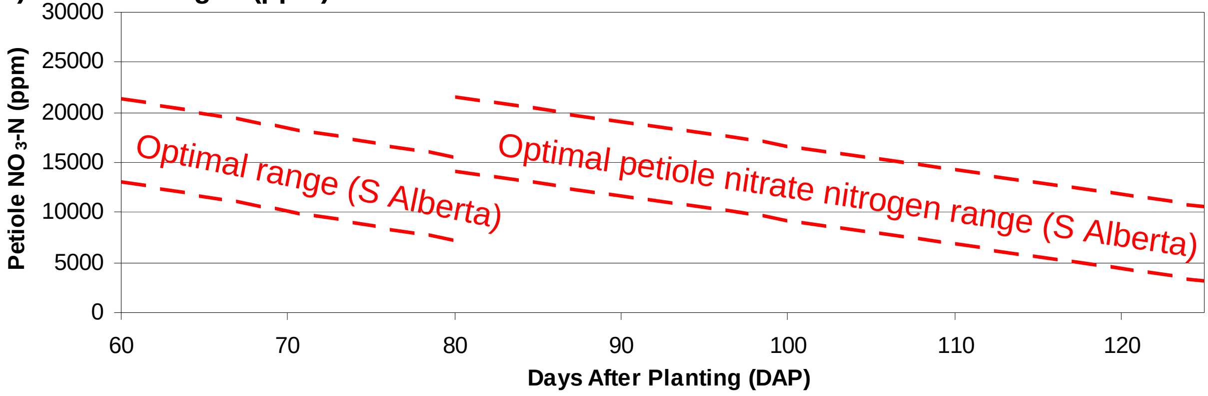
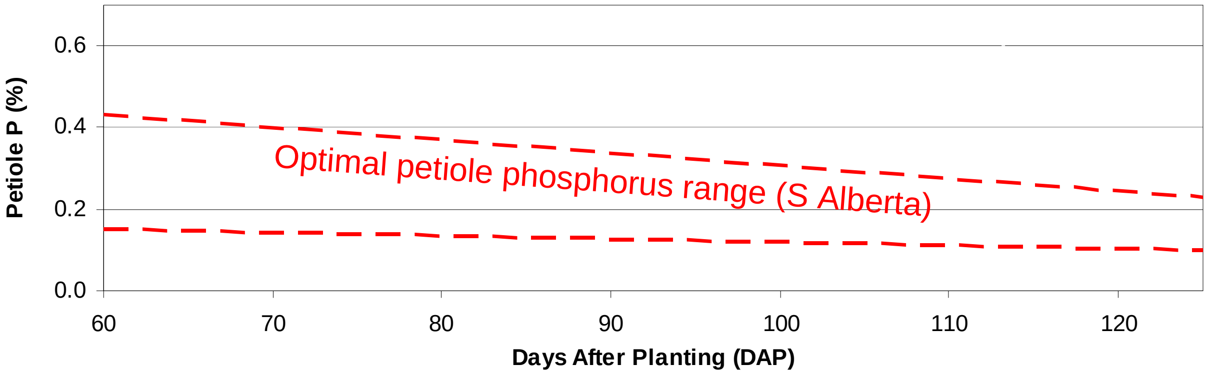


Figure 21. Current petiole nutrient (NO_3-N, P, and K) concentration recommendations based on information from the northwest United States (NW USA).

a) Nitrate Nitrogen (ppm)



b) Phosphorus (%)



c) Potassium (%)

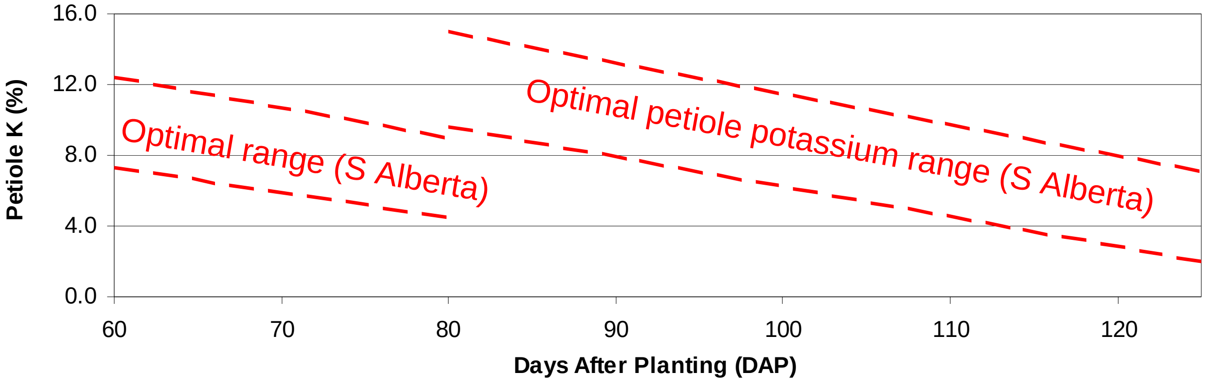


Figure 22. Suggested Russet Burbank petiole nutrient (NO_3-N, P, and K) concentration recommendations based on information from southern Alberta.

CONCLUSIONS

New optimal petiole nutrient concentration ranges for optimal marketable yield have been developed that are specific to Russet Burbank potatoes grown in southern Alberta's soil and climatic conditions. These proposed optimal petiole nutrient concentrations were compared to data collected in previously-completed studies and were found to be valid. No consistent or significant relationships between petiole nutrient concentration and specific gravity were observed. Potassium fertilizer did not have a consistent impact on specific gravity.

The suggested petiole nitrate nitrogen range is slightly lower than the northwest USA standards at the beginning of the growing season (DAP < 80) and late in the growing season (DAP > 105). The revised optimal petiole phosphorus ranges are substantially lower than the northwest USA standards. The recommended petiole potassium ranges are wider than the northwest USA standards overall and are similar early in the growing season (DAP < 80). Later in the growing season, the upper limits of the new petiole potassium recommendations are greater than for the northwest USA standards.

The new suggested optimal ranges should be considered as guidelines only and should be viewed in the context of previous years' data from any given site. Petiole nutrient concentrations will be affected by many factors, in addition to available soil nutrients. Some of these factors include temperature, precipitation, soil texture, and other environmental factors, as well as human factors such as petiole sampling technique, irrigation management, location of samples within the field, and laboratory analysis. Petiole nutrient concentrations should be considered on a field-specific basis. Spatial variability exists across any field, so care must be taken to choose petioles from benchmark locations that are representative of the field, in terms of location and plant appearance.

The conclusions drawn in this study are based on three years of experimental data and it is suggested that the PGA, along with growers and processors, continue to refine these recommendations based on petiole nutrient concentrations they observe currently and in the future.

REFERENCES

Alberta Agriculture and Rural Development. 2008. Alberta Soil Information Viewer. [Online] Available: http://www2.agric.gov.ab.ca/app77/imf.jsp?site=agrasid [14 May 2008].

Belanger, G., Walsh, J. R., Richards, J. E., Milburn, P. H. and Ziadi, N. 2001. Critical nitrogen curve and nitrogen nutrition index for potato in eastern Canada. Amer. J. of Potato Res. **78**: 355-364.

Belanger, G., Walsh, J. R., Richards, J. E., Milburn, P. H. and Ziadi, N. 2003. Critical petiole nitrate concentration of two processing potato cultivars in eastern Canada. Amer. J. of Potato Res. **80**: 251-262.

Brady, N. C., and Weil, R. R. 1998. The Nature and Properties of Soils. Prentice Hall, New Jersey, USA. 881 pp.

Doll, E. C., Christenson, D. R. and Wolcott, A. R. 1971. Yields as related to nitrate levels in petioles and soils. Amer. Potato J. **48**: 105-112.

Dubetz, S. and Bole, J. B. 1975. Effects of nitrogen, phosphorus and potassium fertilizers on yield components and specific gravity of potatoes. Am. Potato J. **52**: 399-405.

Dubetz, S. and Dudas, M. J. 1981. K status of a Dark Brown Chernozemic soil after 66 years of cropping under irrigation. Can. J. Soil Sci. **61**: 409-415.

Environment Canada. 2008. Climate Data Search. [Online] Available: http://www.climate.weatheroffice.ec.gc.ca/advanceSearch/searchHistoricData_e.html [22 September 2008].

Konschuh, M. N. 2001. Influence of potassium on specific gravity of Russet Burbank potatoes. unpublished data.

Lewis, R. J. and Love, S. L. 1994. Potato genotypes differ in petiole nitrate-nitrogen concentrations over time. HortScience **29**: 175-179.

Mackay, D. C. and Carefoot, J. M. 1987. Potassium status of irrigated Brown Chernozemic soils of southern Alberta. Can. J. Soil Sci. **67**: 877-891.

Mackay, D. C., Entz, T., Carefoot, J. M. and Dubetz, S. 1989. Comparison of critical nutrient concentrations with DRIS for assessing nutrient deficiencies of potatoes on irrigated Chernozemic soils. Can. J Plant Sci. **69**: 601-609.

McKenzie, R. C., Woods, S. A., Schaupmeyer, C. A., Green, M., Goddard, T. W. and Penney, D. C. 2002. Site specific management of potatoes. AARI Project No. 96M979. 92 pp.

Schaupmeyer, C. A. 1999. Personal communication.

Schippers, P.A. 1976. The relationship between specific gravity and percentage dry matter in potato tubers. Am. Potato J. **53**: 111-122.

Stark, J. C. 2004. Personal communication.

Waterer, D. and Heard, J. 2005. Fertility and fertilizers (for potato production). [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/opp9572 [15 November 2005].

Westcott, M. P., Stewart, V. R. and Lund, R. E. 1991. Critical petiole nitrate levels in potato. Agron. J. **83**: 844-850.

Woods, S. A., McKenzie, R. C., and Hingley, L. E. 2002. Phosphorus and compost on irrigated potato crops. *In* Proceedings of the 39th Alberta Soil Science Workshop, p. 210-214.

Woods, S. A., Hingley, L. E., and Konschuh, M. N. 2004. Petiole nutrient (N, P, and K) recommendations for Russet Burbank potatoes grown in southern Alberta (2004). Report prepared for the Potato Growers of Alberta. January 2004.