PGA RESEARCH ARCHIVE

NUTRIENT EFFICIENCY & MANAGEMENT

POTATO GROWERS OF ALBERTA

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A COMPARISON OF SELECTED POTASSIUM FERTILIZER FORMULATIONS ON RUSSET BURBANK POTATOES

An evaluation of the effects of three potassium products on emergence, plant stand, early vigor, tissue nutrition, yield and quality in a commercial field in the central portion of the Columbia Basin in Washington State.

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by
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THE INFLUENCE OF POTASSIUM FORMULATION ON POTATO PRODUCTIVITY

A LITERATURE REVIEW OF THREE POSASSIUM FERTILIZER FORMULATIONS

Ongoing refinements in potato production are progressively reducing the growers margin for error. Today's more vigorous and productive crops place increasing demands against all of the growth requisites. Of major concern is the adequate and timely supply from residual soil fertility and applied nutrients to satisfy the developing plants needs. To complicate matters, the requirements for essential nutrients change considerably through the course of a growing season. Generally the greatest concerns focus on peak demand periods. Whenever nutrient demand exceeds the crops fertilizer uptake, the production potential is diminished. An appropriate selection from the available nutrient formulations is also becoming increasingly important to the success of the crop. This consideration is especially relevant for potassium fertilizers. While no potassium formulation has more negative than positive properties, there are clearly some types with more desirable benefit/risk ratios in specific crop situations. With increasing frequency we are finding unusually high fertilizer rates being applied where exceptional yields are expected. The effectiveness of potassium as a fertilizer depends in part on the form and formulation in which it is applied. Many potassium fertilizers are formulated as salts. The potential concern for elevated soil salts is an agronomic consideration that should not be ignored. Accumulations of dissolved ions that have little or no role in plant nutrition may directly interfere with the osmotic functions of nutrient uptake and translocation. For this reason the salt index of various potassium fertilizers merits a careful review. Potassium sulfate (K_2SO_4) has is a 52% equivalent of K_2O and a fertilizer salt index of 45. With Potassium nitrate, (KNO_3) there is a 47% equivalent of K_2O, and it has a salt index of 74. This 64% increase in salt index is significant. Muriate of potassium or potassium chloride (KCl) has a 60% equivalent K_2O and a salt index of 116. KCl thus has a salt index that is 152% higher than K_2SO_4 and 57% higher than KNO_3. The soluble salts in soils and the salt index of the fertilizer selected are always interrelated considerations. The salt index is a measures of a soluble materials potential to change the dissolved ion concentration or osmotic pressure of the soil solution. Fertilizer materials with high salt index's have the greatest effect on raising the soil solutions osmotic pressure and therefore the highest potential for phytotoxic "burn". By selecting a lower salt index formulation, the potential for salt induced yield and quality reduction is minimized. Also the higher the fertilizer application rate, the more important these considerations become. This is especially true where warm arid climates and high soil evaporation losses occur.

Fertility availability to the plant is influenced in part by the salt index of the formulation. Since "plants drink, they don't eat" all nutrients must dissolve before they become available. Furthermore, all nutrients move into the plant across selectively permeable membranes in water as dissolved ions. This is in direct response to the magnitude of existing osmotic pressure gradients. "Salts" as dissolved ions can also change the osmotic potential of the soil solution. If the osmotic pressure within the cell gets too high, neither is water taken into the root nor are the dissolved nutrient ions. If the salt concentration gets too high, water may actually be withdrawn producing a fertilizer "burn". All things considered, the rates of application must be lower with fertilizer forms with a high salt index. The elevated sodium content in irrigation water is another important concern in salt management strategies.

There is considerable evidence of an inhibitory effect on potassium uptake as chloride ions concentration increases. This antagonistic relationship is not present when sulfate or nitrate formulations are selected. Yield and quality responses are also better with sulfate and nitrate formulations, not so much because of the nitrate or sulfate presence. but because of the negative effects of chloride ions at the higher levels.

Nutrient balance and interaction is always an important consideration. When a need for high K levels exists we may need to make special allowances for interactions with potassium fertilizers. Calcium, magnesium, boron and molybdenum uptake may be reduced because of antagonistic interactions with potassium. Conversely high K levels are known to enhance Zn, Mn and Cu uptake. Potassium also tends to enhance nitrogen use and interact synergistically with phosphorus. Chlorides however tend to inhibit potassium uptake.

Injury caused by chloride ions occurs in sensitive crops at the 3,000 to 5,000 ppm range. The potato plant is generally considered to be moderately sensitive to chloride ions. The potato is also a relatively high user of potassium. Considering these factors together it may be wise to select carefully the formulation(s) of potassium fertilizer to be applied to a potato crop. By carefully managing the nutrient balance, plants will generally be able to assimilate adequate quantities of all the essential nutrients as long as sufficient soil levels are maintained. In other words, the effectiveness of potassium as a nutritional element is related to the crops need being satisfied on a daily basis and also the interaction(s) with the carrier ion with which it is formulated. These considerations are further complicated by the requirements of the specific crop, moisture and evaporation conditions and existing soil salt properties.

When undisturbed, potassium exists in the soil in a balanced and stable equilibrium. The chemistry and physical properties of the soil itself effects this relationship. The potassium equilibrium is composed of the SOLUBLE (available, dissolved ions);

EXCHANGEABLE (unavailable, electrically bonded on soil particle surfaces) and FIXED (unavailable, bound within the mineral structure of the soil particles) forms. During the growing season when plants are present this equilibrium is continually out of balance due in large part to root system potassium withdrawals. This interaction is therefore in an ongoing dynamic flux. It is governed most by the soil characteristics, the rate of addition (fertilizer applications) and withdrawal (plant uptake). All the potassium we apply enters the equilibrium in the SOLUBLE form and then largely ties up on the soil particle surfaces as EXCHANGEABLE potassium. While plants may have brief access to in season K applications before tie up occurs, the most important benefits are from the new equilibrium that will provide proportionately more available potassium and for extended periods. Potassium does not limit growth or vigor as long as the available, i.e. SOLUBLE, supply exceeds the level of assimilation demand which satisfies the plants needs. As plants continue to remove soluble potassium, the equilibrium shifts to restore that which is removed by the root system. When the conversion from EXCHANGEABLE to SOLUBLE does not satisfy the plants need we may see a deficiency condition develop. Good agronomics will then dictate that we apply some form of potassium fertilizer to the field. This balance in fertility is the growers attempt to meet the crops needs and at the same time maintain the best economic return on the fertilizer investment. Since more than 40% of crop yield is provided by applied fertilizers, correct decisions about rate, timing, form and formulations are critically important.

Potassium's primary function in the plant is to optimize the functions of photosynthesis. We are also concerned with activating enzymes to accelerate growth, regulating energy and water relations and the assimilation and translocation of nutrients and carbohydrates. Potassium is recognized as having more influence on crop quality than any other individual nutrient element. Furthermore, because crop performance is the objective and profit our primary measure of success, we tend to look at this aspect with particular interest.

Irrigation practices are also important since all nutrients are taken into the plant in the form of dissolved ions. The ion solutions in our soils are subject, in varying degrees to relocation whenever an over watering situation occurs. This may move our available nutrients out of reach to our plants root system. When soils are over-irrigated, i.e. saturated, some of the dissolved nutrients may be washed away from their equilibrated positions. Based on solubilities, the potential for K_2SO_4 to leach is half that of KCl and KNO_3. The soil equilibriums for potassium will be restored from the non-soluble reserves but there is a delay while this process occurs. This equilibrium recovery varies considerably with different soils. During this lag time the amount of soluble potassium necessary to satisfy crop needs may be temporarily inadequate. The overall effect is predictably one of reduced productivity and lost profit. Considerable evidence indicates that whenever a deficiency in soil potassium availability occurs, there is limited benefit to applying a single large application. Very high rates, that may be uneconomical (greater than 500 lbs/a), can however make corrections to potassium supply in the short term. A much better option may be to apply small amounts of soluble K frequently through the irrigation water in order to remain on the desirable side of the cost/benefit relationship. Fertilizer formulation solubility therefore becomes an important consideration since we are in effect supplementing the soil reserves with the additional nutrient needed in an available form. Application timing and rate must match the plants need by the amount that this need exceeds the soils current potassium release rate. The results demonstrate that the smaller and the more frequent these additions are made, the more efficient the results. It also suggests that preplant rates in some situations can be reduced and that in some situations the total amount applied can be lower for an equal or better result.

The relative effectiveness of potassium fertilizer formulations in terms of potato yield, specific gravity and starch accumulation favors K_2SO_4 over KNO_3 and KNO_3 over KCl. The effectiveness of potassium therefore depends on both the formulation and the crop to which it is applied. It is generally believed the poorer responses associated with muriates is due to the negative effects of chlorides rather than the positive benefits of sulfates or nitrates. It is further noted that the consequences of elevated chloride ions is greatest on course soil types and in situations where arid climates and high soil surface water losses as upward percolation exists. While the information about potassium fertilizer formulation and potato crops comes from throughout the world there is little data currently available from the Columbia Basin in Washington State. To address this issue a replicated and randomized trial was undertaken in the central part of the basin area during summer of 1992 to compare Russet Burbank potato crop performances with the three most common potassium fertilizer formulations used commercially in the Pacific Northwest.

METHODS AND PROCEDURES

A field site was selected that had an unusually low potassium soil test value. This field was deliberately selected to enhance the opportunity for performance differences between applied potassium formulations to be exhibited. A location well into the selected field (more than 600 feet from the perimeter) was chosen for its topographic and soil type uniformity. The perimeter of the plot site was measured and staked prior to the commercial preplant broadcast fertilizer application to the remainder of this 100 acre pivot irrigated field. The broadcast application and the test treatments were applied on April 20th. These were incorporated using a tightly set finishing disc to minimize the movement of the applied fertilizers during the incorporating process. Following this tillage operation, the borders of the replicated and randomized test blocks were remeasured and staked. On April 27th the plot rows were individually opened, the 10 inch seed interval marked and the seed was hand planted. Four rows each twenty five feet in length of each 30 foot treatment area was planted with 30 seed pieces on 10 inch spacings and 34 inch row centers. The soil covering the seed was shaped by hand tools to exactly duplicate the size and shape of the hill created by the growers mechanical planter. Seed piece depth was 6 1/2 inches below the top of the hill's soil surface. Every effort was made to duplicate the commercial situation of the field. After planting was complete, with the exception of stand counts on May 21st, the extensive petiole sampling beginning July 6th and ending September 18th and the split KNO_3 applications (July 15th-31st and August 14th), nothing culturally was done within the plot site that did not occur in the remainder of the field until harvest. That is to say the plots were cared for under good commercial agronomic practices to make the results more relevant to commercial potato production. Weekly petiole sampling consisted of collecting 40 petioles (10 from each replicated block) fourth from the top of the stem, leaves removed and placed in ID coded paper sample bags. All samples were delivered to the lab within one hour of being collected. All were collected before 10 AM in the morning and were transported to the lab in an ice chest.

The plots were harvested on October 9th with a single row potato lifter after vine senescence. All the remaining vines were removed by hand prior to digging. The center two rows of each four row block were dug for yield and grade evaluation. The harvested crop was hand sacked, tagged and taken to a USDA grade facility where it was evaluated by USDA inspectors using USDA process grade criteria on October 16th. The balance of plot rows and the field was harvested after the plot harvest was complete by the commercial grower; Johnson Agriprises Inc.

The growers preplant fertility program applied to test field (except for the test plot site) based on soil test and projected crop need.

Nitrogen	140 lbs/a
Phosphorus	150 lbs/a
Potassium	225 lbs/a
Sulfur	50 lbs/a
Zinc	5 lbs/a
Boron	1 lb/a

Figure 1

POTASSIUM FORMULATION EVALUATED

Treatment 1	KCl	100% preplant applied April 20th
Treatment 2	K_2SO_4	100% preplant applied April 20th
Treatment 3	KNO_3	100% preplant applied April 20th
Treatment 4	KNO_3	50% preplant applied 16.7% applied July 15th 16.7% applied July 31st 16.7% applied August 14th

Figure 2

PLOT LAYOUT

NORTH

3	1	4	2	REP 1
2	3	4	1	REP 2
1	3	2	4	REP 3
4	2	1	3	REP 4

SOUTH

Treatment Code:

1 = KCl
2 = K_2SO_4
3 = KNO_3
4 = KNO_3 (split)

Each treatment block was 30 ft long X 11' 4" wide or 339.0 sq ft.
339.9 sq ft X 4 replications = 1360 sq ft or .003 acres

Diagram 1

PLANT POPULATIONS

	TOTALS
Treatment 1	237
Treatment 2	235
Treatment 3	236
Treatment 4	236
OVERALL TOTAL	944

Percent Stand 944/960 = 98.33%

Figure 3

STAND COUNTS AT 4" GROWTH STAGE

21 MAY 1992

	REP 1	REP 2	REP 3	REP 4
Treatment 1	30*30	29 29	30 30	30 29
Treatment 2	29 30	28 29	30 30	30 29
Treatment 3	29 30	29 29	29 30	30 30
Treatment 4	29 30	29 28	30 30	30 30

*Plant count per 30 seed pieces planted.

Figure 4

RESULTS AND DISCUSSION

The established plant population in the plot site was 98.33% of the seed planted. Figure 3. This is based on stand counts made on May 21st when the plants were approximately four inches tall. Figure 4. Of the 960 seed pieces planted 944 emerged. Missing plants were due equally to three pathogens *Fusarium* sp., *Rhizoctonia* sp., and *Pithium* sp. and losses were distributed very equitably between the four treatments and the four replications. In other words, the loss in stand, small as it was, was randomly distributed throughout the plot site and not related to the treatments.

Early vigor and plant development was examined closely and found not to be different between treatments or replications.

Petiole sampling began July 6th when the plants were 12 to 14 inches tall. The collection of petioles was delayed to this stage of growth because the seed pieces planted were relatively large (2.5 oz. average) and seed this large is recognized as having an important influence on crop nutrient status at least through the 10 to 12 inch plant height. All treatments had first sample NO_3-nitrogen petiole levels above 20,000 ppm with the exception of the split KNO_3 treatment. Figures 5 through 8, Tables 1 through 4. Petiole levels increased in all treatments for the next two weeks. After that, all treatments exhibited a characteristic (normal) downward trend through September 18th when sampling ended. Petiole sample collection was discontinued at that time due to the maturation progress of the potato vines. In other words, there wasn't enough healthy tissue remaining to collect a credible and representative sample.

The phosphorus tissue levels was measured a PO_4-P percentage. Figures 9 through 12, Table 5. The phosphorus levels were slightly higher for the split potassium nitrate treatment from the start. In eight of the eleven weeks the KNO_3 split treatment was equal to or higher than any other treatment. The potassium chloride treatment had equal to or the highest phosphorus levels in five of the eleven sample periods. The potassium sulfate and potassium nitrate treatments each had one highest value in the eleven weekly samples. It is interesting to note that the phosphorus tissue level showed a distinctly elevated value the week after each of the three mid-season KNO_3 split applications.

The potassium level in the tissue sample analysis also produced some interesting results. Figures 13 through 16, Table 6. The tissue levels were highest in the potassium chloride plots during the first three sample periods. With the exception of the final sample period, the potassium nitrate treatment either individually or together with another formulation had the highest tissue potassium level for the last seven weeks. The split potassium nitrate treatment consistently maintained the highest potassium levels through most of the growing season.

The sulfur levels in the tissue analyses show the potassium sulfate treatment had the highest sulfur levels in four of the first five sample periods and again in the last three sample periods. Figures 17 through 20, Table 7. The potassium chloride treatments were highest or equal to the highest levels after August 1st. Sulfur levels were consistently lower in the potassium nitrate treatments by comparison.

The yield and quality performances of the plants in the four tested treatments exhibited some very useful relationships. Figures 21 through 23, Table 8. This performance, when measured in yield and quality parameters, indicates that all the potassium formulation applied entirely pre-plant incorporated were significantly better than the KNO_3 split applications. The 100% PPI potassium nitrate produced a crop with a value $275.39 per acre higher than the KNO_3 split treatment. The KNO_3 and K_2SO_4 yields were very nearly equal with only a one half percent yield or $24.23 per acre in crop value difference in this trial. The internal defects in the K_2SO_4 treatment was significantly higher than any of the other treatments which were not different from one another. Figure 24.

The poorest performance of the three 100% K pre-plant incorporated treatments was the muriate of potassium formulation. The KCl plots averaged .89 tons/acre or $111.46 less crop value per acre than did the K_2SO_4 treatment and $87.23 less than the KNO_3 plots.

The harvested tuber size distributions showed no consistent or important differences of economic significance. Figure 25 through 28, Table 9. The effect of potassium formulation on tuber specific gravity shows the K_2SO_4 and KNO_3 split had the best averages. Figure 29, Table 10. The KCl treatment had the lowest dry matter results. As expected the smallest tubers had the lowest specific gravities. This is the most likely direct result of immaturity. The 4 to 6 oz. potatoes had in all cases higher gravities than the 2 to 4 oz. tubers and in all cases lower gravities than either the 6 to 10 oz. or the 10 to 14 oz. size categories. The largest tuber size, the 10 to 14 oz. group, had equal to or higher gravity properties as compared to the 6 to 10 oz. sizes. The differences occurring in this trial are commercially significant and of monetary consequence to the grower.

The sugar content of the harvested tubers as measured by fry color on the USDA color chart showed the KNO_3 treatments had significantly more 1 and 2 color fry strips than did KCl and K_2SO_4. Table 11. While samples graded directly out of field seldom exhibited sugar levels of concern there may be reason to wonder what the outcome might be after an extended storage exposure. This was not done as the entire sample was consumed as the grade evaluation was done.

PETIOLE ANALYSIS DATA

Treatment 1 - KCl 100% PPI

	NO_3-N (PPM)	S (%)	P (%)	K (%)
7/06	20,750	.21	.36	10.0
7/15	22,250	.26	.45	19.9
7/24	22,875	.30	.55	12.7
7/31	17,050	.27	.36	11.3
8/07	16,500	.29	.36	10.4
8/14	14,125	.32	.33	10.6
8/21	12,125	.31	.43	8.7
8/28	8,500	.21	.22	8.6
9/04	9,000	.22	.21	9.3
9/11	7,750	.25	.17	8.8
9/18	4,725	.19	.14	7.9

Table 1

Treatment 2 - K_2SO_4 100% PPI

	NO_3-N (PPM)	S (%)	P (%)	K (%)
7/06	20,125	.22	.37	9.7
7/15	23,450	.26	.38	10.9
7/24	25,950	.37	.50	12.0
7/31	21,950	.33	.32	11.6
8/07	19,750	.29	.30	10.1
8/14	15,250	.28	.42	10.9
8/21	12,955	.23	.23	9.5
8/28	10,000	.20	.27	9.3
9/04	9,550	.22	.21	8.9
9/11	5,450	.25	.15	8.5
9/18	4,675	.20	.13	8.0

Table 2

PETIOLE ANALYSIS DATA

Treatment 3 - KNO_3 100% PPI

	NO_3-N (PPM)	S (%)	P (%)	K (%)
7/06	21,000	.25	.41	9.6
7/15	21,000	.25	.32	10.7
7/24	25,850	.28	.48	12.2
7/31	21,100	.29	.30	11.1
8/07	21,125	.29	.43	10.7
8/14	19,075	.30	.30	11.4
8/21	14,550	.26	.32	9.8
8/28	9,350	.26	.29	9.6
9/04	8,000	.19	.17	9.1
9/11	5,325	.20	.16	8.5
9/18	4,750	.19	.13	7.9

Table 3

Treatment 4 - KNO_3 Split (50% PPI and three 16.7% applications)

	NO_3-N (PPM)	S (%)	P (%)	K (%)
7/06	19,000	.24	.42	9.8
7/15	20,550	.26	.40	10.5
7/24	25,000	.30	.57	12.0
7/31	19,125	.30	.38	10.8
8/07	20,375	.27	.50	12.4
8/14	16,500	.27	.26	10.8
8/21	12,125	.25	.43	11.3
8/28	8,500	.23	.22	9.6
9/04	9,000	.22	.21	9.3
9/11	7,750	.20	.17	8.8
9/18	4,725	.19	.14	7.9

Table 4

POTASSIUM CHLORIDE 100% PPI
PETIOLE NITRATE LEVELS

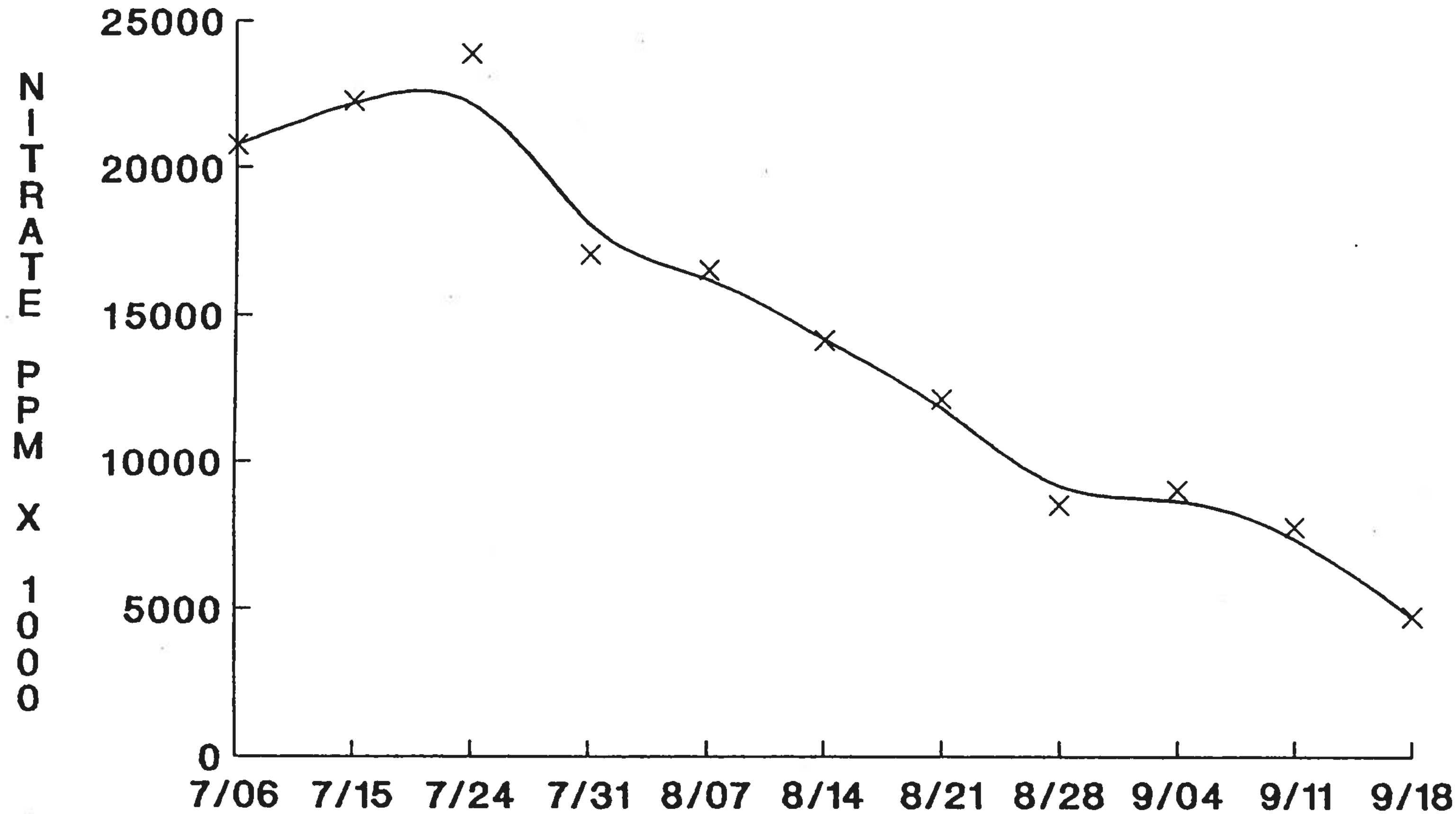


Figure 5

POTASSIUM SULFATE 100% PPI
PETIOLE NITRATE LEVELS

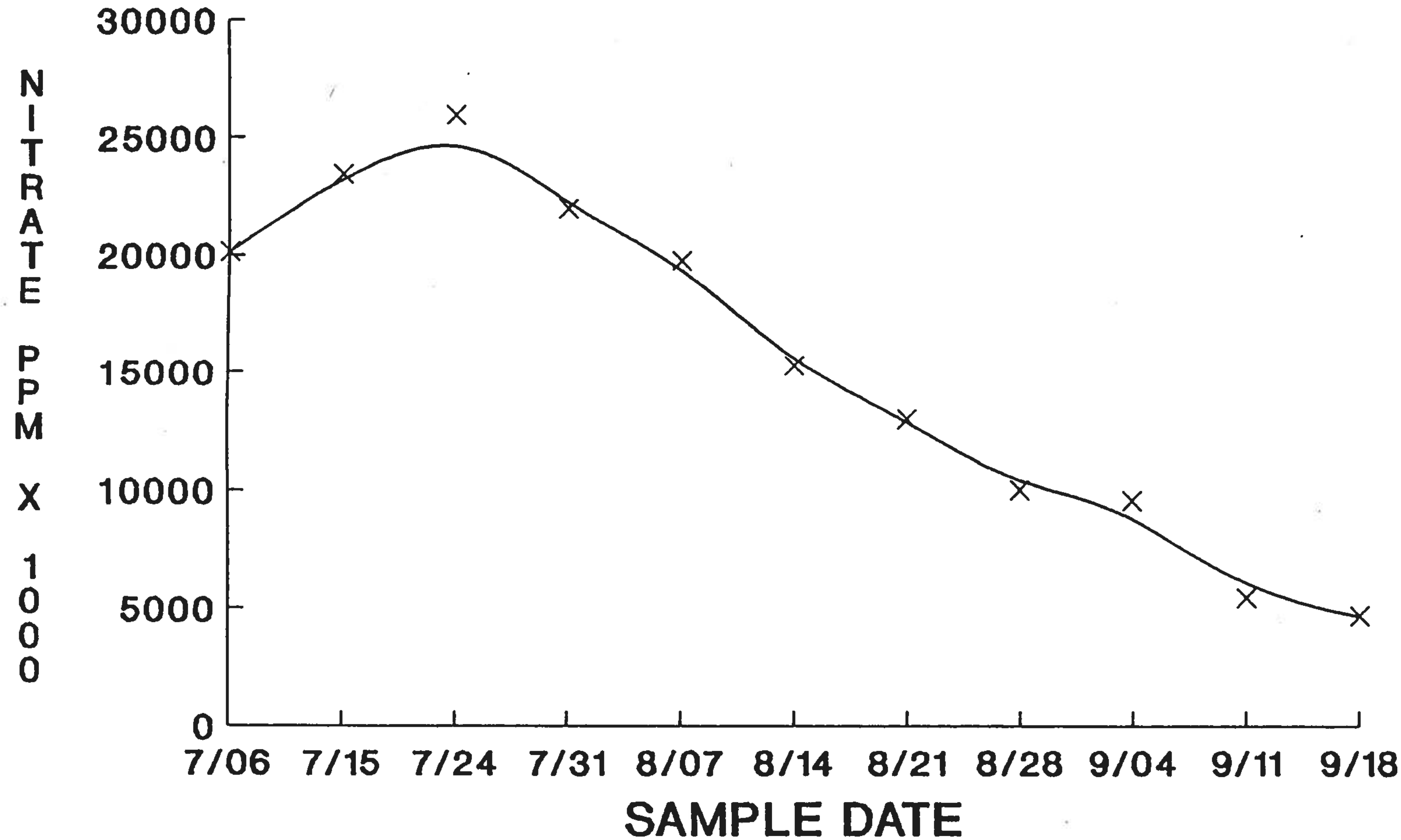
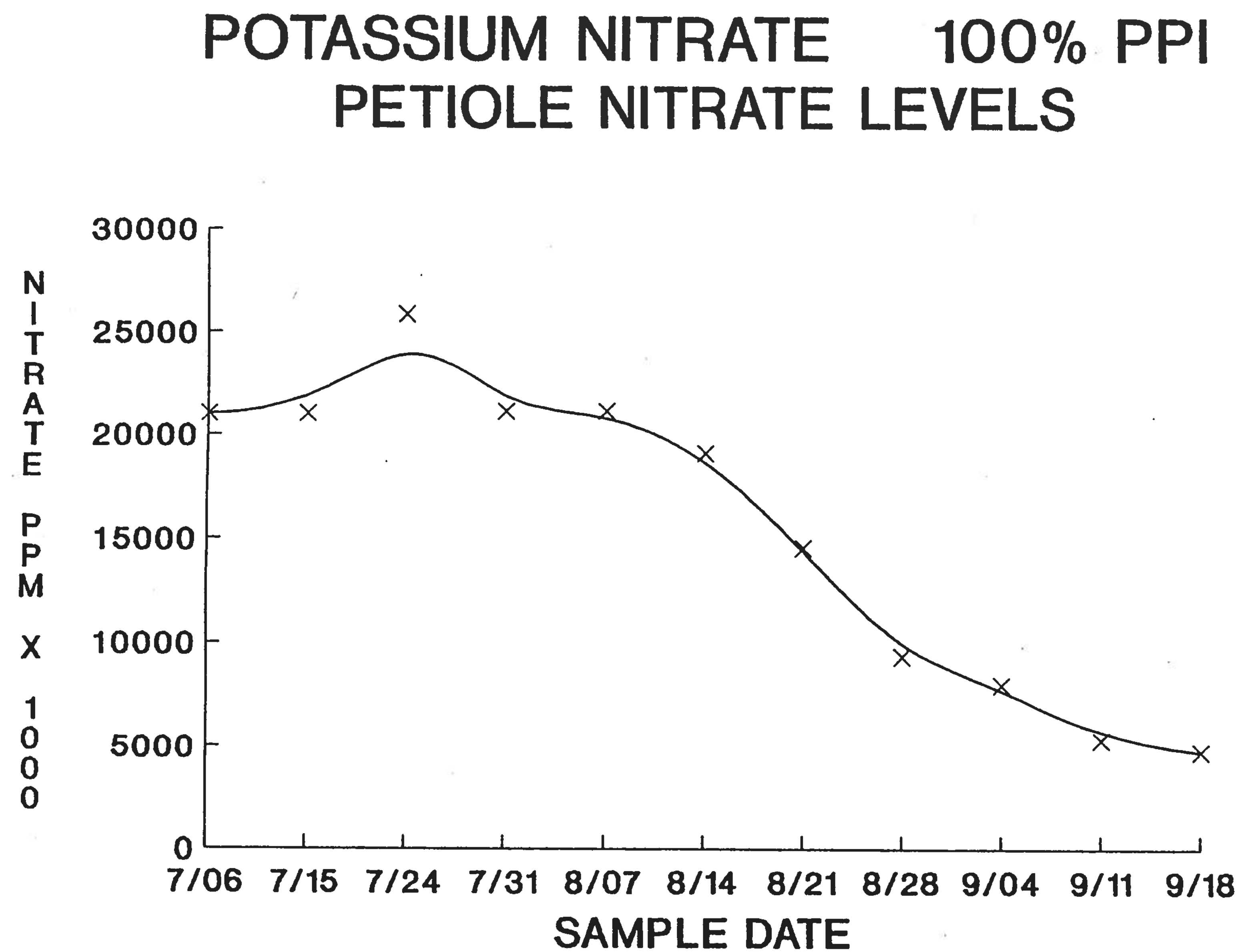


Figure 6


POTASSIUM NITRATE 100% PPI
PETIOLE NITRATE LEVELS
NITRATE PPM X 1000
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25000
20000
15000
10000
5000
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7/06
7/15
7/24
7/31
8/07
8/14
8/21
8/28
9/04
9/11
9/18
SAMPLE DATE

Figure 7

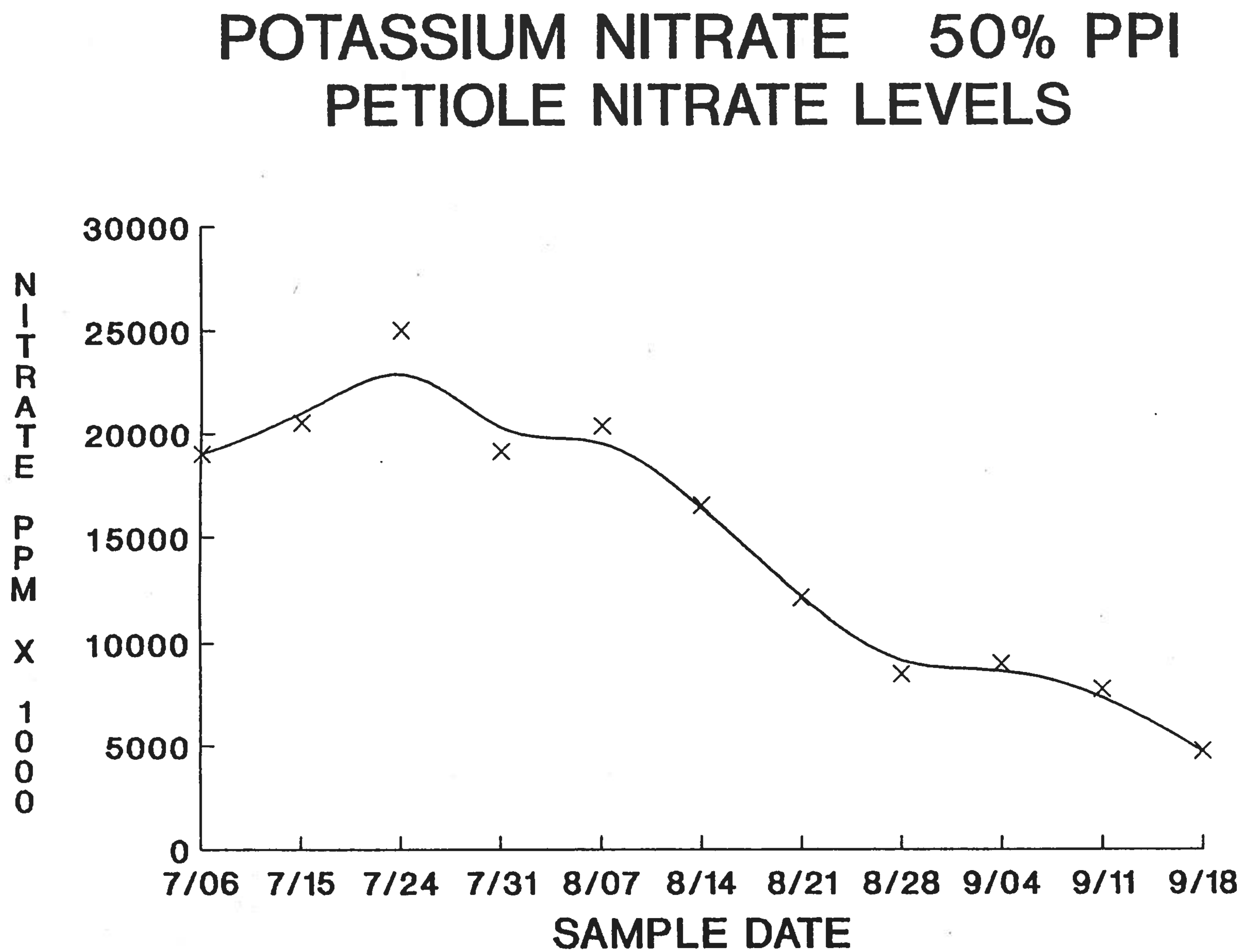

POTASSIUM NITRATE 50% PPI
PETIOLE NITRATE LEVELS
NITRATE PPM X 1000
30000
25000
20000
15000
10000
5000
0
7/06
7/15
7/24
7/31
8/07
8/14
8/21
8/28
9/04
9/11
9/18
SAMPLE DATE

Figure 8

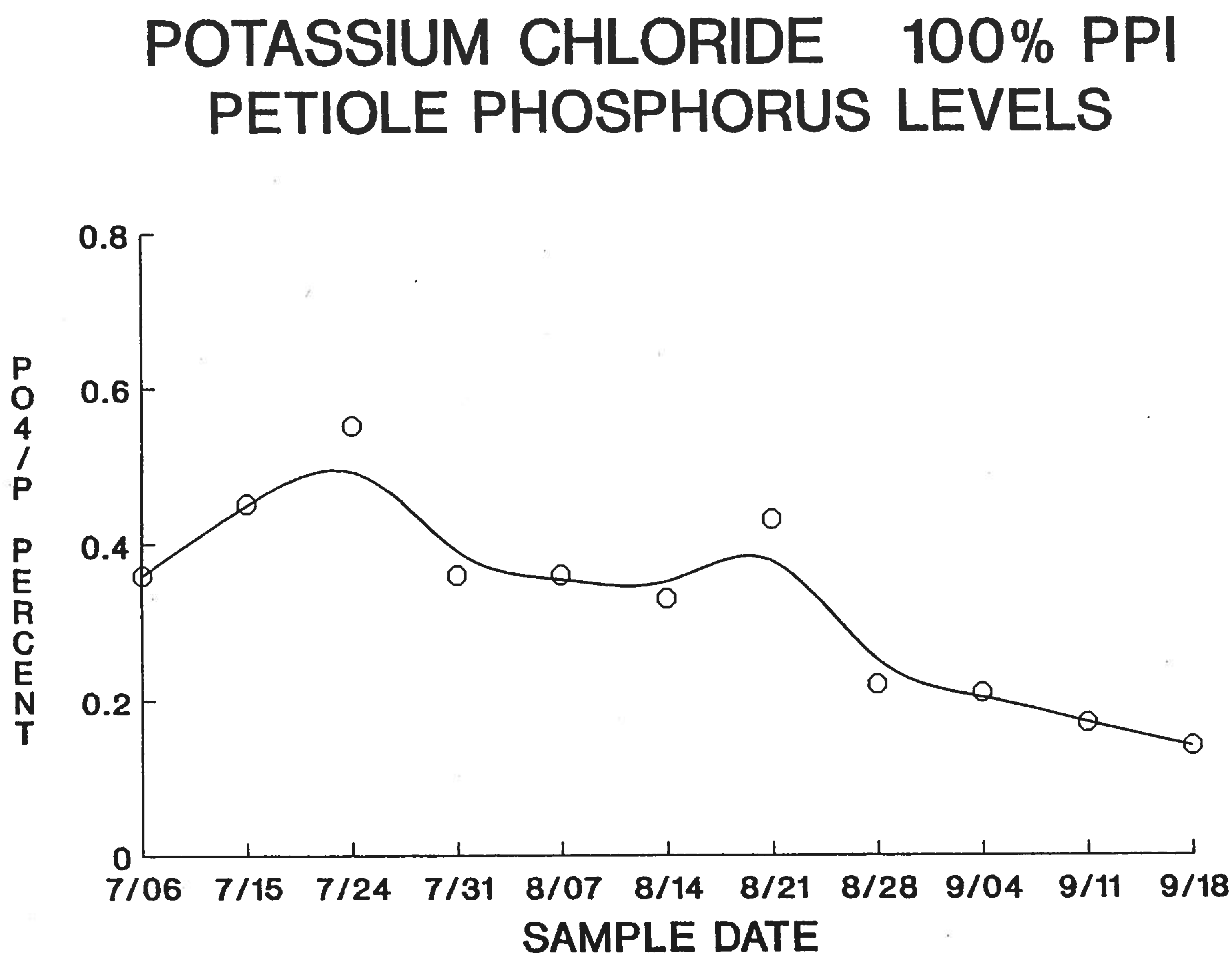

POTASSIUM CHLORIDE 100% PPI
PETIOLE PHOSPHORUS LEVELS
PO4/P PERCENT
0.8
0.6
0.4
0.2
0
7/06
7/15
7/24
7/31
8/07
8/14
8/21
8/28
9/04
9/11
9/18
SAMPLE DATE

Figure 9

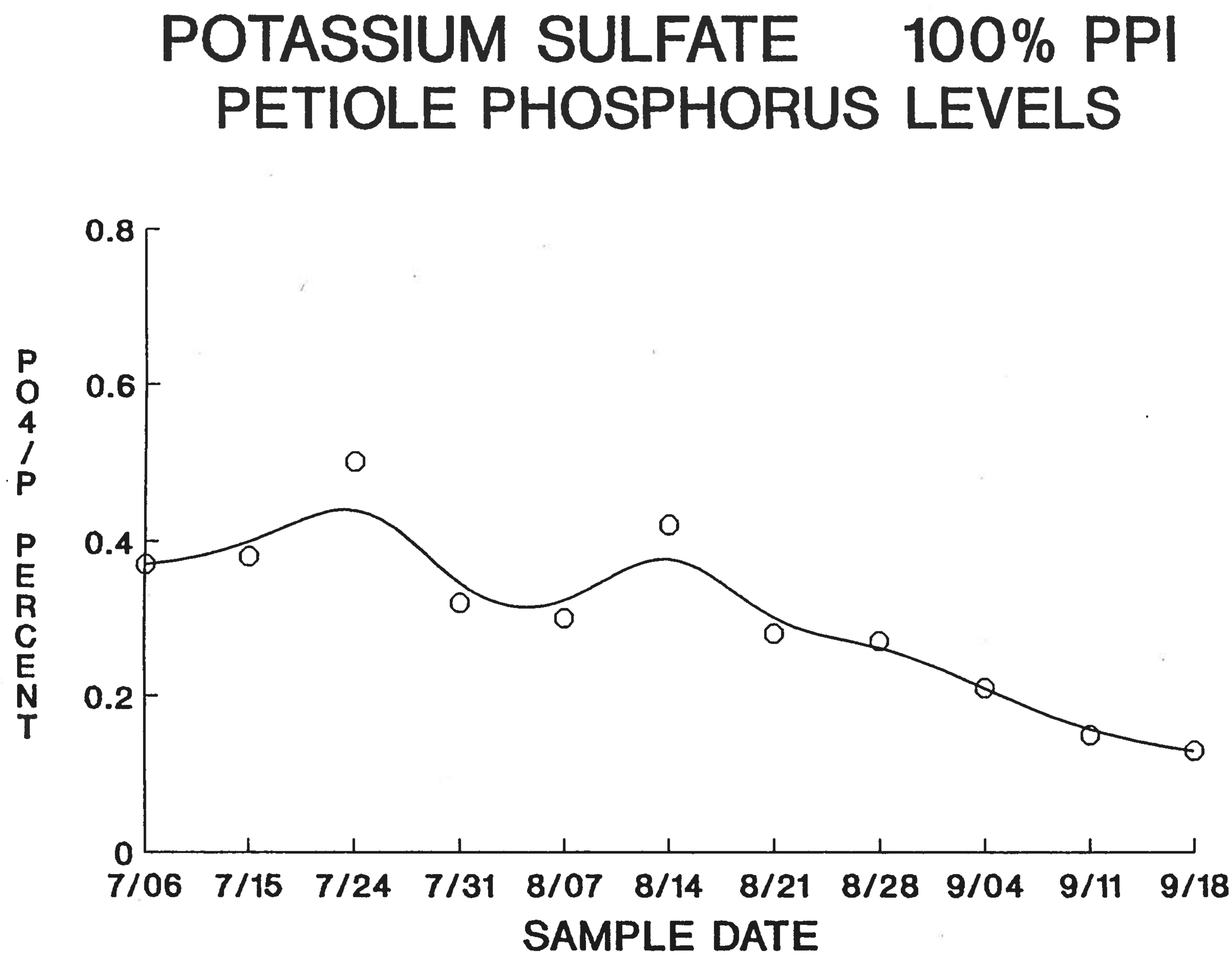

POTASSIUM SULFATE 100% PPI
PETIOLE PHOSPHORUS LEVELS
PO4/P PERCENT
0.8
0.6
0.4
0.2
0
7/06
7/15
7/24
7/31
8/07
8/14
8/21
8/28
9/04
9/11
9/18
SAMPLE DATE

Figure 10

POTASSIUM NITRATE 100% PPI
PETIOLE PHOSPHORUS LEVELS

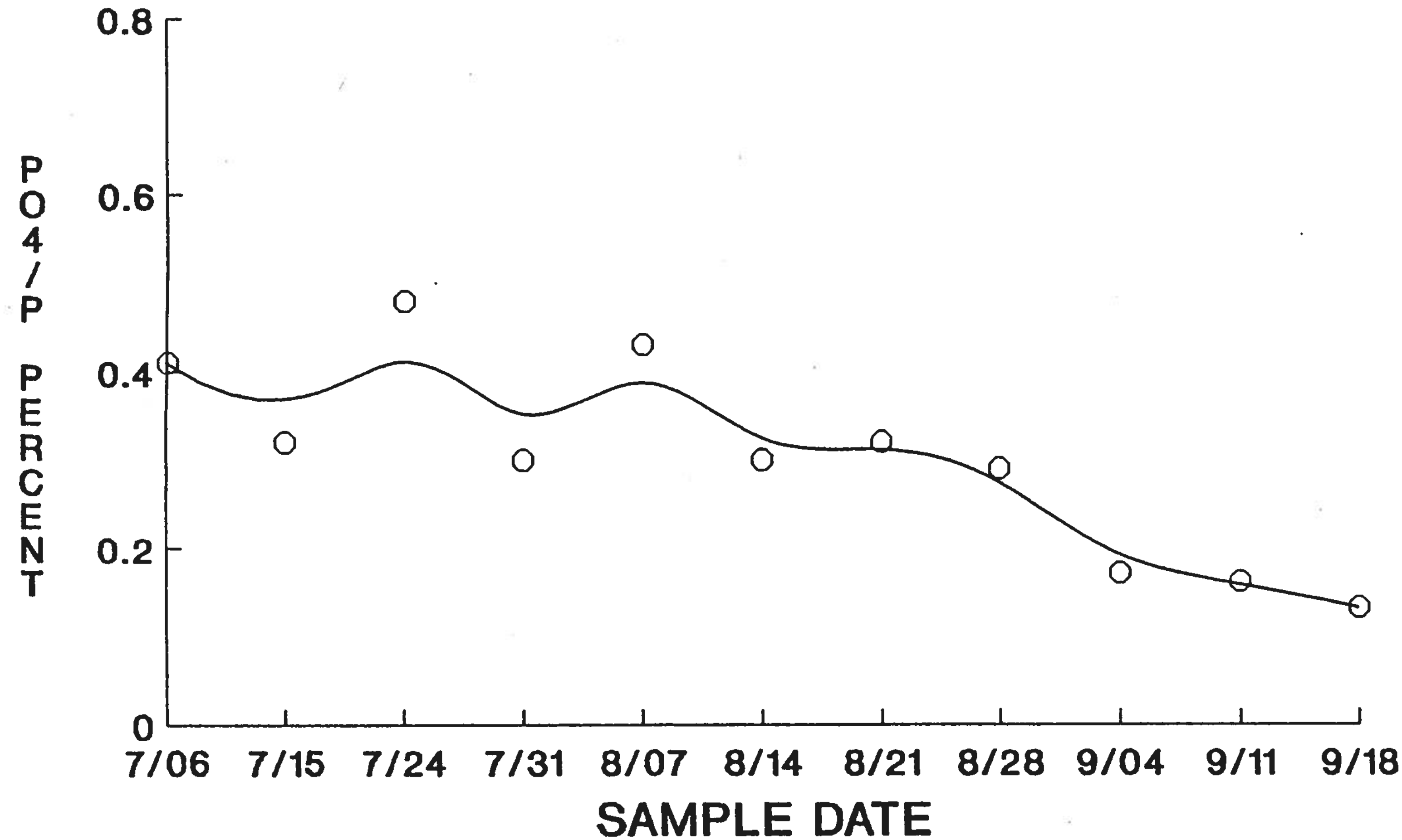
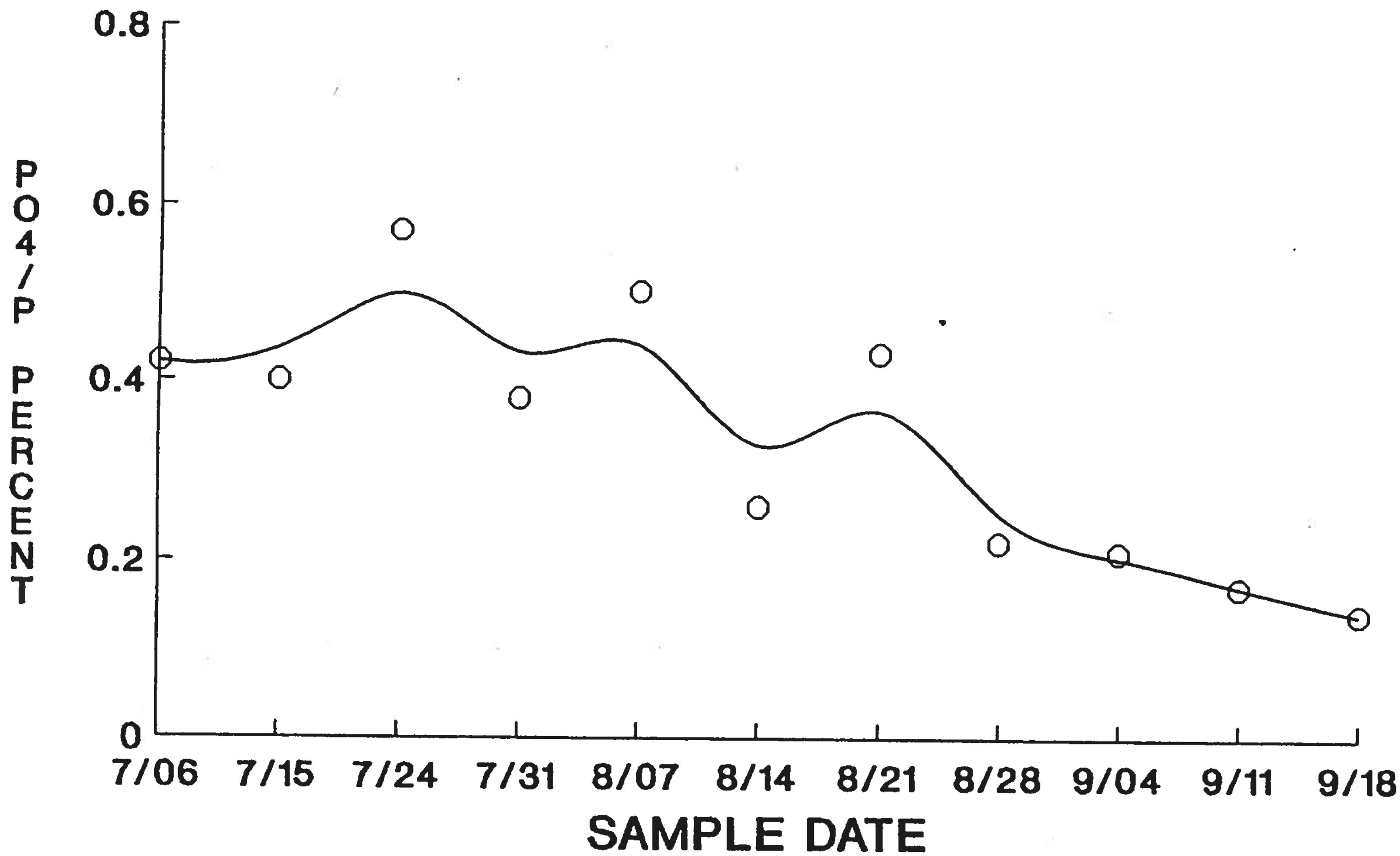


Figure 11

POTASSIUM NITRATE 50% PPI
PETIOLE PHOSPHORUS LEVELS



PHOSPHORUS TISSUE LEVELS (PERCENT)

DATE	KCL	K_2SO_4	KNO_3	KNO_3 Split
7/06	.36	.37	.41	.42
7/15	.45	.38	.32	.40
7/24	.55	.50	.48	.57
7/31	.36	.32	.30	.38
8/07	.36	.30	.43	.50
8/14	.33	.42	.30	.26
8/21	.43	.23	.32	.43
8/28	.22	.27	.29	.22
9/04	.21	.21	.17	.21
9/11	.17	.15	.16	.17
9/18	.14	.13	.13	.14

Table 5

POTASSIUM TISSUE LEVELS (PERCENT)

DATE	KCL	K_2SO_4	KNO_3	KNO_3 Split
7/06	10.0	9.7	9.6	9.8
7/15	11.9	10.9	10.7	10.5
7/24	12.7	12.0	12.2	12.0
7/31	11.3	11.6	11.1	10.8
8/07	10.4	10.1	10.7	12.4
8/14	10.6*	10.9	11.4	10.8
8/21	8.7	9.5	9.8	11.3
8/28	8.6	9.3*	9.6	9.6
9/04	9.3	8.9	9.1*	9.3*
9/11	8.8	8.5	8.5	8.8
9/18	7.9	8.0	7.9	7.9

*The trial in the Pacific Northwest suggests that plant senescence is initiated in Russet Burbank when K tissue levels go below 9.0 in most seasons.

Table 6

POTASSIUM CHLORIDE 100% PPI
PETIOLE POTASSIUM LEVELS

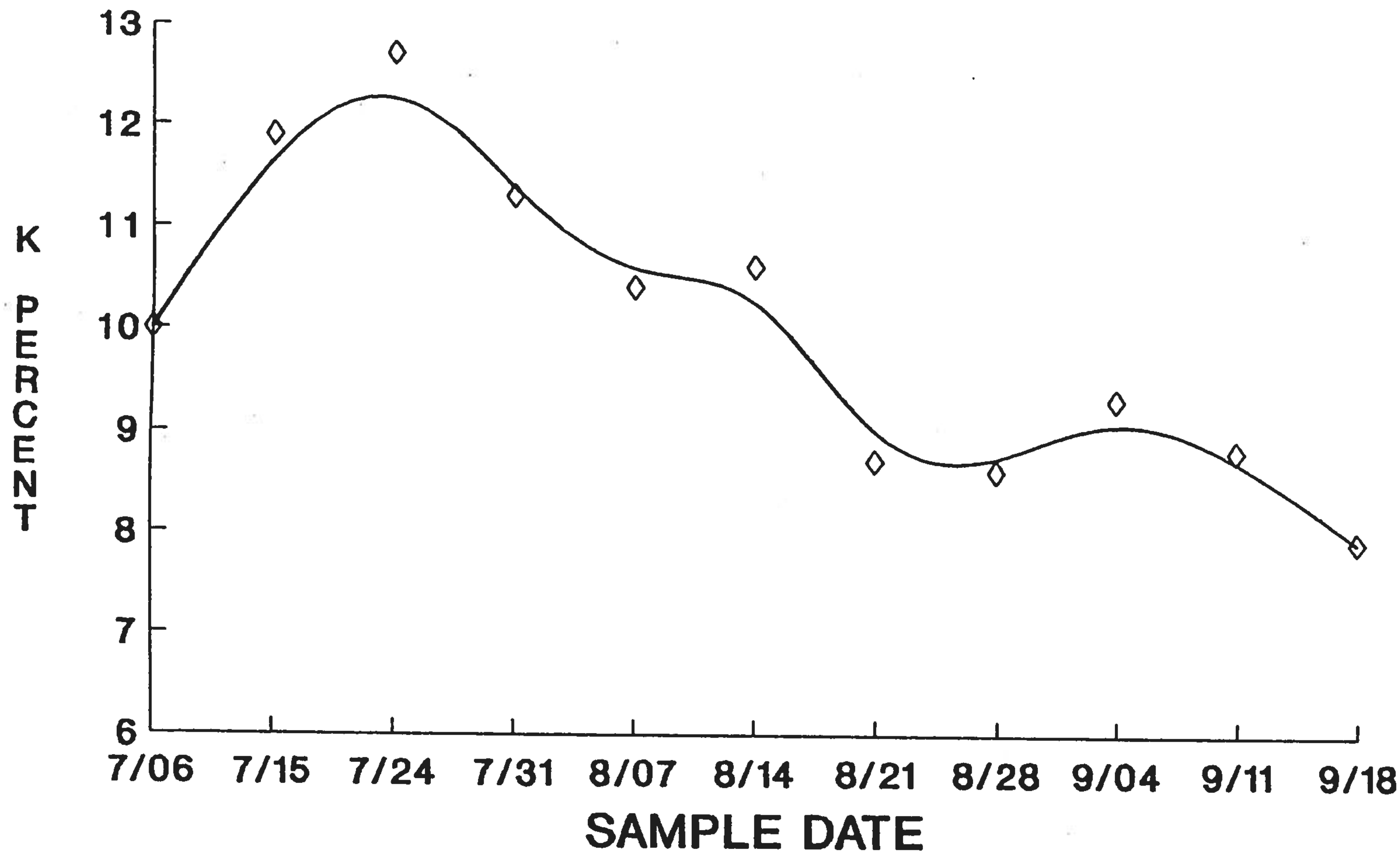
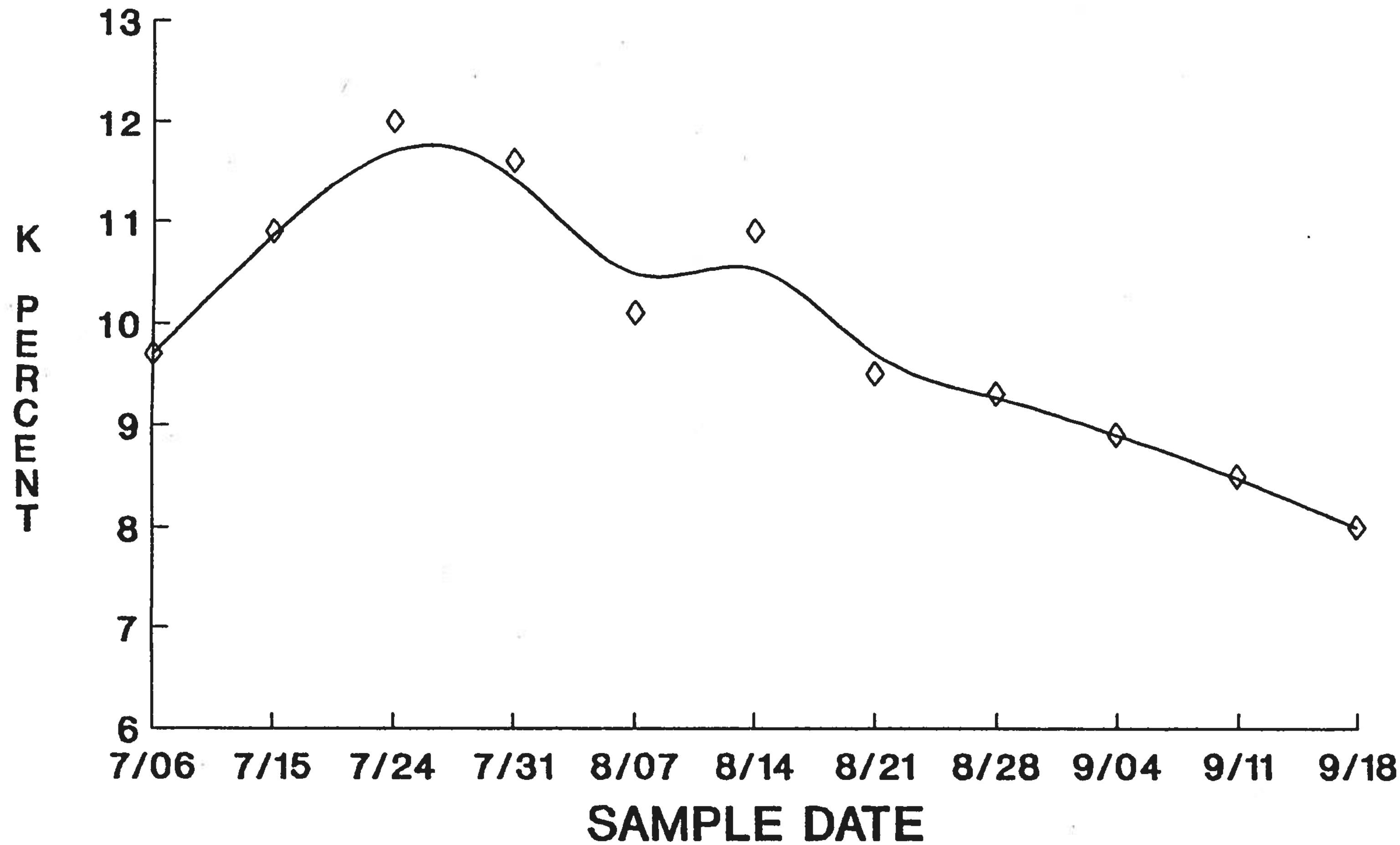


Figure 13

POTASSIUM SULFATE 100% PPI
PETIOLE POTASSIUM LEVELS



POTASSIUM NITRATE 100% PPI
PETIOLE POTASSIUM LEVELS

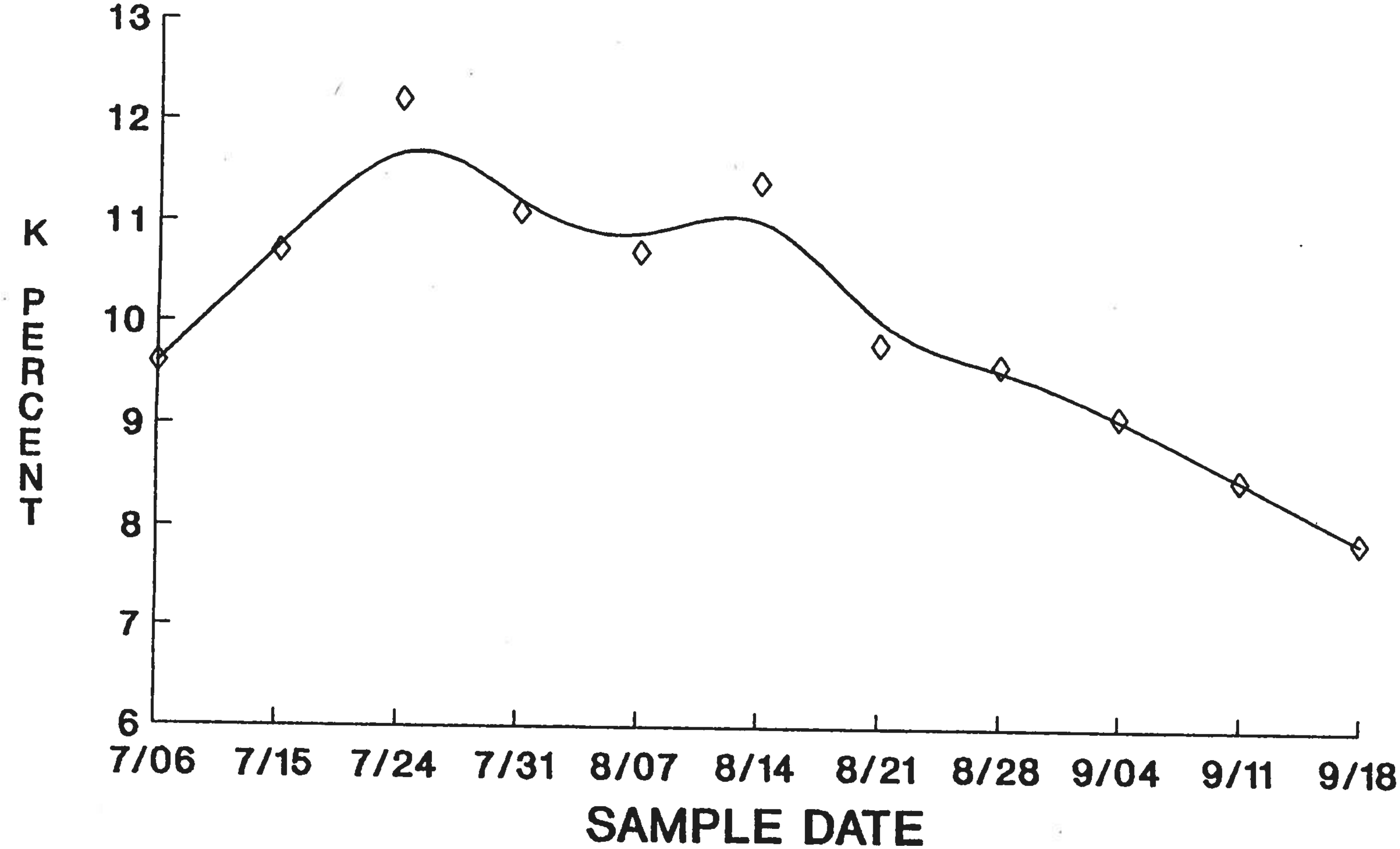
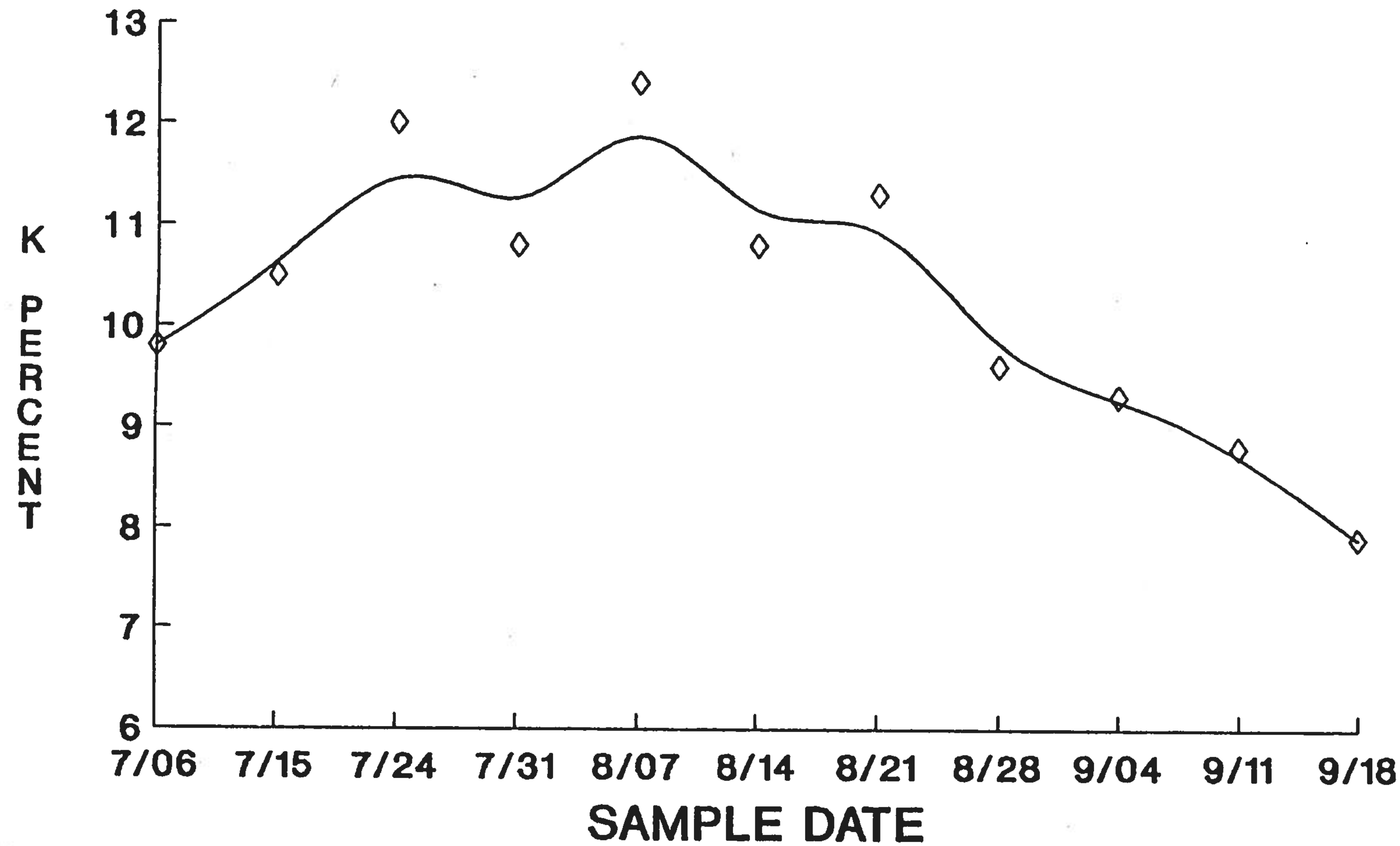


Figure 15

POTASSIUM NITRATE 50% PPI
PETIOLE POTASSIUM LEVELS



SULFUR TISSUE LEVELS (PERCENT)

DATE	KCL	K_2SO_4	KNO_3	KNO_3 Split
7/06	.21	.22	.25	.24
7/15	.26	.26	.25	.26
7/24	.30	.37	.28	.30
7/31	.27	.33	.29	.30
8/07	.29	.29	.29	.27
8/14	.32	.28	.30	.27
8/21	.31	.23	.30	.27
8/28	.21	.20	.29	.23
9/04	.22	.22	.19	.22
9/11	.25	.25	.20	.20
9/18	.19	.20	.19	.19

Table 7

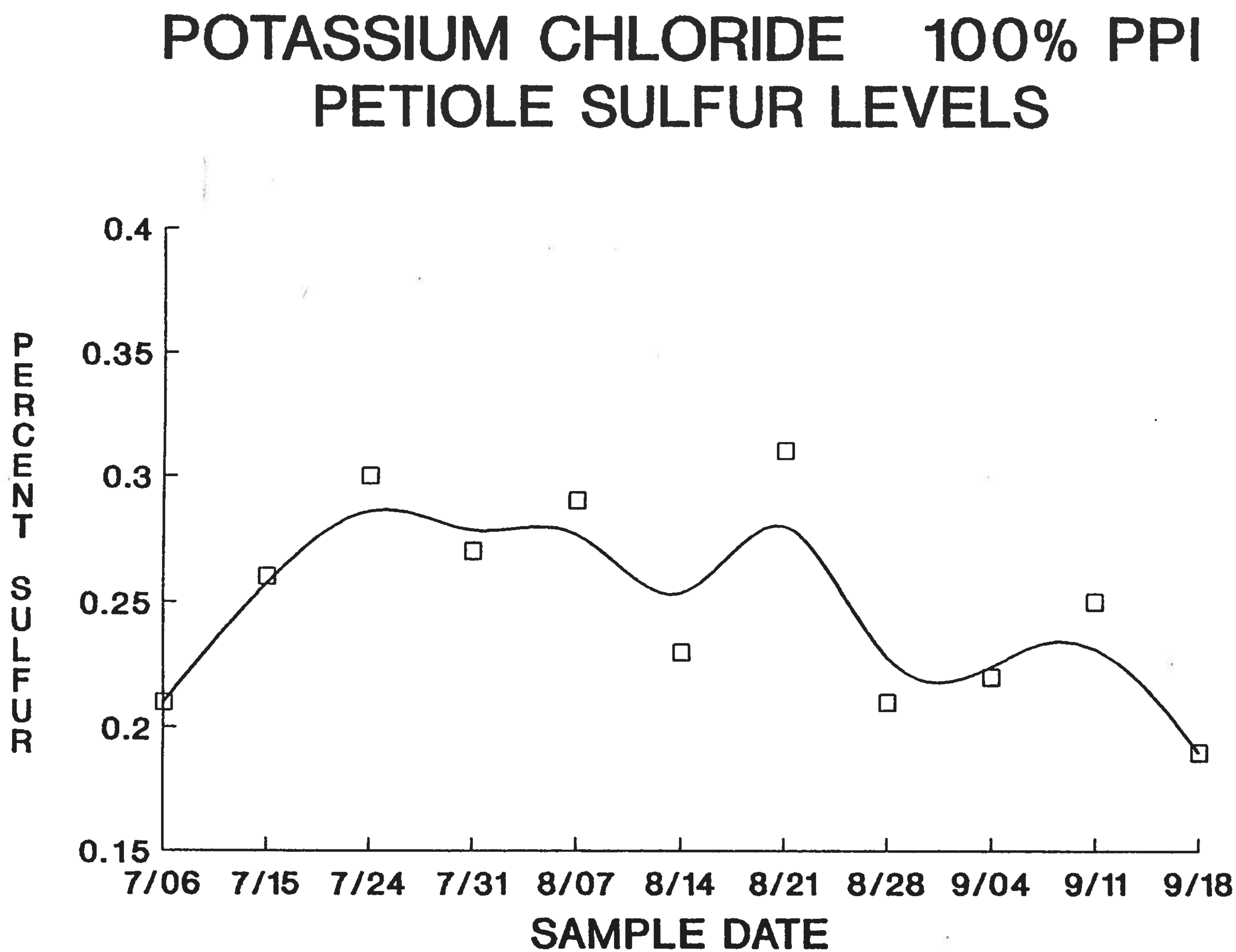

POTASSIUM CHLORIDE 100% PPI
PETIOLE SULFUR LEVELS
PERCENT SULFUR
0.4
0.35
0.3
0.25
0.2
0.15
7/06
7/15
7/24
7/31
8/07
8/14
8/21
8/28
9/04
9/11
9/18
SAMPLE DATE

Figure 17

POTASSIUM SULFATE 100% PPI
PETIOLE SULFUR LEVELS

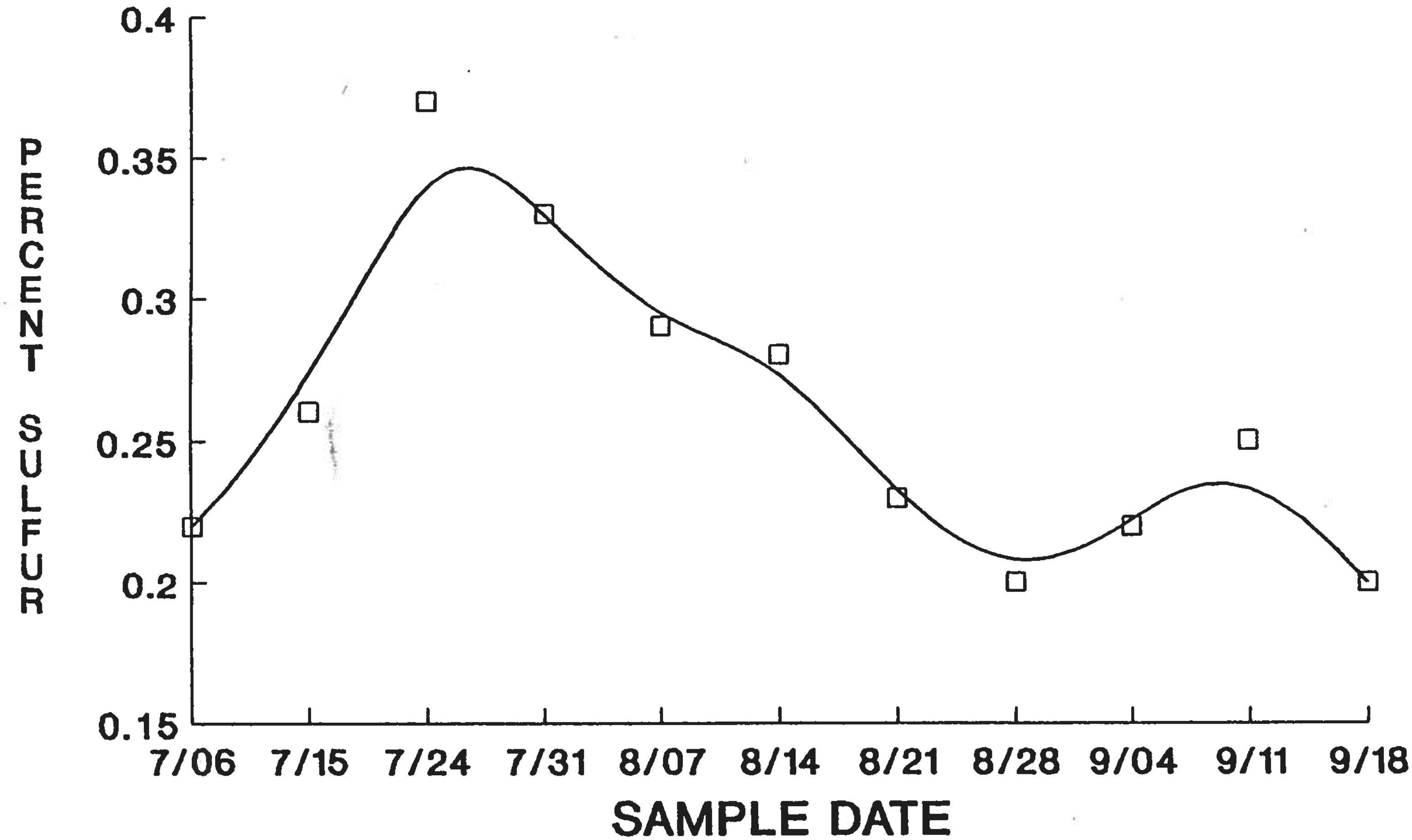


Figure 18

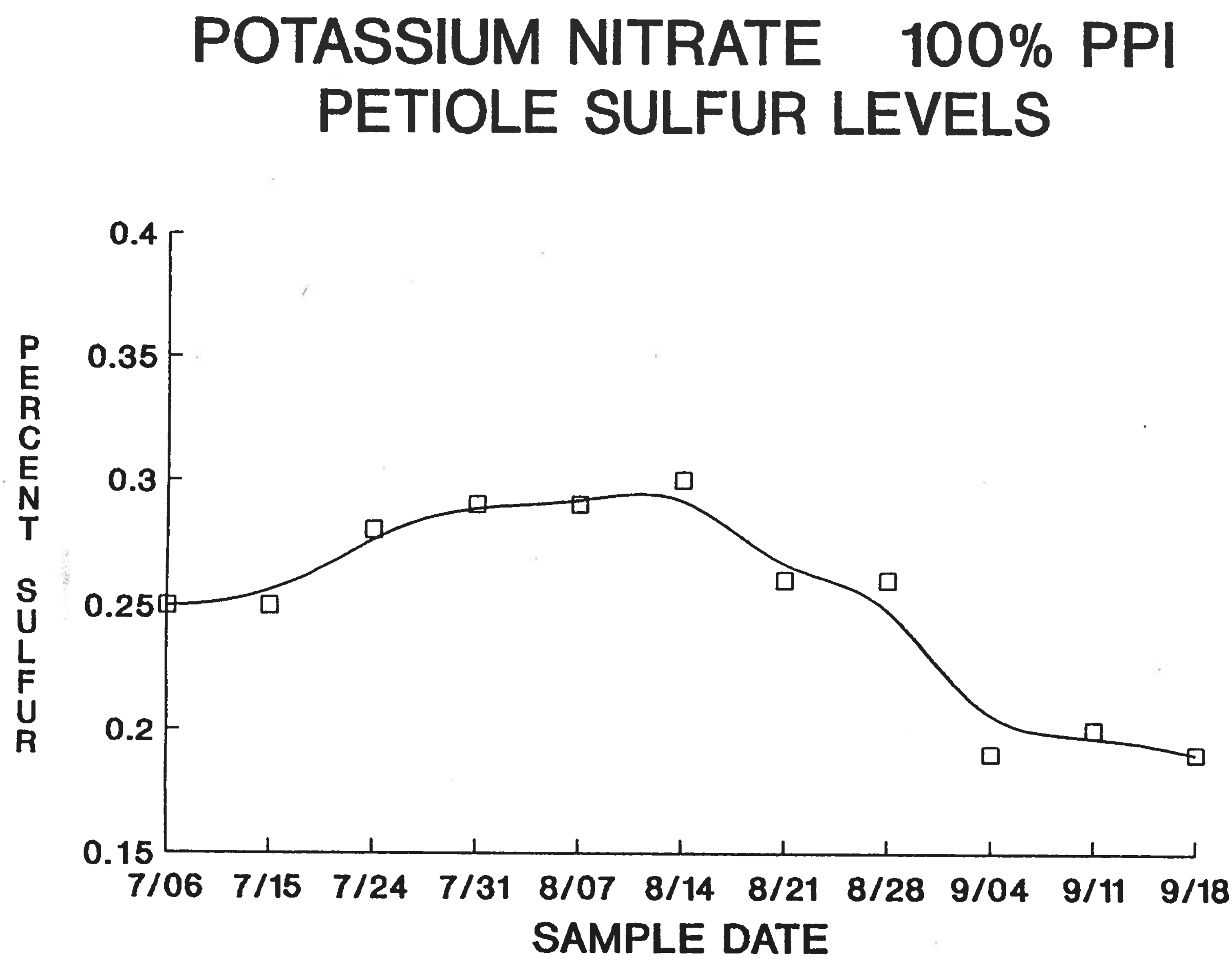

POTASSIUM NITRATE 100% PPI
PETIOLE SULFUR LEVELS
PERCENT SULFUR
0.4
0.35
0.3
0.25
0.2
0.15
7/06 7/15 7/24 7/31 8/07 8/14 8/21 8/28 9/04 9/11 9/18
SAMPLE DATE

Figure 19

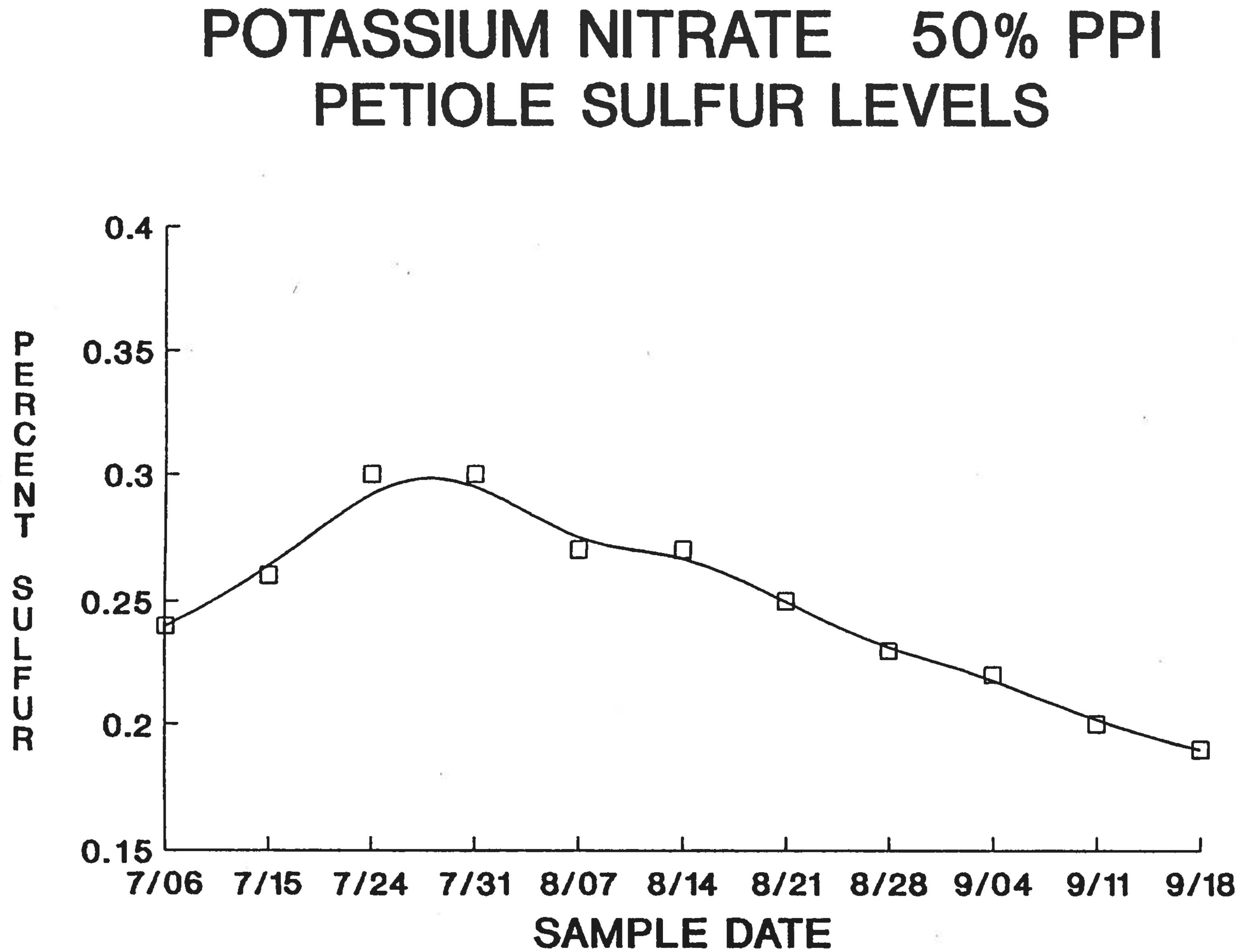

POTASSIUM NITRATE 50% PPI
PETIOLE SULFUR LEVELS
PERCENT SULFUR
0.4
0.35
0.3
0.25
0.2
0.15
7/06
7/15
7/24
7/31
8/07
8/14
8/21
8/28
9/04
9/11
9/18
SAMPLE DATE

Figure 20

YIELD DATA

TREATMENT

REP	1	2	3	4
1	227	219	199	192
2	188	202	216	183
3	236	224	247	234
4	206	258	218	210
Totals:	857	903	880	819
Average Yld:	214.25 b*	225.75 a	220 a	204.75 c
Ton/Acre:	32.96 T/A	34.73 T/A	33.85 T/A	31.5 T/A
1	29	31	20	23
2	23	25	32	21
3	24	34	2	26
4	22	31	22	27
Totals Culls:	24.5	30.25	25.75	24.5
% Culls:	11.4% a	13.4% b	11.7% a	12.0% a
1	198	188	179	169
2	165	177	184	162
3	212	190	218	208
4	184	227	196	182
Totals:	759	782	777	721
Avg Payables:	189.75	195.50	194.25	180.25
Ton/Acre:	29.19 T/A b	30.08 T/A a	29.88 T/A b	27.76 T/A c
*Crop Value/A:	$3,678.23	$3,789.69	$3,765.46	$3,490.07

Treatment 4 had the lowest yield, lowest payables and tied for lowest culls.

Treatment 2 had the highest yield, but was on 1/2% higher than treatment 3.

*Analysis at 90% level of significance.

*Payable yield X grower return ($126/ton) = crop value per acre.

TABLE 8

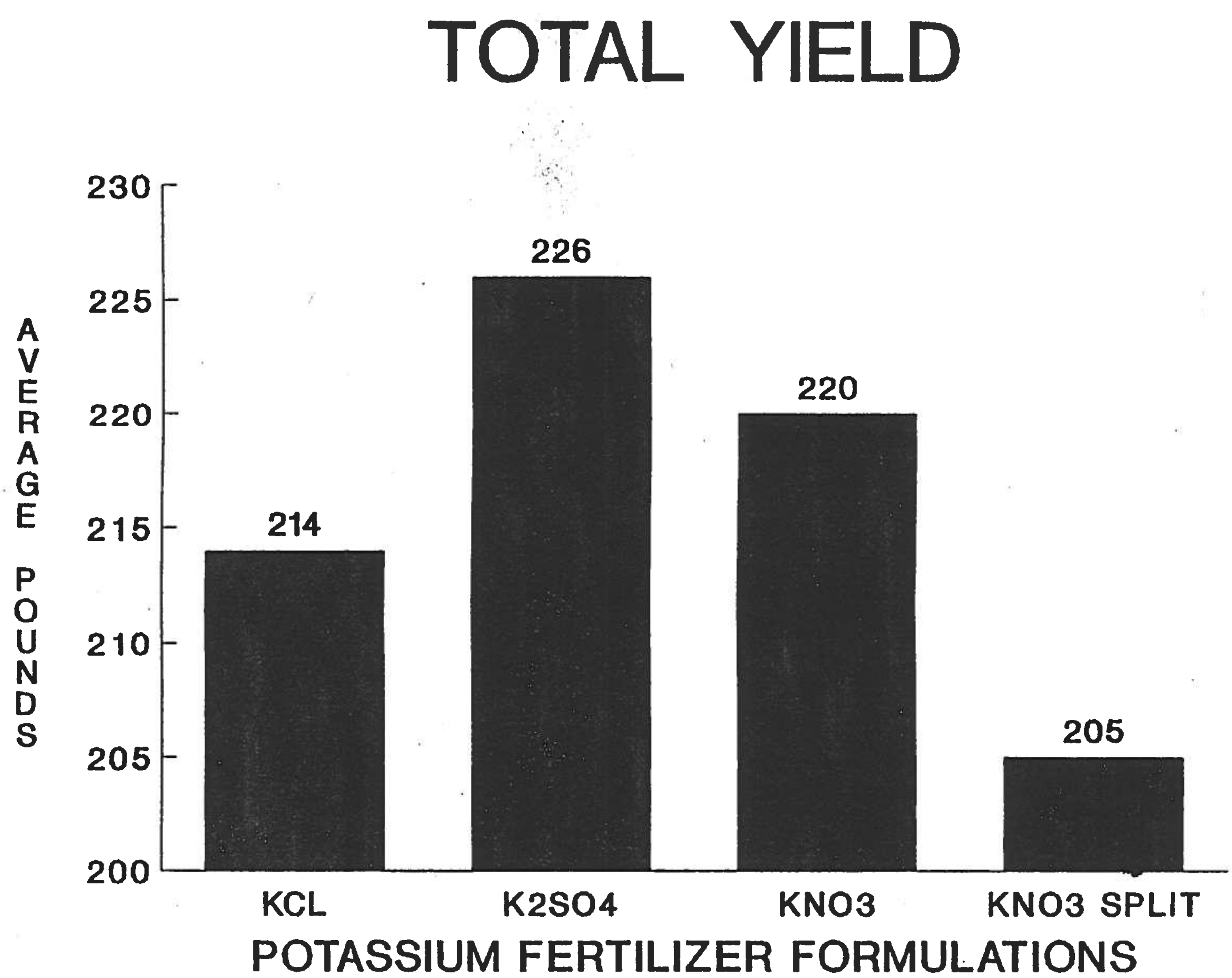

TOTAL YIELD
AVERAGE POUNDS
230
225
220
215
210
205
200
214
226
220
205
KCL
K2SO4
KNO3
KNO3 SPLIT
POTASSIUM FERTILIZER FORMULATIONS

Figure 21

U. S. No. 1'S

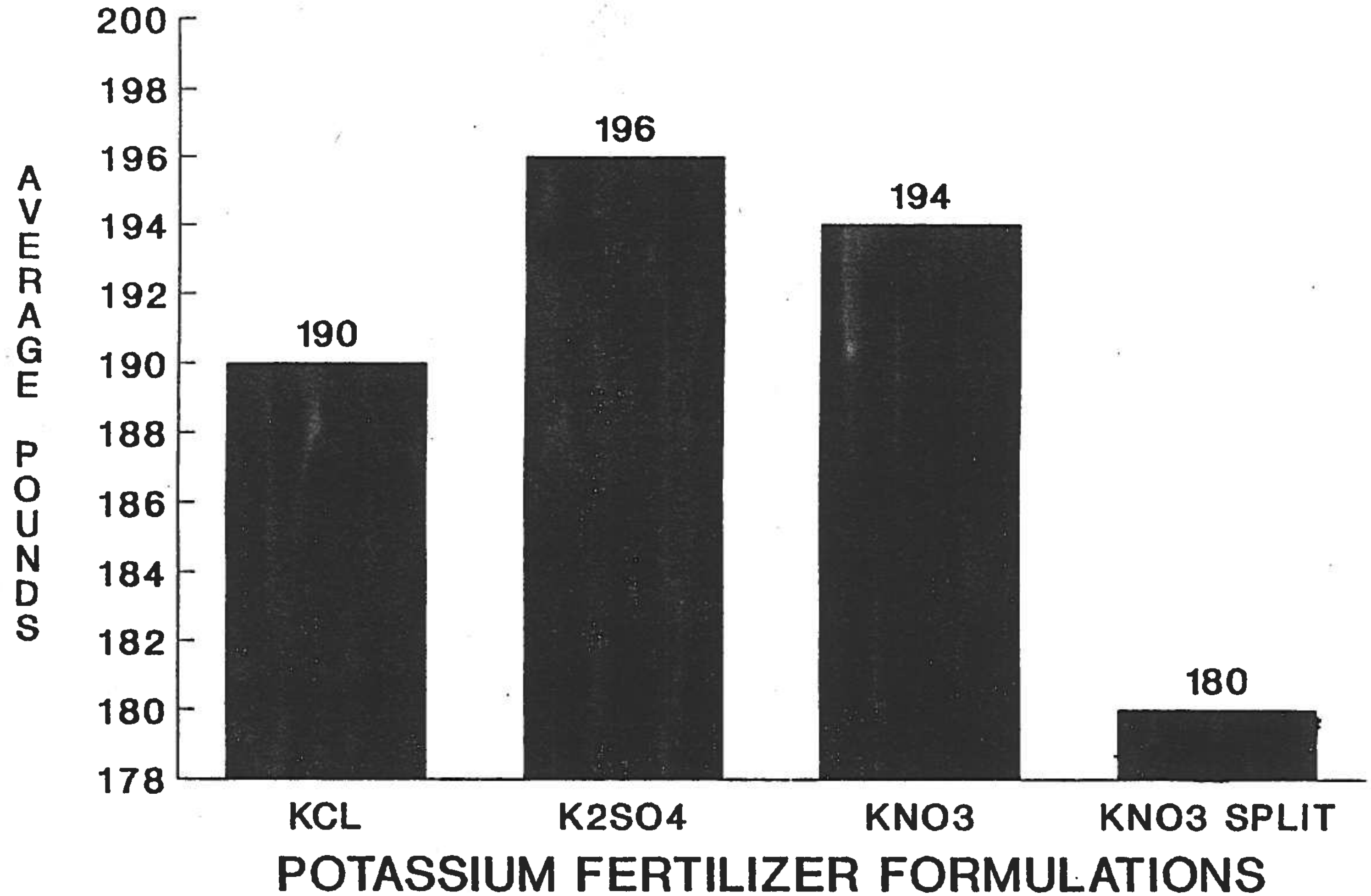


Figure 22

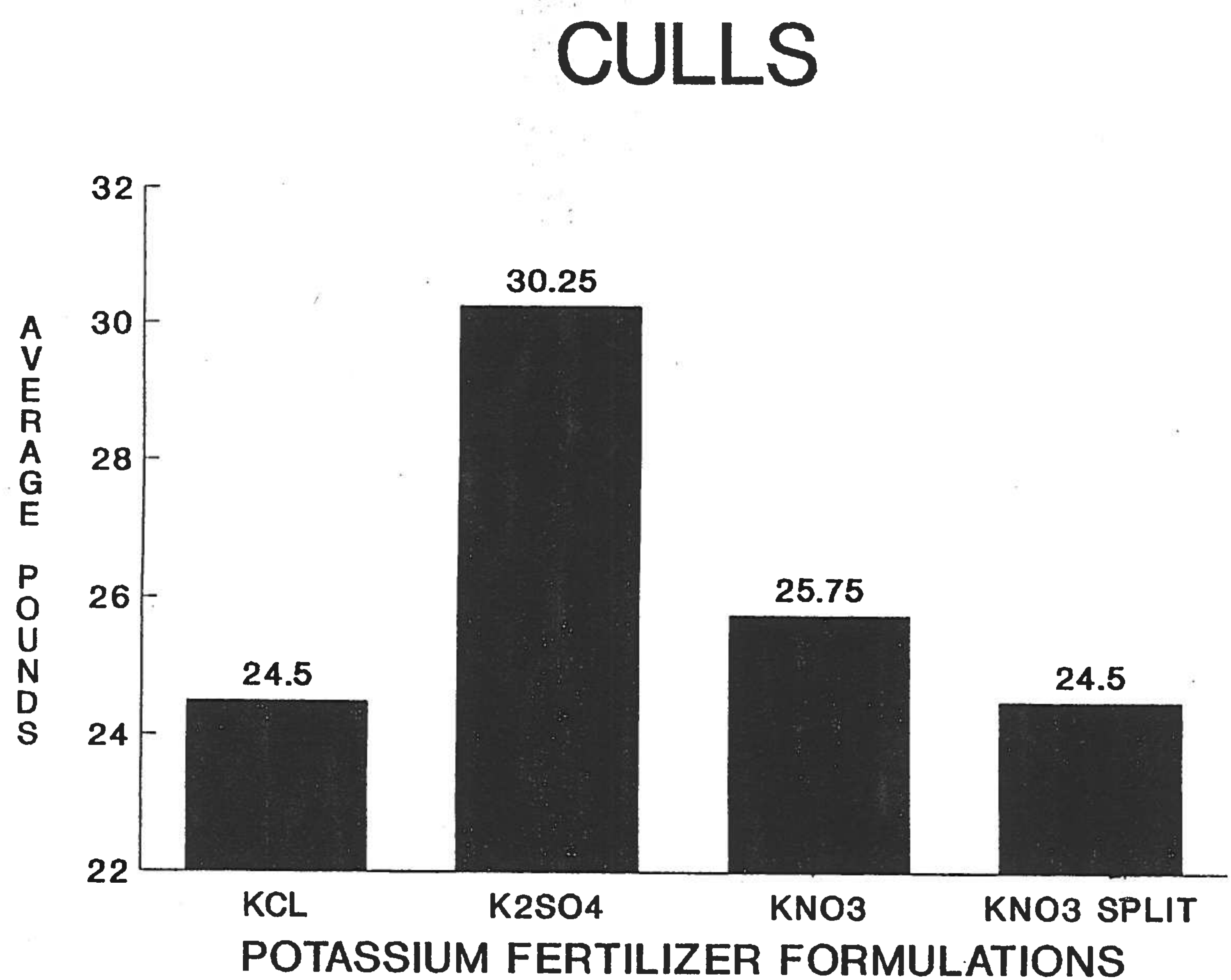

CULLS
AVERAGE POUNDS
32
30
28
26
24
22
30.25
25.75
24.5
24.5
KCL
K2SO4
KNO3
KNO3 SPLIT
POTASSIUM FERTILIZER FORMULATIONS

Figure 23

INTERNAL DEFECTS

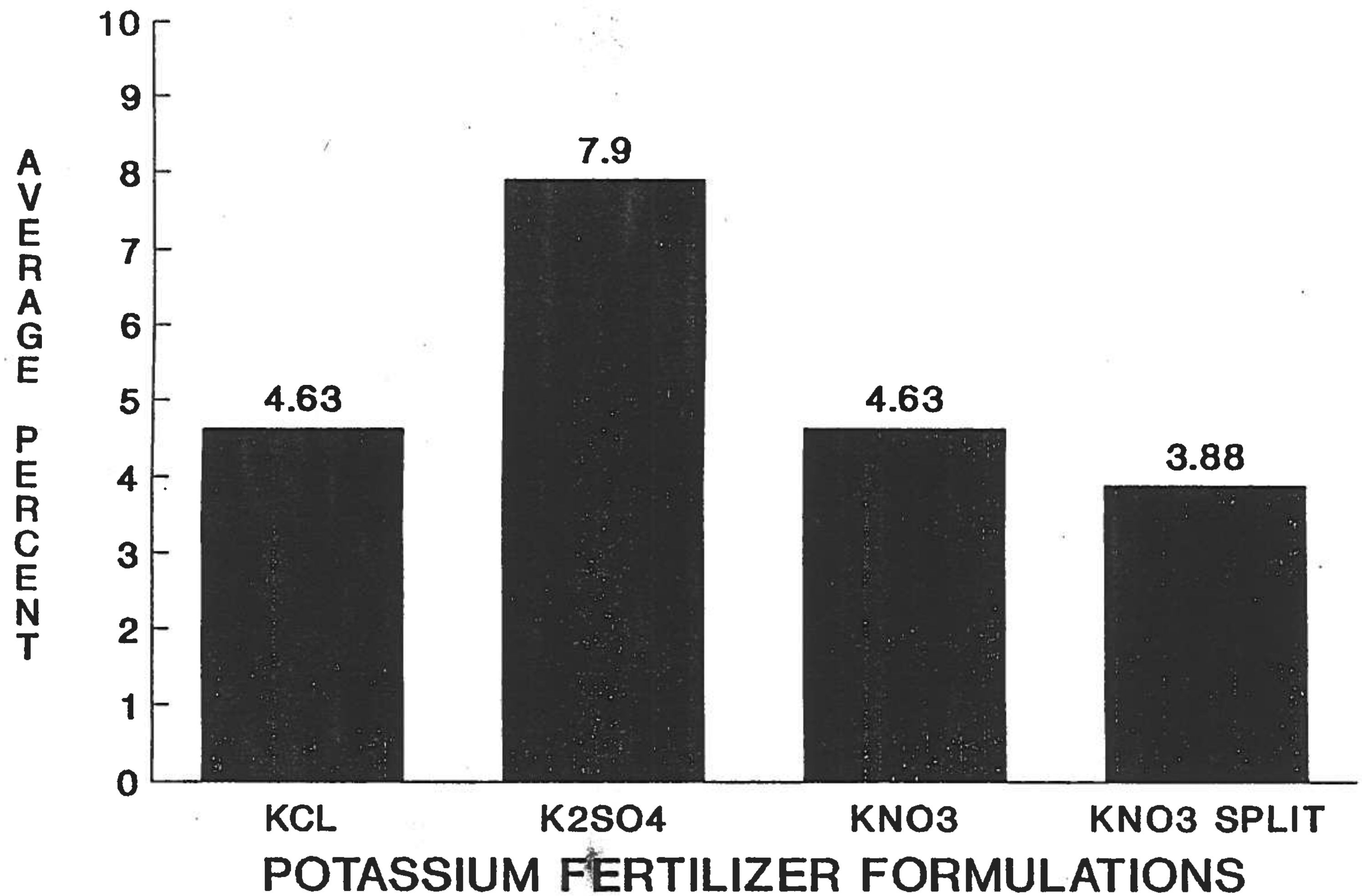


Figure 24

POTATO SIZE DISTRIBUTIONS

TREATMENT	REP	4-6 OZ	6-10 OZ	10-14 OZ	>14 OZ
(1)	1	67	80	30	21
	2	33	60	42	30
	3	53	82	35	42
	4	41	82	35	26
	Totals:	194	304	142	119
	Average:	48.5	76	35.5	29.75
		25.6% a*	40.0% a	18.7% a	15.7% a
(2)	1	53	78	29	27
	2	45	60	35	37
	3	48	63	48	31
	4	60	84	41	42
	Totals:	206	285	153	137
	Average:	51.5	71.25	38.25	34.25
		26.4% a	36.5% a	19.6% a	17.5% a
(3)	1	49	76	36	18
	2	48	69	45	22
	3	56	84	41	37
	4	50	88	27	36
	Totals:	203	317	149	113
	Average:	50.75	79.25	37.25	28.25
		26.0% a	40.5% a	19.1% a	14.4% a
(4)	1	35	63	37	34
	2	28	48	44	42
	3	50	75	47	36
	4	49	86	30	17
	Totals:	162	272	158	129
	Average:	40.5	68	39.5	32.25
		22.5% a	37.7% a	21.9% a	17.9% a

TUBER WEIGHT CATAGORIES (column heading spanning 4-6 OZ through >14 OZ)

*Analysis at 95% level of significance.

TABLE 9

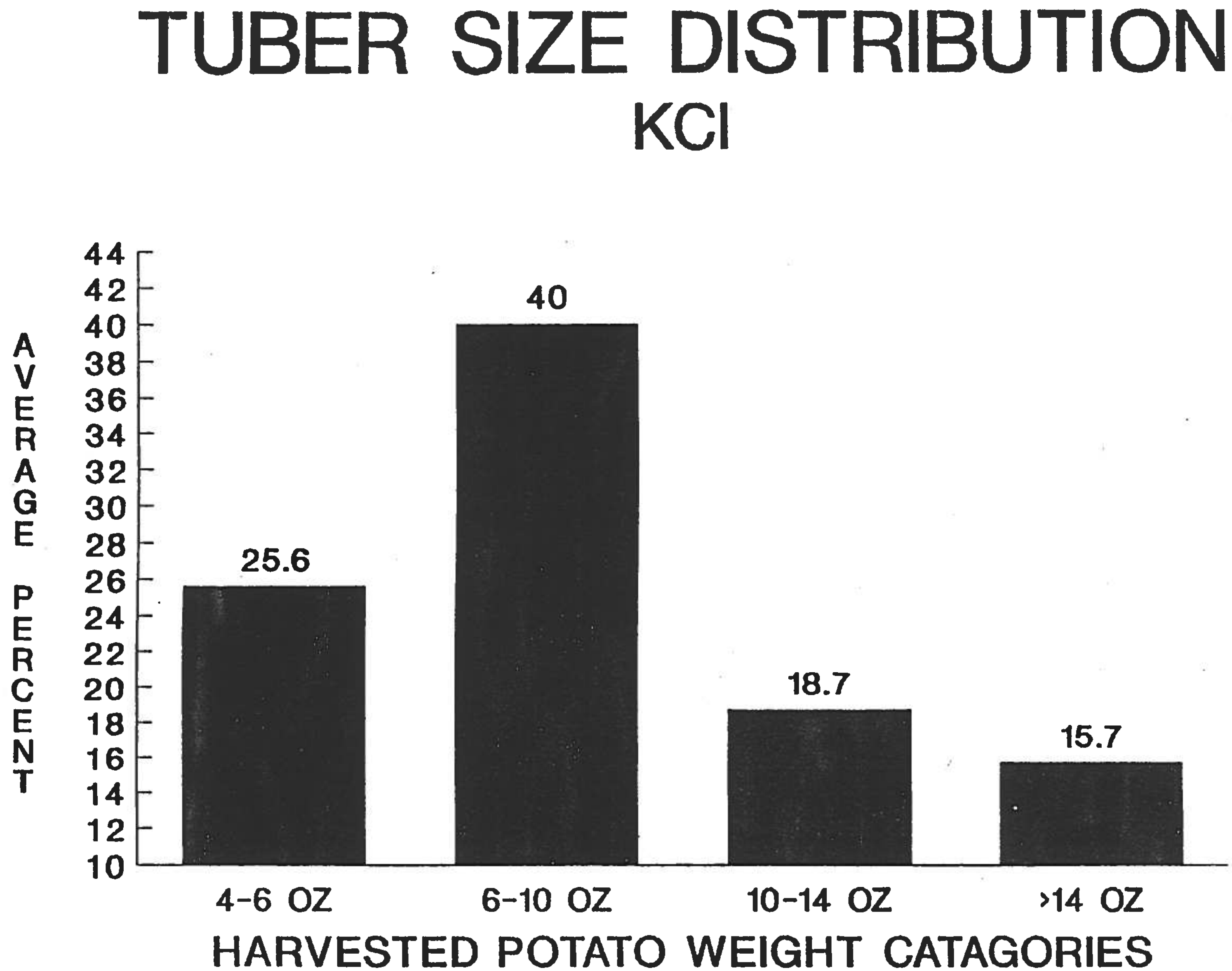

TUBER SIZE DISTRIBUTION
KCl
AVERAGE PERCENT
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
25.6
40
18.7
15.7
4-6 OZ
6-10 OZ
10-14 OZ
>14 OZ
HARVESTED POTATO WEIGHT CATAGORIES

Figure 25

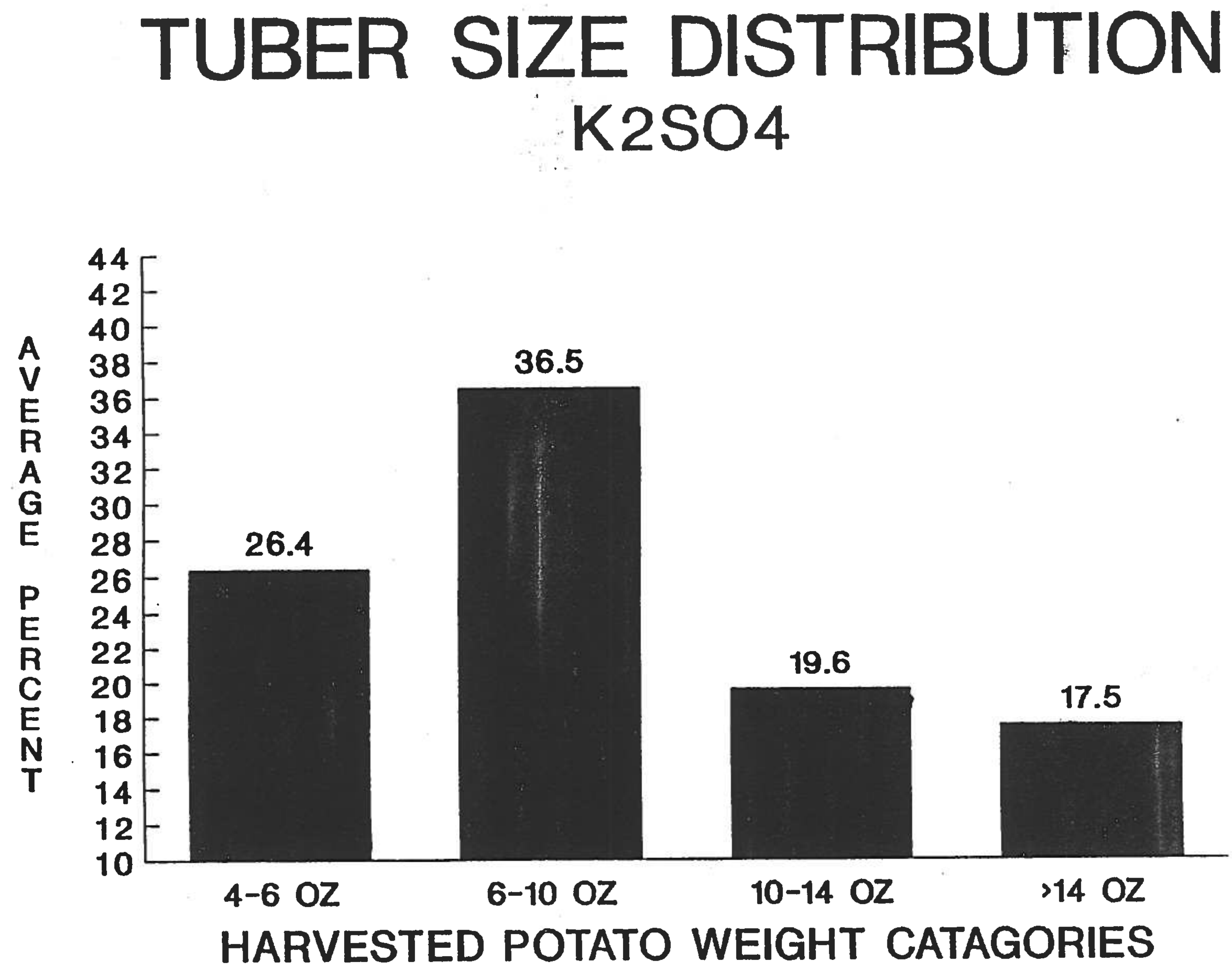

TUBER SIZE DISTRIBUTION
K2SO4
AVERAGE PERCENT
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
26.4
36.5
19.6
17.5
4-6 OZ
6-10 OZ
10-14 OZ
>14 OZ
HARVESTED POTATO WEIGHT CATAGORIES

Figure 26

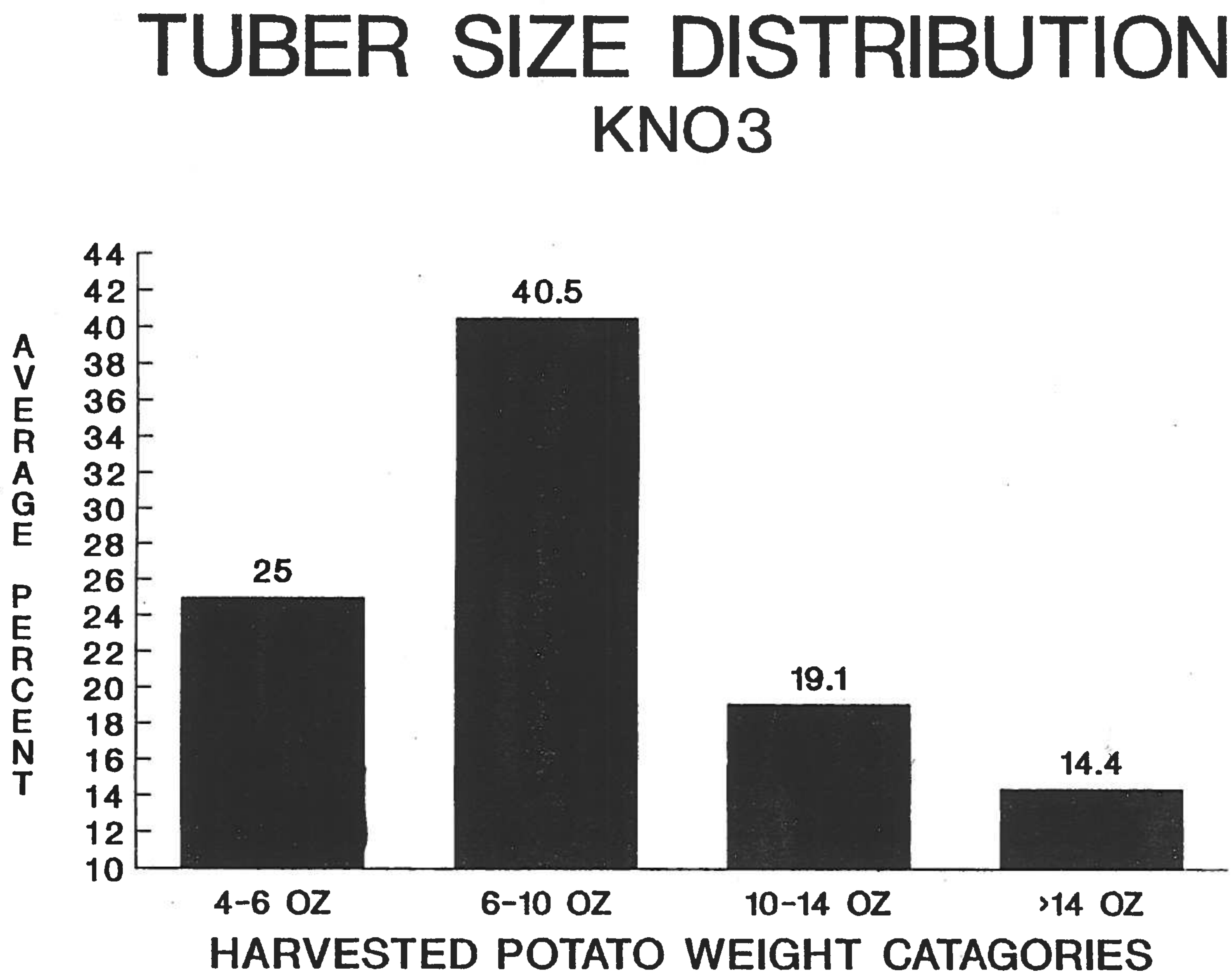
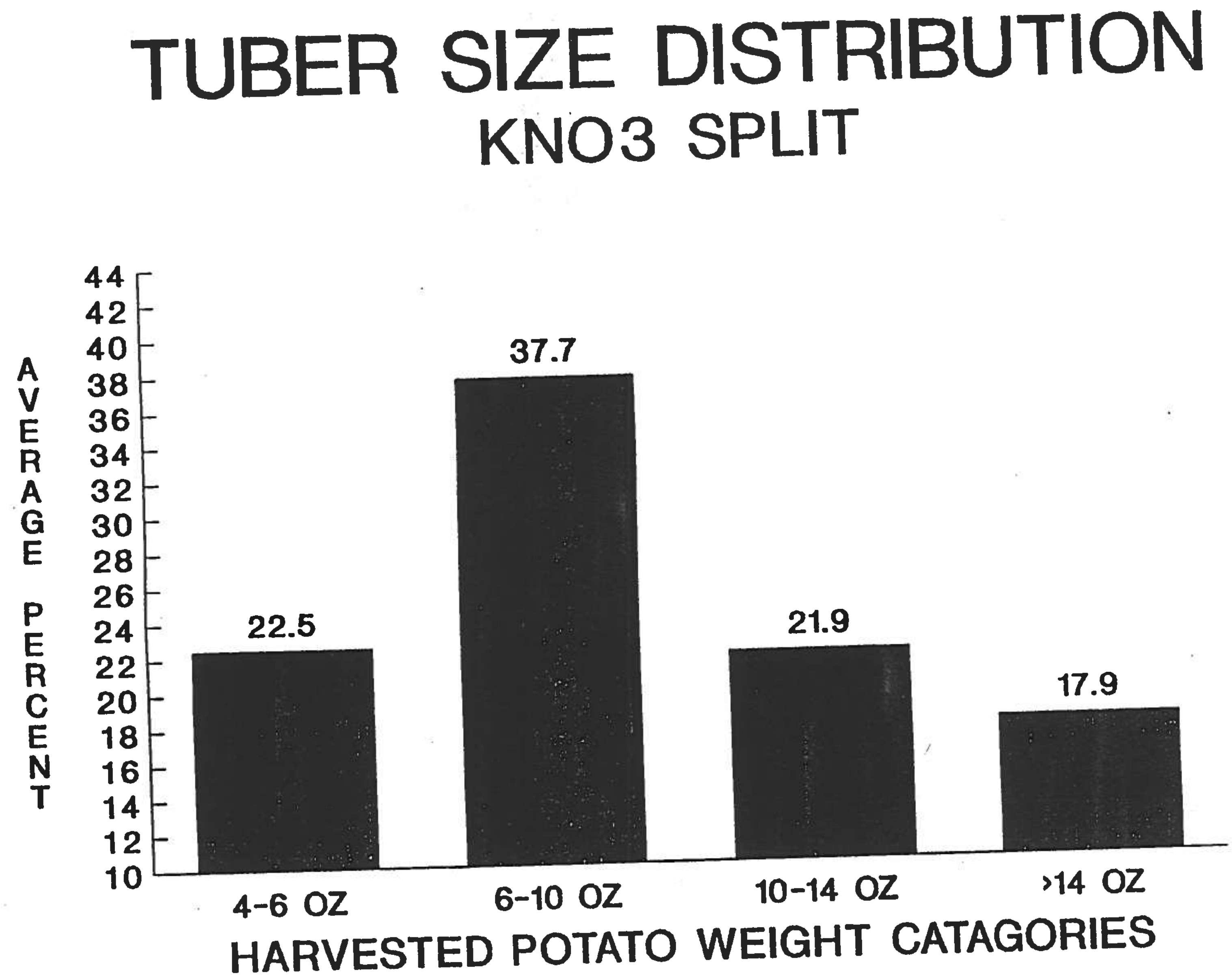

TUBER SIZE DISTRIBUTION
KNO3
AVERAGE PERCENT
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
25
40.5
19.1
14.4
4-6 OZ
6-10 OZ
10-14 OZ
>14 OZ
HARVESTED POTATO WEIGHT CATAGORIES

Figure 27


TUBER SIZE DISTRIBUTION
KNO3 SPLIT
AVERAGE PERCENT
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
22.5
37.7
21.9
17.9
4-6 OZ
6-10 OZ
10-14 OZ
>14 OZ
HARVESTED POTATO WEIGHT CATAGORIES

SPECIFIC GRAVITIES

TREATMENT	REP	2-4 OZ	4-6 OZ	6-10 OZ	10-14 OZ	OVERALL AVERAGE
	1	1.0790	1.0849	1.0857	1.0849	1.0830
(1)	2	1.0746	1.0800	1.0840	1.0851	1.0808
	3	1.0807	1.0837	1.0840	1.0860	1.0834
	4	1.0781	1.0820	1.0829	1.0808	1.0811
	Average:	1.0781 c*	1.0827 b	1.0842 c	1.0842 d	1.0821 c
	1	1.0815	1.0866	1.0866	1.0897	1.0856
(2)	2	1.0808	1.0835	1.0821	1.0855	1.0829
	3	1.0753	1.0799	1.0823	1.0850	1.0801
	4	1.0825	1.0835	1.0845	1.0847	1.0836
	Average:	1.0800 b	1.0834 a	1.0839 d	1.0862 b	1.0831 a
	1	1.0793	1.0853	1.0854	1.0869	1.0838
(3)	2	1.0810	1.0797	1.0838	1.0831	1.0814
	3	1.0769	1.0811	1.0853	1.0833	1.0811
	4	1.0817	1.0816	1.0878	1.0889	1.0837
	Average:	1.0797 a	1.0819 c	1.0856 b	1.0856 c	1.0825 b
	1	1.0792	1.0844	1.0841	1.0817	1.0827
(4)	2	1.0811	1.0863	1.0892	1.0866	1.0849
	3	1.0773	1.0825	1.0842	1.0871	1.0824
	4	1.0789	1.0819	1.0893	1.0924	1.0833
	Average:	1.0791 b	1.0838 a	1.0867 a	1.0870 a	1.0833 a

Treatment 4 had the highest gravities overall and for each category above 4 oz tuber weight. *LSD 10% by size category and 5% for overall.

Treatment 1 had the lowest gravities overall and for the 2-4 oz and 10-14 oz size categories and was only slightly better than the lowest levels in the 4-6 oz and 6-10 oz size groups.

TABLE 10

FRY COLOR (SUGARS) DATA

TREATMENT	REP	4-6 OZ	6-10 OZ	10-14 OZ	>14 OZ	
	1	00	00	00	00	
(1)	2	00	00	01	00	a
	3	00	00	00	00	
	4	00	00	00	00	
	Totals:	00	00	01	00	
	1	00	00	00	00	
(2)	2	00	00	00	00	a
	3	01	00	00	00	
	4	00	00	00	00	
	Totals:	01	00	00	00	
	1	00	00	00	00	
(3)	2	00	00	00	02	a
	3	00	00	00	00	
	4	00	00	00	00	
	Totals:	00	00	00	02	
	1	00	00	00	00	
(4)	2	00	00	01	01	b
	3	00	02	00	00	
	4	00	00	00	00	
	Totals:	00	02	01	01	

Although sugar accumulation is normally very low at harvest, treatment 4 had more sugar and symptoms than any of the others by a factor of 2X. Sugar ends are generally associated with stress conditions during the growth of the plant. It has not been directly linked in this researchers experience to lower potassium tissue levels. This connection merits further investigation because such a relationship would be very important to understand and may be a grower controlled variable.

TABLE 11

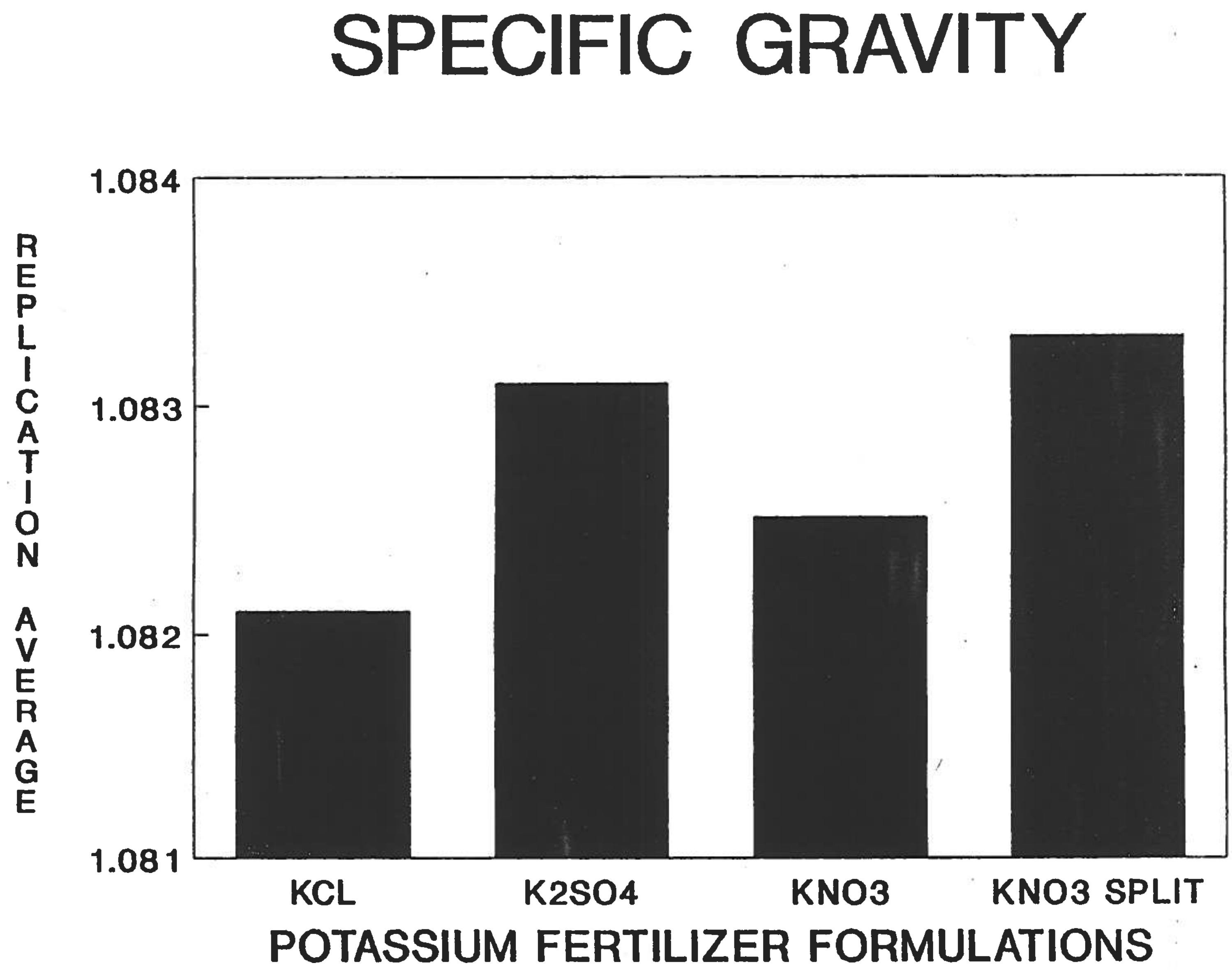

SPECIFIC GRAVITY
REPLICATION AVERAGE
1.084
1.083
1.082
1.081
KCL
K2SO4
KNO3
KNO3 SPLIT
POTASSIUM FERTILIZER FORMULATIONS

Figure 29

UNDERSTANDING THE ROLE OF THE NUTRIENT POTASSIUM

Steve Holland

There are growing numbers of potato producers who would argue that growing a crop which one can be proud of is an increasingly complex undertaking. Each season they re-examine countless variables while contemplating the important choices to be made. Some of their decisions will involve parameters we don't control while others are reasonably manageable. It makes a lot more sense to focus our attention on those things which we can improve, if we make the right choices, than to dwell on the aspects we can't change. Growers recognize crop fertility as an aspect of potato production that can be effectively managed. It is nevertheless only a small part of the overall decision making process that needs to be re-addressed annually. Almost everyone appreciates the importance of the fertility program, yet, surprisingly few understand all that they should about the rather intricate role each nutrient plays in soil and plant systems.

This discussion will review some of the more important properties of potassium as a plant nutrient. Each of the sixteen elements recognized as having nutrient properties are considered *ESSENTIAL* to the growth and vigor of plants. Accept, if you will, that "*essential*" means nothing more or less than **ABSOLUTELY NECESSARY**. Each nutrient has at least one and generally many very specific functions. In fact, most nutrients are involved in a number of complex activities and interactions both in the soil and inside the plant. Potassium is one of the three *major* nutrients along with nitrogen and phosphorus. *Major* simply means it is required by plants in much larger quantities than are any of the *micro* and *minor* nutrient elements. It is however no more or less "*essential*" than any of the other fifteen nutrients. Typically almost as much potassium is removed from the soil by the potato plant as are all the rest of the nutrients combined. Somewhere between .5 and .6 lb is contained in each hundred weight harvested. This does not correlate well with application rates since nutrient uptake efficiencies vary widely with soil type, texture, structure, organic content, pH, temperature, and moisture, etc etc. Potassium is unique among the fertilizer elements in that it does not chemically react with anything in the plant. It remains a free ion and performs its function in that form alone throughout the entire season. Potassium is perhaps best known for its' role in balancing water relations within the plant. A number of the other functions of potassium in the plant are less widely understood. Potassium appears to be necessary for (1) synthesis of simple sugars and starch, (2) the translocation of carbohydrates, (3) chemical reduction of nitrates, (4) synthesis of proteins (particularly in meristems), (5) normal cell division, (6) opening and closing of the stomata, (7) maintaining permeability of cytoplasmic membranes, (8) hydration of protoplasm and (9) promoting foliage and tuber maturity. The bulk of the potassium normally absorbed by the plant is taken in through the root hairs during the early stages of growth. Since potassium remains in an inorganic and ionic form it is readily transported from one plant part to another throughout the life of the plant. Older leaves and organs frequently lose potassium to new growing regions. Potassium is almost always the most abundant univalent cation in plant cells. Potassium is absorbed from the soil in quantities far in excess of the amounts necessary for the plants physiological processes. Potassium's importance to water relations within plants especially in high temperature and low humidity climates cannot be over emphasized. Since potassium is not chemically combined to any extent into organic compounds within the plant, it remains in ionic form in the vacuole of cells and this property alone permits it to remain osmotically active. This activity enables the plant roots to extract water from the soil and to resist transpiration loses through the leaves. The symptoms of potassium deficiency commonly observed are also those commonly associated with water deficits and include such symptoms as low turgor pressure, reduced cell division, limited stomatal opening, dark green foliage color, tissue necrosis, leaf margin scorch, shedding of lower leaves, reduced yield, high dry matter, immaturity and highly black spot susceptible tubers.

In the soil, potassium exists in three forms: exchangeable K, solution K, and mineral K, all in a dynamic equilibrium. Only the soluble form which represents 1%-2% of the total soil K is available to plants and it like all other disolved nutrient ions must be osmotically absorbed by the plant root hairs. This is especially important to the plant since without adequate water, cell turgor is lacking and without cell turgor there is no cell division. Thus, at the risk of over-simplification, potassium functions as a nutrient as well as a water regulator. A high concentration of potassium ions within the cell can by virtue of an associated high osmotic pressure, prevent or delay water movement out of cells and the loss of plant turgor, i.e., wilting. Thus, high levels of potassium within a plant or tuber will have a buffering effect against water loss and reductions in turgor be it in the field or in the storage. As already noted, potassium is able to move freely to all parts of the plant during the growing stages and again this is primarily because potassium is not tied chemically to any components within, or as part of, the plant itself. The amount of potassium that ends up in the tuber is roughly equal to the amount of potassium translocated out of the vines during the tuber bulking period. Roots can not absorb potassium rapidly enough to meet the needs of the tubers during bulking and at the same time maintain the required high level in the vines. Therefore, as noted, much of the high potassium content of the vines, absorbed early in the growth season, ultimately ends up translocated to the tubers by fall. If adequate potassium is not present in the vines relatively early in the growing season there will most likely not be enough taken in during mid and late season to supplement the translocation to the tubers. In this situation, yield and quality, as they relate to hydration and tuber bulking due to translocation will suffer. For semi arid climates with high rates of evapo-transpiration, adequate potassium is particularly important since it plays its greatest role in hot weather where low humidity persists. High potassium rates play a very active role in preventing early dying and generally tend to improve quality, yield and long term storage keeping potential.

There exists an inverse interrelationship for both nitrogen and potassium with dry matter content (specific gravity) in potatoes. This decrease due to potassium results from the hydrating influence of potassium ions effectively diluting the solids within the cells. The effect of high nitrogen availability is that plants generally have more foliage with larger leaves and are more susceptible to water stress which closes stomates, reduces photosynthesis, and subsequently limits dry matter content. High nitrogen also causes the plant to continue its vegetative growth phase longer which in turn delays tuber bulking. Bruise, i.e., black spot susceptibility is in several ways directly and indirectly associated with turgor pressure in cells. Leaving the crop in the field after vine kill or natural senescence and allowing the soil to dry may have the effect of tuber dehydration thereby raising specific gravity, decreasing yield and increasing the potato tuber susceptibility to internal bruise, i.e., black spot. Specific gravity however, is not per se, uniquely related to internal bruise.

For immature potatoes, soil moisture should be at or just slightly below 60% of field capacity in the coarser soil types at the time of vine kill. A slow vine kill and semi-dry fields can improve solids whereas, fast vine kill on wet fields generally reduce solids because the roots don't die as quickly as the foliage. They continue to take in soil moisture and much of it ends up going into the tubers. This may boast yields without cost, which may be good as long as it doesn't reduce dry matter below acceptable levels.

Low relatively humidity (below 90% relative humidity) in storage may contribute a reduced ability of the potato to properly wound heal and suberize damaged tissue. It may also contribute to excessive tuber dehydration and ultimately pressure bruise. These problems are always more severe in tubers which are low in potassium. Sunken areas on tubers that have been stored in undesirably low relative humidity situations, which we call pressure bruises, are extremely fragile. The normal impacts associated with unloading and delivering a stored crop is usually enough to cause high levels of black spot bruise to the tissue within the pressure bruise sites. This same response will also occur in highly dehydrated or physiologically old tubers and for the same reasons.

Tuber temperature is also effects bruise susceptibility. Cold potatoes are most susceptible to internal bruise, therefore, it is desirable to avoid harvesting and handling activities when potato pulp temperatures are below 45° F. Immature and low specific gravity potatoes will usually bruise more easily than mature, high gravity potatoes regardless of the harvest time and temperatures. Immature potatoes also accumulate reducing sugars faster, are more prone to skinning, and do not suberize as well. They also accumulate more frying oils, take longer to cook, and have lower recovery rates,. There can also be too much of a good thing. Overly mature potatoes do not suberize well, have more shrink in storage, will sprout sooner, and are more susceptible to internal black spot bruise. It is generally believed that long season, slightly immature potatoes are more desirable for long term storage followed by processing into French fries. For fresh pack utilization, a slightly more mature (vine killed) potato with a firmly set skin is preferred since the appearance factor is most critical.

Stresses on the plant during the growing season resulting from nutrient deficiencies, insects pressures, disease incidence and cultural mismanagement all tend to increase tubers susceptibility to internal bruise. By way of review, high levels of potassium in the soil are not only needed for a top production but they have significant beneficial secondary effects as well. The effects of potassium in reducing tuber black spot have been well documented. The potassium relationship to water content in the tubers as measured by specific gravity are also well established. The effect of proper soil moisture at harvest in reducing black spot is most effective if the plant contains adequate amounts of potassium. If potassium is deficient, adequate soil moisture will not control black spot. Stresses in the storage environment including improper humidity, inadequate (CO_2 build-up) or excessive ventilation (dehydration) and undesirable temperature regimes can contribute further to the potatoes susceptibility to internal disorders. Thus, it is safe to say that potato yield, quality, maturity, black spot susceptibility, specific gravity, and long term storage potential are all closely related to potassium nutrition. Recognize at least that potassium is the only major nutrient that can consistently reduce the severity of black spot bruise in potato tubers.

Alberta
AGRICULTURAL RESEARCH
INSTITUTE

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Fax 403/422-6317
E-mail: christi@agric.gov.ab.ca

October 19, 1999

Mr. Ed Van Dellen
Potato Growers of Alberta
6008 - 46 Avenue
Taber, AB T1G 2B1

Dear Mr. Van Dellen:

Re: Project #99E246, "Phosphorus Requirement of Potatoes"

Enclosed is an originally signed copy of the memorandum of understanding between Westco and the Alberta Agricultural Research Institute for your files.

Your support of agricultural research is appreciated.

Yours sincerely,

Dr. Ralph G. Christian
Executive Director

Encl.

cc: Dr. R.C. McKenzie

Alberta
AGRICULTURE, FOOD AND
RURAL DEVELOPMENT

Crop Diversification Centre
South

S.S. #4
Brooks, Alberta
Canada T1R 1E6

Telephone 403/362-1300
Fax 403/362-1306

June 8, 2000

RECEIVED JUN 0 8 2000

Ed Van Dallen
Potato Growers of Alberta
6008 - 46 Ave.
Taber, AB T1G 2B1

Dear Mr. Van Dallen:

For our research project on Phosphorus and Compost on Potatoes, the Potato Growers of Alberta sent a cheque for $9000 on March 27 and another cheque for $9000 on May 29. The second cheque is in error and I enclose this cheque with this letter.

This project, Phosphorus and Compost on Potatoes, has encountered financial problems as industry support has not been as large as in previous years and as anticipated we have also encountered problems with budgeting. We had accumulated a surplus from staff educational leave account. The surplus funds in this account were used on the Centre's deficit budget at the financial year end of March, 2000. Therefore, we have a wage deficit for this current year of $22,792 which was much larger than anticipated and used up surplus funds from other sources.

Even after allocating $4000 from other projects we are still nearly $10,000 in deficit. If other funds are not available it will be necessary to cut back on the amount of petiole samples, hand samples and disease surveys. I have attached an updated budget on this account.

Thank you for the support and interest you have shown in this research.

Sincerely,

R. Colin McKenzie
Research Agronomist
Soil and Water

/scd

cc Ron Howard
Clive Schaupmeyer

Current Budget (cash outlays)

Lab analysis of plant and soil samples	$12,000
Casual labour petiole samples	4,000
Manual harvest of samples	6,000
Labour for grading doing disease counts on tubers	2,000
In field disease surveys	2,000
Trucking of compost	2,660
Compost spreading	500
Stakes and lath and water wells	340
	$29,500

Revenue

Potato Growers of Alberta	$9,000
McCain Foods	2,700
Westco	3,000
Carry over funds from previous year	950
Funds from other projects	4,000
	$19,650

Southern Ag Services and Agrium supply fertilizer and spreader (no charge) - value $1500
Lakeside Fertilizer application of fertilizer and supply fertilizer (no charge) - value $500

Deficit $9,850

Agriculture and Agri-Food Canada — Agriculture et Agroalimentaire Canada
Research Branch — Direction générale de la recherche

Research Centre
P.O. Box 3000
Lethbridge, AB T1J 4B1

Telephone: (403) 327-4561
Facsimile: (403) 382-3156

April 6, 2000

Fund Centre SPA A02082

Mr. E. Van Dellen
Potato Growers of Alberta
6008 - 46 Avenue
Taber, AB T1G 2B1

Margie: please file IN the Appropriate place

Dear Mr. Van Dellen:

Enclosed please find two signed copies of the Research Support Agreement between the Potato Growers of Alberta and Her Majesty the Queen as Represented by the Minister of Agriculture and Agri-Food for Canada related to Dr. Larney's project entitled, "Irrigated cropping systems for sustainable management".

Please have both copies of the agreement signed in blue ink, witnessed, and retain one copy for your files. Please return one copy to the undersigned. We gratefully acknowledge receipt of your cheque in the amount of CDN$8,000.00.

We are pleased to be involved with you in this study.

Sincerely,

Is this a PDI?

NO

RECEIVED APR 12 2000

P.A. Burnett

P. A. Burnett
Acting Director

:wd
Encs.
cc: F. Larney
W.Willms
Finance

RESEARCH SUPPORT AGREEMENT

BETWEEN:

HER MAJESTY THE QUEEN IN RIGHT OF CANADA
as represented by the Minister of Agriculture and Agri-Food
("Canada")

AND:

Potato Growers of Alberta
a company incorporated under the Province of Alberta,
having its head office at
6008 - 46 Avenue, Taber, AB T1G 2B1
("the Company")

THE PARTIES HERETO COVENANT AND AGREE AS FOLLOWS:

1. The Project

Canada will conduct the research project entitled "Irrigated cropping systems for sustainable management" ("the ***Project***"), described in detail in Appendix "A" hereto.

2. LOCATION AND DURATION

The ***Project*** will be carried out at Agriculture and Agri-Food Canada's Research Centre, Lethbridge, in the Province of Alberta, Canada, between the date of signing and the 31st day of March, 2001.

3. CONTRIBUTION BY THE COMPANY

The Company's contribution for the ***Project*** shall comprise the items listed in Appendix "B" hereto and is estimated at CDN $8,000 dollars as shown in Appendix "B" hereto.

All goods and services purchased by Canada in connection with the ***Project*** with funds from the Company shall remain the property of Canada.

4. CONTRIBUTION BY CANADA

Subject to the availability of funding from the Matching Investment Initiative, Canada's contribution will not exceed the value of the cash plus in-kind contribution from the Company's contribution as shown in Appendix "B".

It is understood that Canada's contribution will be in kind and that no payments will be required to be made by Canada to the Company under this ***Agreement***.

5. REPORTS

Canada shall provide the Company with a copy of public reports arising from this ***Project***.

6. RELATIONSHIP

Nothing contained in this ***Agreement*** shall be considered or construed as creating a partnership or the relationship of principal and agent, lessor and lessee, licensor and licensee or of employer and employee between the parties.

7. INTELLECTUAL PROPERTY

All technical information, inventions, designs, methods and processes and other intellectual property rights related to the ***Project*** that are conceived, developed, or first reduced to practice in the carrying out of the ***Project*** (collectively, the ***"Intellectual Property"***) shall be the property of Her Majesty and, subject to the *Access to Information Act*, shall be treated as confidential.

8. TERMINATION

Canada may, by notice in writing to the Company, terminate this ***Agreement*** if it can no longer continue with the ***Project***, or if in Canada's opinion, the circumstances surrounding the ***Project*** have changed and are such that further support by Canada to the ***Project*** is not warranted.

9. NOTICE

Unless otherwise notified, the representative of the parties for the purpose of the ***Agreement*** shall be:

For Canada:
Dr. F. J. Larney
Research Scientist
Agriculture and Agri-Food Canada
Lethbridge Research Centre
5403 1st Avenue South
Box 3000
Lethbridge, AB T1J 4B1
Telephone: (403) 317-2216
Facsimile: (403) 382-3156
Internet: larney@em.agr.ca

For the Company:
Mr. E. Van Dellen
Potato Growers of Alberta
6008 - 46 Avenue
Taber, AB T1G 2B1
Telephone: (403) 223-2262
Facsimile: (403) 223-2268

10. ENTIRE AGREEMENT

This ***Agreement*** constitutes the entire agreement between the parties and sets forth all representations forming part of or in any way affecting or relating to this ***Agreement***. The parties acknowledge that there are no representations, either oral or written, between Canada and the Company, relating to this ***Agreement***, other than those expressly set out in this ***Agreement***.

11. GENERAL

a) This ***Agreement*** shall be governed, firstly, by applicable Canadian Federal laws, and secondly, by the laws of the Province of Alberta.

b) All amendments to this ***Agreement*** shall be in writing.

IN WITNESS WHEREOF this ***Agreement*** has been signed by duly authorized representatives of the parties.

Executed in duplicate this 6 day of April, 2000.

- For Her Majesty:

Chris Heerschap
(Witness)

P A Burnett
(Signature)
S.D. Morgan Jones, Ph.D., Director
Lethbridge Research Centre

- For Potato Growers of Alberta:

(Witness)

(Signature)

Ed Van Dellen
(Name in Block Letters)

Interim Manager
(Title)

APPENDIX "A"

(to the Research Support Agreement)

DESCRIPTION OF RESEARCH PROJECT

PROPOSAL FOR NEW MATCHING INVESTMENT INITIATIVE
2000-2001
Western Region

Centre: Lethbridge Research Centre
Project Title: Irrigated cropping systems for sustainable management
Project Managers: F.J. Larney and R.E. Blackshaw

Industry Partner(s):

Potato Growers of Alberta	($8,000 cash)
Alberta Pulse Growers Commission	($6,000 cash)
Alberta Pulse Growers Commission (Zone 1)	($2,000 cash)
Rogers Sugar Ltd.	($20,100 in-kind)
Sugar Beet Industry Development Fund (SBIDF)	($8,000 third party)
Alberta Environmentally Sustainable Agriculture (AESA)	($8,000 third party)

Objectives: To devise crop sequences and tillage management systems for irrigated land that: 1) reduce soil erosion, enhance soil quality and ensure long-term sustainability; and (2) minimize weed and disease problems.

Impact and Benefits: Irrigated crop production plays a vital role in southern Alberta's economy. It offers a diversity of crop choices that is not feasible with dryland rotations. In recent years, there has been increased expansion of the potato, sugar beet and pulse industries in southern Alberta. It is imperative that this expansion be sustainable and not jeopardize soil, water or air quality. Sustainability of a cropping system can only be assessed using long-term field experiments.

Crop sequencing and tillage plays a major role in weed and disease pressure and hence crop yield. Some weeds are inhibited by lack of soil disturbance resulting in less weed pressure and more uniform weed flushes. Some diseases are reduced due to the environment created by high residue conditions while others are favoured by these systems. However, weed and disease pressures associated with crop sequences under high residue management are not well defined for irrigated cropping in southern Alberta.

This study will address issues such as crop yield and quality, disease and weed pressures, soil chemical, physical and biological properties and economics for a range of different crop rotations on irrigated land. It is envisaged that the study will provide valuable information to the farming community and help ensure the preservation of our soil resource. The study was devised with input from farmer representatives of the various industry partners. Hence it has had producer buy-in from the outset.

Relationship to Mandate: The mandate of the Soil Management Project at Lethbridge Research Centre is to devise management practices that enhance soil productivity and ensure its preservation for future generations.

Work Plan / Milestones: The four crops chosen for the rotations are: soft wheat (W), beans (B), potatoes (P) and sugar beet (SB). Timothy (T) will also be included as a forage break in one rotation. The experimental design will comprise of 7 rotations: one 1-yr rotation (continuous W), two 3-yr rotations (P-B-W), two 4-yr rotations (W-SB-B-P), one 5-yr rotation (P-W-SB-W-B) and one 6-yr rotation (W(t)-T-T-SB-B-P). Each phase of each rotation will appear in any given year resulting in 26 treatments. The plots will be replicated four times giving 104 plots. For the 3-yr and 4-yr rotations, one will be managed with sustainable practices and one with conventional practices. Sustainable practices will include reduced tillage where possible, use of fall cover crops, replacement of inorganic fertilizer with compost and direct cutting rather than undercutting of beans.
2000-01: Seed wheat, beans, potatoes and sugar beet at site in Vauxhall. This site has already been sampled for soil properties and planted to barley (1999) for yield uniformity assessment. Fertilize with recommended rates of N and P. Irrigate accordingly. Perform soil nutrient sampling, weed counts, mid-season biomass measurements, disease assessments, yield measurements and soil erodibility sampling.
2001-06: Repeat 2000-01. Annual interim reports detailing first six years of crop rotations on crop yields, soil quality, weed populations and plant pathogen buildup. Final report detailing the above parameters as well as an economic assessment.

Technology Transfer Plan: Results from the study will be presented at field days during the growing season and at producer meetings during the winter.

Budget:

a. Industry contribution (annual).

	00-01	**01-02**	**02-03**
Pay:			
Salary (EG-3)	13,300	14,820	4,544
Non-Pay Operating:			
Mat & Supplies[1]	5,000	3,700	1,413
Student[2]	8,000		
Travel[1,*]	2,955	2,735	1,000
Admin Svcs	2,745	2,745	1,043
In-kind[3]	20,100	20,500	21,000
TOTAL INDUSTRY	**52,100**	**44,500**	**29,000**

Type of funding: Cash $ 40,000 In-Kind $ 61,600 Third Party $ 24,000

[1]$8,000 cash from Sugar Beet Industry Development Fund (SBIDF), including $5,000 M&S plus $2,340 Travel, not matchable but subject to 9% admin. services (administered by AAFC).
*The remaining Travel money,$615, is from the cash contributions and subject to 15% admin. services.
[2]AESA administered by Alberta Pulse Growers Commission and Alberta Sugar Beet Growers, not subject to admin. services (3rd party, $8,000 for student).
[3]Rogers Sugar Ltd., $20,100 in-kind (labour for land preparation, seeding, pesticide application, monitoring and harvest; materials and supplies and travel).

b. MII requirement (annual).

	00-01	**01-02**	**02-03**
Pay:			
Salary (EG-3)	24,730	24,730	20,808
Benefits (20% of salary)	4,946	4,946	4,161
Non-Pay Operating:			
Mat & Supplies	48	131	
Admin Svcs	3,716	3,729	3,121
Subtotal (MII Drawing Rights)	**33,440**	**33,536**	**28,090**
***Benefits** (20% of employee salaries paid through industry cash funding)	2,660	2,964	910
TOTAL AAFC	**36,100**	**36,500**	**29,000**

A-base Contribution: 0.4 py, $180,000

APPENDIX "B"

(to the Research Support Agreement)

COMPANY'S CONTRIBUTION

	2000-01
Salary (EG-3)	$6,960
Administrative Services*	1,040
Total	$8,000

* Administrative costs will be deposited to a separate Specified Purpose Account reserved specifically for these costs.

Project #99E246
New: X Renewal:___

MEMORANDUM OF UNDERSTANDING

Between:

Potato Growers of Alberta

and the

Alberta Agricultural Research Institute
(hereafter referred to as the "Institute")

Project Title: "Phosphorus Requirement of Potatoes"

Objectives: To measure the response of irrigated potatoes to phosphorus fertilizers. To measure the phosphorus response of potatoes and relate this to soil salinity, calcium carbonate content and pH.

STATEMENT OF WORK

The Alberta Agricultural Research Institute is willing to undertake the study for the Potato Growers of Alberta, which hereby agrees to pay to the Institute the costs of researching the information required as described on the attached.

PERIOD OF WORK

The research study will commence April 1, 1999. A final report will be provided to the Potato Growers of Alberta by July 1, 2000.

BASIS OF PAYMENT

The Potato Growers of Alberta have provided $5,000 to the Institute to cover manpower, travel, supplies and the administration fee.

Payment of research project expenditures will be made from funds made available to the Institute up to the maximum amount of funds received, less the administrative fee. The administrative fee is 7% of the total expense incurred by the project and administered by the Institute.

Pd [illegible] Aug 24/99
ck# 1050

The Institute will provide a record of revenue and expenditure upon project completion or depletion of funds. Any remaining funds after completion or termination of the project can be used for research at the discretion of the project manager.

RESPONSIBILITY OF PROJECT MANAGER

The project manager for this research study will be Dr. R. Colin McKenzie. He will provide all reports to the Institute and the sponsor.

The project manager will authorize expenses and submit them to the Institute for payment.

The project manager is not eligible for any manpower funds for himself.

AMENDMENTS OR TERMINATION

This Memorandum of Understanding may be amended by mutual consent of the parties as evidenced by an exchange of letters.

Either the Institute or the Potato Growers of Alberta may terminate this Memorandum of Understanding by providing two weeks notice in writing to the other party.

NOTICES AND REPRESENTATIVES

Notices for all purposes of or incidental to this Memorandum of Understanding shall be effectively given if delivered personally, or sent by registered or certified mail to the representatives of the parties designated as follows:

Potato Growers of Alberta:
ED VAN DELLEN
~~Mr. Glenn Hurst~~
6008 - 46 Avenue
Taber, AB T1G 2B1

Alberta Agricultural Research Institute:

Dr. Ralph Christian
Executive Director
J.G. O'Donoghue Building
7000 - 113 Street
Edmonton, AB T6H 5T6

Information generated from the project may be used by the Department of Agriculture, Food & Rural Development, the Institute and the Potato Growers of Alberta.

The Potato Growers of Alberta relinquishes ownership of supplies and assets purchased with these funds to the Institute which assigns control to the project manager's departmental division.

If you agree, and the terms of this Memorandum of Understanding are acceptable to you, please sign and date both originals and return both copies to this office. An original copy of this Memorandum will be returned to you after Institute authorization.

R. Robin McKenzie

Signature, Project Manager

Oct 1 / 1999

Date

I agree that the project manager named above may supervise this project.

Signature, Division Director

Oct 4/99

Date

Signature, Potato Growers of Alberta

Sept 22/99

Date

Technical Director

Title

Signature, Executive Director
Alberta Agricultural Research Institute

Oct 20/99

Date

Phosphorus Requirement of Potatoes

R.C. McKenzie
Crop Diversification Centre South, AAFRD
Brooks, Alberta
June 7, 1999

Background

Alberta farmers have applied phosphorus fertilizers to potatoes according to recommendations provided by AAFRD or by local soil testing laboratories. These normally ranged from 60-140 lbs/ac of P_2O_5. Since 1998, new recommendations from Idaho and Washington are for 140 to 300 or 400 lbs/ac of P_2O_5 for potatoes.

The soils where these USA recommendations were developed are often higher in lime than Alberta soils and may contain allophone, a clay mineral. Both lime and allophone adsorb phosphorus and reduce its availability. These new recommendations were developed as a result of field experiments which are not fully described. Alberta farmers, fertilizer dealers and agronomists are uncertain what is the rate of phosphorus to use on potatoes.

Alberta also has a problem with phosphorus loading of soils contributing to runoff which contains excess phosphorus . A survey completed by Alberta Agriculture and Alberta Environment in 1998 found about 90% of the surface waters in the agricultural areas of Alberta contained more phosphorus than allowed by the Canadian aquatic water quality standards. The phosphorus problem has been mostly associated with the livestock industry. The potential exists for the expanding potato industry in southern Alberta (22,000 acres in 1998 and about 55,000 expected in 2002) to become a significant contributor to phosphorus contamination of surface waters.

Objectives

- To measure the response of irrigated potatoes to phosphorus fertilizers.
- To compare the phosphorus response of potatoes to soil test phosphorus, soil pH, soil calcium carbonate content and to salinity.
- To measure the effect of compost as a means of supplying phosphorus
- To establish a relationship between tissue phosphorus and yield.

Methods

Two fields will be operated in 1999, one as part of a farmer's field SW of Vauxhall. Rates of phosphorus and of compost will be applied to replicated 400 m strips in the field. At this site, the field will be yield monitored using Global Positioning techniques and hand samples will be taken. Both fields will be monitored during the summer to determine tissue phosphorus level. Remote sensing will be done during the season. The Vauxhall site contains differing levels of soil phosphorus, calcium carbonate, soil pH and salinity. A second small plot site will be operated at Brooks on land leased by CDC North. It will be used to test low to high rates of phosphorus to establish a response curve for phosphorus. The amount of phosphorus retained in the soil as measured by soil test of available phosphorus will be determined.

Project Budget

Manpower/Professional/Technical Services	$11,565
Travel	$1,000
Supplies	$800
Administration Fee	$935
	$14,300

Sponsors:

Westco	$6,000
Others Anticipated	$8,300

Note: Budget can be adjusted and used at the discretion of the project manager.

Sandra Day
03/03/2000 02:44 PM

To: Clive Schaupmeyer/AAFRD@AAFRD
cc:
Subject: The use of phosphorus & compost on potatoes

Dear Mr. Van Dellen:

This is the matching grants application which was rejected by Alberta Agriculture Research Institute. I will be approaching Cargill, Westco and the Potash and Phosphate Institute of Canada for $5000 each and the Potato Growers of Alberta for $9000. I anticipate Agricore and Southern Agri Services will supply materials and equipment.

Sincerely,

Colin McKenzie
Phone: 403-342-1347
Fax: 403-362-1311

Pd 3/27/2000
ck#1484 $9,000.00

Alberta Agricultural Research Institute (AARI)
Matching Grants Program Application - 2000/2001

Office Use Only: Date Received Application Number

1. Project Title (maximum 15 words)

The use of phosphorus and compost on potatoes.

2. Commencement and Duration of Project

Expected commencement date for this request for funding: April, 2000

Anticipated duration of project is 2 year(s) Is this a renewal application? No

If yes, state the first year the project was funded ______ and the current project # ______

3. Choice of Research Committee

Beef & Dairy		Pork, Poultry, Sheep & Other Livestock	
Cereals & Oilseeds		Forage, Pulse, Vegetable & Other Crops	√
Resource Conservation		Policy, Economics & Marketing	

4. Principal Researcher

Name	R.C. McKenzie	Mailing Address	CDC South
Title	Soil & Water Agronomist		SS 4
Organization	AAFRD, NCDU		Brooks, AB T1R 1E6
Department	CDC - South	Telephone #	403-362-1347
		Fax #	403-362-1306

5. Co-applicants

Name	C.A. Schaupmeyer	Mailing Address	5011 49th Ave.
Title	Potato Agronomist		Taber, AB T1G 1V9
Organization	AAFRD		
Department	CDC - South	Telephone #	403-223-7903
		Fax #	403-223-3396

Name	D. K. Fujimoto	Mailing Address	PO Box 3000
Title	Res. Sci/Potato Biotechnoogy		Lethbridge, AB
Organization	Agric.& Agri-Food Canada		T1J 4B1
Department	Crop Sciences	Telephone #	403-317-2287
		Fax #	403-382-3156

6. *Outline of Research Proposal (one page may be added to this block if required)*

A. Background, Objectives and Key Results Expected

i. *Background* (Provide a brief statement indicating what this research is about and why it is considered important ?)

Alberta potato growers are uncertain what rates of phosphorus fertilizers they should be using. They have traditionally used from 60 to 140 lbs/ac P_2O_5. New recommendations from Idaho suggest using 100 to 300 or more lbs/ac P_2O_5 (J. Stark et al 1998). Agronomists in Washington state suggest applying 700 lbs/ac P_2O_5 over four years in soil which has potatoes once in a four-year rotation. Alberta agronomists and soils labs are uncertain what recommendations to provide. A 20 ton/ac potato crop has an uptake of about 66 lbs/ac of P_2O_5 and removal of 36 lbs/ac P_2O_5 (Can. Fert. Inst. 1998).

Alberta has an excess of livestock wastes. Manure contains a large amount of phosphorus. According to Canadian aquatic guidelines, over 90% of surface waters in agricultural areas of Alberta have excess phosphorus, much of which has been derived from agricultural land. Potato fields as well as heavily manured fields may become a significant source of phosphorus losses to surface water if high rates of P are used.

Potato growers have been reluctant to use manure on potatoes because of fear of the occurrence of scab on potatoes being increased. Manure is also considered a source of weeds and in the past, Tordon, a broadleaf herbicide, has been transmitted by manure and caused damage to potatoes.

The difficulties which can occur from use of manure can be overcome by use of compost which is different from manure and is an excellent source of phosphorus. Starting in 1999 large supplies of compost from cattle feedlot manure are available in southern Alberta. The fermentation in preparation of the compost destroys most weeds. Since 1994, Tordon has not been registered. Reports on manure causing scab of potatoes are associated with fresh manure, not with compost.

There is some evidence that manure and organic materials reduce the presence of some potato diseases. Lazarovits with Agriculture Canada at London, Ontario, has reported some reductions of disease organisms on soils receiving high rates of manure. In 1999 in southern Alberta, McKenzie, et al, with two rates of P fertilizer, compost and manure found the following amounts of Snowden potatoes showed severe disease (rhizoctonia, black leg, early blight and a small amount of leaf roll) on the tops: low phosphorus 9.1%, high phosphorus 7.1%, low manure 7.6%, high manure 6.5%, low compost 6.6%, high compost 5.9%. This was based on counts of about 2200 plants on each treatment and the LSD was at the 5% level 1.8%.

ii. *Objectives*

1. To establish what effect high rates of phosphorus fertilizer has on yield and quality of potatoes.
2. To determine critical soil and tissue levels at which a response to phosphorus can be expected.
3. To compare compost to mineral phosphorus fertilizer as a means of supplying phosphorus to potatoes.
4. To determine if compost applications have the ability to suppress the occurrence of diseases in potatoes.

iii. *Key Results Expected*

1. Develop appropriate recommendations for phosphorus fertilizer applications for potatoes in Alberta. To obtain optimum yield and to minimize the risks of soil and water overloading with P.
2. Improve knowledge about and usefulness of tissue analysis of potato petioles for phosphorus.
3. Develop recommendations to permit the use of compost with potatoes in combination with mineral fertilizers.

4. Improve the productivity and sustainability of potato production in Alberta.

B. Progress to Date (renewal applications only)

Provide a concise report of the results achieved. It should contain a summary of the data collected and any preliminary conclusions made. The report should clearly state whether the results expected under the action plan for the preceding year have been achieved. If not, provide reasons. Include all changes or modifications to original expectations, citing reasons. One page may be added to this section if required.

A similar one-year direct funded program was operated in 1999 - " Phosphorus Requirements of Potatoes". In a replicated experiment, seven rates of phosphorus and four rates of compost were used in a farmer's field. Nine rates of phosphorus were applied at another site in a small plot experiment. Yield samples were collected but results have not yet been measured and analysed. Tissue tests from these experiments indicated that it took about two times as much phosphorus applied as compost to supply an equivalent amount of phosphorus as a mineral phosphorus fertilizer. Tissue tests also estimated what were deficient, adequate and excess applications of phosphorus.

C. Research Plan

Two farmers' fields will be selected for phosphorus applications. These fields will be sandy loam or loamy sand in texture, suitable for yield monitoring. Fields chosen will be fall bedded and spring fertilized. Fertilizer or compost strips will be laid out 4 to 8 rows wide, equivalent to one pass of the farmer's harvester and windrower.

Fields selected will have medium to low levels of soil phosphorus (less than 60 ppm of P in the 0-15 cm layer). Fertilizer treatments will be up to 200 kg/ha P with compost treatments designed to apply twice as much P as the fertilizer treatments.

The seven treatments will consist of four rates of phosphorus fertilizer and three rates of compost and will be replicated three times. These treatments will be broadcast on the rows for the length of the field. They will be incorporated when the farmer rehills the field prior to planting. The area occupied by the plot will be about 20 acres.

Data collected will include tissue samples taken at a series of 3 points on each treatment within each replicate. Disease counts and identification will be made on sections of each treatment.

Yield samples will be harvested by hand from each treatment and yield monitor samples will be determined on each treatment using a global positioning system and a yield monitor mounted on the potato harvester.

Average yields for treatments will be determined and compared by regression to tissue and soil test levels of phosphorus.

Disease frequencies will be compared to measure the effect of compost and phosphorus fertilizer on disease. Tuber samples will be examined to determine the effects of treatments on quality.

A small plot of potatoes will be grown on irrigated land near Brooks. This plot will have five rates of phosphorus fertilizer and four rates of compost, each replicated four times. Treatments will be from 0 to 400 kg/ha P and compost treatments to provide twice the amount of phosphorus as the fertilizer treatments. Tissue samples and hand samples of tubers will be taken on all treatments and replicates of the small plot. Disease counts will be taken on tubers.

D. Action Plan

i. 2000-2001

- Grid soil sample project fields for 0-15, 15-30 and 30-60 cm.
- Apply fertilizer and compost treatments in April prior to planting by the farmer.
- Locate treatments with Global Positioning techniques.
- Tissue samples will be taken twice during the summer.
- Disease counts will be made during early August on sections of rows within treatments.
- Samples will be taken to confirm identification of diseases.
- Samples will be dug by hand prior to harvest to determine yields and tuber quality.
- Data will be tabulated and reports prepared. Results will be presented to Alberta Potato Growers.

ii. 2001-2002

- Repeat process from previous year.
- Write final reports.

iii. 2002-2003

E. Expected Industry Impacts/Benefits

Recommendations for optimum applications of phosphorus fertilizer will improve production of potatoes and increase the profitability of the potato industry.

The potato industry's acceptance of the use of compost will provide a large area of land for disposal of livestock wastes: 20,000 ha potatoes x 4 year rotation = 80,000 ha (200,000 acres). Compost will assist in maintaining organic matter levels and reduce loss of soil and soil phosphorus to water. An annual application of 6 t/ha (2.7 t/ac) compost would apply 216 kg/ha (192 lbs/ac) P_2O_5 in four years. This would account for 480,000 tonnes of compost per year which requires 960,000 tonnes of manure or the manure of about 300,000 cattle.

If compost is shown to suppress diseases of potatoes, this reduces the disease problems which develop on land which is used frequently in rotations including potatoes. This will increase the sustainability of potato production in Alberta.

F. Related Research Performed in Your Organization

- Site Specific Management of Potatoes. 1996-2000. McKenzie, R.C., Schaupmeyer, C.A., Green, M., Goddard, T.W., Penney, D.C.
- Phosphorus requirement of potatoes. 1999-2000. McKenzie, R.C.

G. Related Research Performed in Other Agencies

H. References

- Conn, K.L. and Lazarovits, G. 1999. Impact of animal manures on verticillium wilt, potato scab, and soil microbial populations. Can. J. Plant Path. 21 : 81-92.
- Lazarovits, G. 1997. Assessment of the Influence of Manures for the Control of Soilborne Pests including Fungi Bacteria and Nematodes Research Report 1.10 Agriculture and Agrifood Canada, London, Ontario.
- McKenzie, R.C. 1999. Site Specific Management of Potatoes. 1998. Progress Report AARI #96M979.
- Can. Fertilizer Institute 1998. Nutrient Uptake and Removal by Field Crops in Western Canada.

- Stark, J. Westerman, D. and Tyndall, T. 1998. Revised Univ. of Idaho N, P, K Fertilizer Guidelines for Potatoes. Unpublished report 4 pp.

I. Environmental Assessment

Will the project activities have any negative influence on the environment? Yes ------- No ---√---

If yes, provide a description of the mitigation plans to address them.

i.

ii.

iii.

J. Biotechnology Related Proposals

i. Does this proposal involve biotechnology research? Yes _____ No ___√__

If yes, state any potential adverse impact the project results may have on:

- food safety and human health:
- environmental sustainability:

ii. Does the research involve transfer of DNA between unrelated organisms? Yes _____ No __√___
If yes, state:
- the common name of the source of the genetic material:
- the Latin name:

K. Technology Transfer Plan

Presentations will be made at Alberta Potato Growers meetings. C. Schaupmeyer has regular contact with potato growers and provides management information to growers.

7. ***Budget and Manpower Needs for 2000-2001***

State the amount being requested in each category. One page may be added to this block to describe budget requests or any unusual items.

A. Manpower

	Name	Title	Person Years Required for 2000-2001	Amount Requested for 2000-2001
Principal Researcher	R.C. McKenzie	Soil & Water Agronomist	0.25	
Co-applicant (1)	C.A. Schaupmeyer	Potato Specialist	0.05	
Co-applicant (2)	D. Fujimoto	Plant Pathologist	0.05	
Professional	J. Holley	Plant Pathology	0.05	
Technical			0.20	8,000
Graduate Students				
Other (specify)	Field labour and laboratory labour		0.80	16,000
		TOTAL A	1.30	24,000

Justification must be outlined below if more than a total of one person year is hired for the project or the amounts requested for technicians and graduate students exceed $38,000 and $18,000, respectively, per person per year:

Justification for labour - Field and Lab - Technical labour will be required for yield monitoring using Global Positioning and for analysing data. Labour will be required for grid soil sampling of fields, tissue sampling potatoes, applying fertilizers and compost, disease surveys and manually sampling tuber yield. Labour will be supplied to the AAFRD soil and crop diagnostic lab to assist with analysis of samples. Labour will be required for seeding, irrigation, weed control, fertilizing and sampling the small plot.

Note: Principal researchers and co-applicants who are employees of public institutions are not eligible for wages, honoraria, or other compensation from project funds. However, they must note the amount of time they expect to devote to the project during the fiscal year. Applicants should carefully read the instructions before completing block 7.

B. Capital Assets (specify)

TOTAL B	

Justification for capital assets:

C. Supplies and Services

i. *Travel* (includes travel and accommodation costs)

a. Project Travel

Traveller's Name: various staff

Destination(s):

Number of Trips: 40

Mode of Travel: government truck

Purpose: collect samples
apply treatments
harvest treatments

Cost: 700

b. Conference Travel

Traveller's:

Destination(s):

Number of:

Mode of Travel:

Purpose:

Cost:

Justification is required for requests over $1,500:

ii. *Materials/Supplies* (if you have more than six items, please attach a list)

List Item	Quantity	$ Per Unit	Cost
Laboratory supplies			400
Bags for samples			200
Repairs to GPS equipment			
Seed potatoes small plot			400
		Total:	1,000

iii. *Computer Cost*

Justification is required for requests over $500:

iv. *Publication Cost* (specifically for this project's results)

Justification is required if request is over $700:

v. *Rentals and Leases*

truck rentals	1,500

vi. *Contract Personnel*

GPS Engineer - 2 days	600
Compensation paid to farmers for losses from treatments	1,000
TOTAL C	4,800
TOTAL A + B + C	28,800

D. Overhead Cost

Indicate how overhead costs were calculated (refer to instructions on page 7):

TOTAL AMOUNT REQUESTED FOR 1999-2000 (A + B + C + D) 28,800

Principal Researcher - Biographical Data

This personal information is being collected for the purpose of assessing the researchers' qualifications under the authority of the AARI Act. It is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

Name (Surname first):
McKenzie, R. Colin

Post-Secondary Education and Training Relevant to Proposal:

Institution	Field of Specialization	Degree/Diploma	Year
Univ. of Alberta	Soil Science Soil Plant Relationships	Ph.D.	1973
Univ. of Alberta	Soil Science	M.Sc.	1970
Univ. of Sask.	General Agric.	B.Sc. Ag.	1957

Relevant Professional Experience (Begin with present position):

Dates	Position or Function	Employer	Location
1987-present	Research Agronomist Soil & Water	CDC - South	Brooks, AB
1979-80	Instructor Soil Science	Univ. of Man.CIDA	Lusaka, Zambia
1973-1987	Soil & Crop Specialist	Irrig. & Cons. Div. AB Agric.	Brooks, AB

Research Activities Related to Research Proposal:

Phosphorus requirement of potatoes. R.C. McKenzie 1999-2000

Precision farming systems to maximize profits and minimize environmental impacts.
D.C. Penney, T.W. Goddard, R.C. McKenzie and P. Crown. 1993-97

Site specific management of irrigated potatoes.
R.C. McKenzie, C.A. Schaupmeyer, T.W. Goddard, M. Green and D.C. Penney. 1996-2000

Tolerance of forage and turf grasses to salinity. McKenzie & Najda. 1990-94

Relevant Articles Published in Refereed Journals and Other Relevant Works in the Last Three Years:

McKenzie, R.C., Woods, S.A., Kryzanowski, L. and McKenzie, R.H. 1999. Fertilizer response of irrigated alfalfa in Alberta. *In* Proceedings, Western Nutrient Management Conference, Salt Lake City, Utah. March 1999. pp 49-56

McKenzie, R.C. and Williams, P. 1998. Influence of irrigation on wheat strength. *In* Wheat Protein Production and Marketing. Ed. By D.B. Fowler, W.E. Geddes, A.M. Johnston and K.R. Preston. Pub. By Univ. of Sask. Extension Press. 278-280.

Campbell, C.A., Selles, F., Zentner, R.P., McConkey, B.G., McKenzie, R.C. and Brandt, S.A. 1997. Factors influencing grain N concentration of hard red spring wheat in the semiarid prairie. Can. J. Plant Sci. 77:53-62.

McKenzie, R.C., George, R.J., Woods, S.A., Cannon, M.E. and Bennett, D.L. 1997. Use of the electromagnetic induction meter as a tool in managing salinization. Hydrology Journal. 5. 1: 37-50.

Approved for $15,400

POTATO DEVELOPMENT, INC.

FUNDING APPLICATION

Phosphorus and Compost on Potatoes

Submitted by

R.C. McKenzie
CDC South
SS 4
Brooks, AB T1R 1E6

February 2, 2001

Note to applicants:

Applicants who receive funding from PDI must get approval from the PDI chairman before reporting any findings.

3C) **PROJECT CONTINGENCIES**

a) If you do not get grant monies from sources can this project be conducted as submitted?

Yes ____ No __X__ Yes, with changes ____

b) Modifications necessary:

BACKGROUND, OBJECTIVES, AND PLAN (Maximum of 3 pages for items 5A - 5D.)

5A) Background to the Proposed Project

Alberta potato growers are uncertain what rates of phosphorus (P) fertilizers they should be using. They have in recent years used from 60 to 140 lbs/ac P_2O_5. New recommendations from Idaho suggest from 245 lbs/ac P_2O_5 for a soil testing 10 ppm sodium bicarbonate P and low lime content to 365 lbs/ac P_2O_5 for a soil testing high in lime content (J. Stark et al 1998). Alberta Agriculture recommendations are based on fertilizer tests done by Agriculture Canada at Lethbridge in the 1970's are for a maximum of 100 lbs/ac P_2O_5. Agronomists in Washington State suggest applying 700 lbs/ac P_2O_5 over four years in soil which has potatoes once in a four-year rotation. Alberta agronomists and soils labs are uncertain what recommendations to provide. A 22-ton/ac potato crop has an uptake of about 73 lbs/ac of P_2O_5 and removal in the tubers of 40 lbs/ac P_2O_5 (Canadian Fertilizer Institute 1998).

Many parts of southern Alberta have an excess of livestock manure. Manure contains a large amount of P. According to Canadian aquatic guidelines, over 90% of surface waters in agricultural areas of Alberta have excess P, much of which has been derived from agricultural land. Soil particles and soluble P from potato fields, as well as heavily manured fields, may become a significant source of P losses to surface water where high rates of P are used.

Potato growers have been reluctant to use manure on potatoes because of fear of the occurrence of scab on potatoes being increased. Manure is also considered a source of weeds and in the past, Tordon, a broadleaf herbicide, has been transmitted by manure and caused damage to potatoes.

The difficulties which can occur from the use of manure can be overcome by the use of compost which is different from manure and is an excellent source of P. Starting in 1999 large supplies of compost from cattle feedlot manure are available in southern Alberta. The fermentation in preparation of the compost destroys most weed seeds. Since 1994, Tordon has not been registered for use and is banned. Reports on manure causing scab on potatoes are associated with fresh manure, not with compost. There is some evidence that manure and organic materials reduce the presence of some potato diseases. Lazarovits, a Plant Pathologist with Agriculture Canada at London, Ontario, has reported some reductions of disease organisms on soils receiving high rates of manure.

Precision agriculture experiments with potatoes indicate that fields which received large amounts of P fertilizer showed adequate levels of petiole P in the first week of July but samples taken later in the season showed deficient levels of petiole P (McKenzie and Woods 1999).

5D) Action Plan and Work Schedules

a) First year: 1999/2000

Set out plots on one field of potatoes near Vauxhall with rates of phsophorus and compost. One small plot with nine rates of phosphorus was grown near Brooks.

b) Second year: 2000/2001

Three field plots of potatoes near Fincastle, Barnwell and Cranford were grown with rates of phosphorus and compost, disease and specific gravity measurements were made on tubers.

c) Third year: 2001/2002

Two fields will receive treatments which consist of a control with no phosphorus or compost, four rates of phosphorus and three rates of compost. All treatments will receive nitrogen fertilizer. Counts of occurrence of disease will be made in the field and on tubers. Yield size and gravity of tubers will be determined.

5E) RELATED RESEARCH (Literature review - Maximum of 2 pages.)

a) At your institution

Site Specific Management of Potatoes 1996-2000. McKenzie, R.C., Schaupmeyer, C.A., Green, M., Goddard, T. and Penney, D.C.

b) At other institutions

Phosphorus research with potatoes and precision agriculture research with potatoes is being conducted by J. Davenport, Univ. Of WA at Prosser. The results have not yet been published. Olds College has established a com post program. Lethbridge research station has a long-term research program with rates of manure application to crops.

c) References. (List references cited in the above literature review.)

- Conn, K.L. and Lazarovits, G. 1999. Impact of animal manures on verticillium wilt, potato scab and soil microbial populations. Can. J. Plant Path. 21: 81-92.
- Lazarovits, G. 1997. Assessment of the Influence of Manures for the Control of Soilborne Pests including Fungi Bacteria and Nematodes Research Report 1.10 Agriculture and Agrifood Canada, London, Ontario.
- McKenzie, R.C. 1999. Site Specific Management of Potatoes.1998. Progress Report AARI #96M979.
- Can. Fertilizer Institute 1998. Nutrient Uptake and Removal by Field Crops in Western Canada.
- Stark, J. Westerman, D. and Tyndall, T. 1998. Revised Univ. of Idaho N, p, k Fertilizer Guidelines for Potatoes. Unpublished report 4 pp.

7) BUDGET AND MANPOWER NEEDS *FOR 1 YEAR*

7A) MANPOWER TO BE HIRED WITH PDI/OTHER FUNDS

NAME (If known)	POSITION	TIME REQUIRED	RATE OF PAY	AMOUNT REQUIRED
Professional and Technical manpower				
L. Hingley	Technologist	2 mths	2,700	5,400
Casual manpower				
Soil & Water labour	Field & Lab	3 mths	1,900	5,800
Soils Lab, Edmonton		4 mths	1,900	7,600
			TOTAL LABOUR COSTS	A 18,800

7B) TRAVEL EXPENSES TO BE PAID WITH PDI/OTHER FUNDS FOR 1 YEAR

DESTINATION	PERSON(S)	PURPOSE	NUMBER OF TRIPS	TRAVEL COSTS	MEALS AND ACCOM.	TOTAL COST
Taber Cranford Purple Springs	1-4	monitor plots	50		500	500
					TOTAL TRAVEL COSTS	B 500

7C) MATERIALS, SUPPLIES AND SERVICES TO BE PAID WITH PDI/OTHER FUNDS

DESCRIPTION	COST
Lab materials	800
Compost trucking	1,900
Office costs and repairs and fuel for trucks	1,400
TOTAL COST OF MATERIALS, SUPPLIES AND SERVICES FOR 1 YEAR	C 4,100

7G) **VALUE OF "IN KIND" CONTRIBUTIONS BY RESEARCH AGENCY FOR 1 YEAR**
Include estimated value of research staff time and operating budgets contributed by principal researcher's agency, or other cooperator's agency, towards this project in the period covered by this application. (Funding is not requested for these items.)

DESCRIPTION	PERSON YEARS	APPROX. VALUE
Professional, technical, and other staff	0.70	35,000
Materials and supplies (compost Agricore 3000)		6,000
Travel		1,000
Overhead (estimate)		6,000
	TOTAL VALUE "IN-KIND" COSTS	**F 48,000**

ESTIMATED TOTAL PROJECT COST FOR 1 YEAR

ESTIMATED TOTAL COST OF PROJECT (1 YEAR) E & F	74,000

AGRICULTURE, FOOD AND
RURAL DEVELOPMENT

Crop Diversification Centre
South

S.S. #4
Brooks, Alberta
Canada T1R 1E6

Telephone 403/362-1300
Fax 403/362-1306

January 24, 2001

Board of Directors
Potato Growers of Alberta
6008 - 46th Avenue
Taber, Alberta
T1G 2B1

Re: Request for Research Funding - 2001

Dear Board Members:

Enclosed are 20 copies of the research proposal for our preliminary project entitled "Influence of potassium fertilizer on specific gravity in Russet Burbank potatoes in southern Alberta". The proposal is a condensed version of the AARI application submitted in January and the first page is a summary of the proposal. This is a collaborative project addressing concerns expressed by processors regarding specific gravity in Russet Burbank in excess of 1.100. The results of this project will enable us to design solution-oriented research in the future. Industry participants and government cooperators will contribute cash and in-kind funding for the project. We are requesting $2,000 from the PGA for 2001. Please contact me if you have any questions (403-362-1314).

Thank you for your consideration. We look forward to hearing from you.

Sincerely,

Michele Konschuh, Ph.D.
Potato Research Agronomist

Alberta
AGRICULTURE, FOOD AND
RURAL DEVELOPMENT

Approved
$2000 -

Crop Diversification Centre
South

S.S. #4
Brooks, Alberta
Canada T1R 1E6

Telephone 403/362-1300
Fax 403/362-1306

January 24, 2001

Board of Directors
Potato Growers of Alberta
6008 - 46th Avenue
Taber, Alberta
T1G 2B1

Re: Request for Research Funding - 2001

Dear Board Members:

Enclosed are 20 copies of the research proposal for our preliminary project entitled "Influence of potassium fertilizer on specific gravity in Russet Burbank potatoes in southern Alberta". The proposal is a condensed version of the AARI application submitted in January and the first page is a summary of the proposal. This is a collaborative project addressing concerns expressed by processors regarding specific gravity in Russet Burbank in excess of 1.100. The results of this project will enable us to design solution-oriented research in the future. Industry participants and government cooperators will contribute cash and in-kind funding for the project. We are requesting $2,000 from the PGA for 2001. Please contact me if you have any questions (403-362-1314).

Thank you for your consideration. We look forward to hearing from you.

Sincerely,

Michele Konschuh, Ph.D.
Potato Research Agronomist

Farming For the Future Research Funding Program
Application - 2001/2002
Part A

Project Title: (maximum 15 words)
Influence of potassium fertilizer on specific gravity in Russet Burbank potatoes in Southern Alberta

Identify the Strategic Research Priority, which best fits your project. Choose only one.

- [ ] Agri-food & Health - Functional Foods & Nutraceuticals
- [ ] Environmental Sustainability
- [ ] Genomics, Proteomics, Bioinformatics & Other Basic Research
- [ ] Non-food, Fibre & Industrial Uses, including Molecular Farming
- [X] Primary Agriculture and Food Safety
- [ ] Value-added Processing

In the space provided below, please describe how the following aspects of your proposal advance the Strategic Priorities. (delete bulleted text for more space)

- **Overall purpose**

Our overall purpose is to conduct a preliminary trial to determine the effect of potassium fertilization on specific gravity in Russet Burbank potato tubers. The rather unique set of growing conditions in southern Alberta often results in tuber specific gravity (dry matter) that exceeds the ideal range for french fry processing. Processors have identified high specific gravity as a concern with respect to fry quality.

- **Key Objectives**

1. To determine the effect of three rates of potassium fertilization on yield, specific gravity, fry quality, and defects in Russet Burbank potatoes.
2. To correlate tissue potassium concentrations with potassium application rates and specific gravity.
3. To establish the economics of potassium fertilization for control of specific gravity.

- **Potential Benefits to Industry and Society**

Providing potassium fertility information to producers will help them maintain high quality potato production for the processing industry. This will also allow processors to reduce losses associated with high specific gravity. This research will benefit both producers and processors.

- **Total cost of project and dollar amount requested from AARI**

Total cost: $37,800 Amount requested from AARI: $8,500

Please indicate:
Expected Commencement Date: _March, 2001___
Anticipated duration of project: __ One Year___

Where does your project best fit on the Research Continuum? Choose only one.

- [ ] Basic Research
- [ ] Applied Research
- [ ] Development & Adaptation
- [X] Technology Transfer
- [ ] Commercialization

Part B
Progrid Evaluation

1. Contributions to Advancement of Agri-food Knowledge

In point form, please describe the potential benefits to the Agri-food industry and to society, in the space provided.

- The potato processing industry in Alberta has expanded recently and is poised for further growth.
- Processors have clients with very specific requirements for fry production and may begin to impose upper limits on specific gravity in tubers grown for the frozen french fry market.
- Processors have identified concerns with respect to very high tuber specific gravity, such as feathering, blackspot bruising, and economics (potatoes are sold by weight, fries are sold by volume).
- If specific gravity in the potatoes in maintained, processing costs are lower, and processors may be able to offer preferred pricing to producers with the highest quality potatoes.
- Potato fertility (rates, timing, and placement of fertilizer) was identified as a research priority by Potato Development Inc. for 2000-2001.
- Based on this one-year trial, we will be able to plan additional research to optimize rate and source of potassium as well as method and timing of potassium applications required to maintain the high quality of potatoes that industry has come to expect in southern Alberta.

2. Benefits to Alberta's Agri-food Industry

In the space provided, please describe in point form the expected contributions to the advancement of agri-food knowledge.

- Will determine whether it is possible, under southern Alberta conditions, to manipulate specific gravity in Russet Burbank potatoes by applying additional potassium fertilizer.
- Will establish the correlation, if any, between tissue potassium concentrations and potassium application rates.
- Will establish whether a larger scale project of this nature is necessary to fine tune potassium fertility recommendations.
- Will provide local information for producers regarding potassium fertilization for Russet Burbank potatoes.

In point form, please describe the knowledge transfer plan, in the space provided.

- Results of this research will be made available to all of the industry and government participants in the form of a final report.
- Results will be presented at breakfast meetings of the Potato Growers of Alberta (PGA) so that all producers may benefit from the information gathered.
- If specific recommendations are forthcoming as a result of the research results, a fact sheet outlining these recommendations will be produced and made available to the producers, the PGA, and to industry participants.

6. Research Design, Method & Analysis

In the space provided below, please describe the Research Design, Method and Analysis and Research Plan for the duration of the proposed project. Include reference to the most relevant literature references for your research design and methodology.

The research will be conducted at the Lethbridge Correctional Centre. The horticulturist at the Correctional Centre, Cynthia Watson, will provide manpower for planting, hilling and maintaining the plots. Twelve core soil samples will be taken from each replicate block prior to the beginning of the trial. The 0-15 cm layer will be analyzed completely (N, P, K, S, Mn, Fe, Cu, Zn, Bo, Ca, Mg, Na, organic matter, pH, E.C., base saturation and Cl-), and the 15-30 cm and 30-60 cm layers will be analyzed for nitrate, sulfate, pH and E.C. Plots will be planted adjacent to regular potato plots on land at the Correctional Centre and will be maintained in a similar fashion. Plots will be laid out in 6 replicated blocks (randomized complete block design), with three levels (0, 250 and 500 kg/ha) of potassium fertilizer (KCl) in each block. Each treatment will consist of four to six rows, 40 m long, 91 cm between-row spacing and 30 cm in-row spacing. The center two rows will be mechanically harvested for data collection to avoid edge effects. All potassium will be banded on prior to planting the potatoes. All other aspects of the fertility regime will be constant for all of the treatments. Petiole tests will be conducted on three separate occasions during the growing season, approximately three weeks apart, starting in early July. At the time of harvest, samples will be collected for yield data, grading data, specific gravity measurements, and fry quality.

Soil and petiole analyses will be conducted by Norwest Labs using standardized procedures of the analytical labs supporting the potato industry. Yield data will be collected by harvesting and weighing potatoes from a known area in each treatment. Grading will be carried out at CDC South using standards employed by the Western Canadian Potato Breeding Program for size, internal and external defects. Specific gravity will be determined using the weight in air/weight in water method. Fry quality will be determined by McCain Foods following industry protocols.

References:

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

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

McDole, R.E., G.F. Stallknecht, R.B. Dwelle, and J.J. Pavek. 1978. Response of four potato varieties to potassium fertilization in a seed growing area of eastern Idaho. Am. Potato J. 55: 495-504.

Mosley, A.R. and R.W. Chase. 1993. Selecting cultivars and obtaining healthy seed lots. *In:* Potato Health Management (R.C. Rowe, ed.).APS Press, St. Paul, MN. pp. 19-25.

Nogueira, F.D., J.G. de Padua, P.T.G. Guimaraes, M.B. de Paula, and E.B. Silva. 1996. Potato yield and quality under potassium and gypsum levels in southeastern Brazil. Commun. Soil Sci. Plant Anal. 27: 2453-2475.

Panique, E., K.A. Kelling, E.E. Schulte, D. E. Hero, W.R. Stevenson, and R.V. James. 1997. Potassium rate and source effects on potato yield, quality, and disease interaction. Am. Potato J. 74: 379-398.

Silva, G., R.W. Chase and R.B. Kitchen. 1989. Effects of potassium source and rate on potato quality. Am. Potato J. 66: 543-544

Westermann, D.T. 1993. Fertility management. *In:* Potato Health Management (R.C. Rowe, ed.).APS Press, St. Paul, MN. pp. 77-86.

Westermann, D.T., T.A. Tindall, D.W. James, and R.L. Hurst. 1994. Nitrogen and potassium fertilization of potatoes: Yield and specific gravity. Am Potato J. 71: 417-431.

8. Research Budget

Please provide a summary of the total research budget in the space provided.

Research Budget

Year	Source	Type	Personnel	Travel	Capital	Supplies	CDL*	Overhead	Total/year
1	AARI	Cash	$7,000	$500		$1,000			$8,500
	Gov't	Cash						$550	$550
		Inkind	$20,000			$1,500	$250		$21,750
	Industry	Cash	$2,000	$500					$2,500
		Inkind				$4,500			$4,500
	Totals		$29,000	$1,000	N/A	$7,000	$250	$550	$37,800

*Communication, Dissemination, and Linkage

Please provide justification for the amount requested in each of the main budget categories. Ensure the amounts are appropriate and consistent with the Guidelines.

Personnel:
The personnel requirements for this project involve providing technical staff for taking soil samples, petiole samples, harvesting tubers, grading tubers, and handling data input and analyses. Industry will be contributing staff through in-kind contributions. All supervision for the project, and a considerable amount of technical help will be provided as in-kind government contributions. Technical help will be required for the following operations:

1 soil sampling event with 2 people
1 day of site preparation with 2 people
1 day of fertilizer application with 2 people
3 petiole sampling events with 2 people
2 days of harvest with 4 people
2 days grading tubers with 2 people
8 to 10 site visits
2 days of data input
2 days processing soil and petiole samples
All analyses (soil, petiole, culinary, data, etc)

Travel:
Travel requirements of the project largely involve travel to and from the research site which is located in Lethbridge. Staff from CDC South (Brooks) and from Taber will need to make several trips to the research site to monitor the project and to assist with key data collection events.

8 to 10 site visits for two people

Supplies:
Seed potatoes, fertilizer inputs, pesticides, fuel costs, stakes, bags and tags will be required for laying out the research plots and planting the trials. Seed potatoes, fertilizer inputs, pesticides and fuel will be provided by Alberta Justice as in-kind contributions. Soil samples, petiole samples, and all analyses were also included in the supplies section.

CDL:
Communication costs relate to preparing data and results for technology transfer. This will most likely take the form of slides or overheads and perhaps preparation of a fact sheet on potassium fertility.

Overhead:
CDC South charges 5% overhead on all projects funded externally. Overhead charges by government agencies are not eligible for funding through AARI and these charges will be covered from the AAFRD operating budget for the potato program.

Part D

Research Team: Biographical Information

This personal information is being collected for the purpose of assessing the researchers' qualifications under the authority of the ASRA Act. It is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

Team Member - Biographical Data

Please provide the following biographical data for each member of the research team (including the team leader)

Name (surname first):

Konschuh, Michele Nadine

Post-Secondary Education and Training Relevant to Proposal:

Institution	Field Specialization	Degree/Diploma	Year Completed
U of Calgary	Developmental Plant Physiology	Ph. D.	1995
U of Calgary	Biological Sciences - Botany	B.Sc.	1989

Relevant Professional Experience (begin with present position):

Dates	Position or Function	Employer	Location
2000 - present	Potato Research Agronomist	Alberta Agriculture, Food & Rural Development (AAFRD)	Brooks, AB
1998 - 2000	Technologist - Biotechnology	AAFRD	Brooks, AB
1998 - present	Vice-president, R & D	Grow West Plant Regeneration	Medicine Hat, AB
1996 - 1998	Post-doctoral fellow	U of Alberta, AFNS	Edmonton, AB

Research Activities Related to Research Proposal (list up to 4 projects):

Title	Date
Development of a biocontrol for grey mold on tomatoes. J Calpas, JP Tewari	1998 - present
Characterization and production of powerful, consistent, and reliable Echinacea. MN Konschuh, AM Johnson-Flanagan	1998 - 2000
Reducing green seed in canola using antisense technology. AM Johnson-Flanagan, J Singh, L. Robert	1996 - 1998

Relevant Articles Published in Refereed Journals and Other Relevant Works in the Last Three Years

Miranda, J, **MN Konschuh**, EC Yeung & CC Chinnappa (1999) *In vitro* plantlet regeneration from hypocotyl explants of *Stellaria longipes* (Caryophyllaceae). Can J Bot. 77: 318-322.

Politeski Morissette, JC, **MN Konschuh**, J Singh, L. Robert & AM Johnson-Flanagan (1997) Reduction of chlorophyll accummulation in seed of transgenic *Brassica napus* using antisense-technology. Acta Hort. 459: 183-190.

Hawkins, GP, **MN Konschuh** & AM Johnson-Flanagan (1997) Breaking the linkage between freezing tolerance and vernalization in winter *Brassica napus*. Acta Hort. 459: 397-402.

Konschuh, MN & Thorpe (1997) Metabolism of 14C-aspartate during shoot bud formation in cultured cotyledon explants of radiata pine. Physiol Plant. 90: 144-151.

Part D

Research Team: Biographical Information

This personal information is being collected for the purpose of assessing the researchers' qualifications under the authority of the ASRA Act. It is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

Name (Surname first):

McKenzie, R. Colin

Post-Secondary Education and Training Relevant to Proposal:

Institution	Field of Specialization	Degree/Diploma	Year
Univ. of Alberta	Soil Science Soil Plant Relationships	Ph.D.	1973
Univ. of Alberta	Soil Science	M.Sc.	1970
Univ. of Sask.	General Agric.	B.Sc. Ag.	1957

Relevant Professional Experience (Begin with present position):

Dates	Position or Function	Employer	Location
1987-present	Research Agronomist Soil & Water	CDC - South	Brooks, AB
1979-80	Instructor Soil Science	Univ. of Man.CIDA	Lusaka, Zambia
1973-1987	Soil & Crop Specialist	Irrig. & Cons. Div. AB Agric.	Brooks, AB

Research Activities Related to Research Proposal:

Phosphorus requirement of potatoes. R.C. McKenzie — 1999-2000

Precision farming systems to maximize profits and minimize environmental impacts. D.C. Penney, T.W. Goddard, R.C. McKenzie and P. Crown. — 1993-97

Site specific management of irrigated potatoes. R.C. McKenzie, C.A. Schaupmeyer, T.W. Goddard, M. Green and D.C. Penney. — 1996-2000

Fertilizer requirement of irrigated alfalfa. R.C. McKenzie, R.H. McKenzie and L. Kryzanowski. — 1994-1996

Relevant Articles Published in Refereed Journals and Other Relevant Works in the Last Three Years:

McKenzie, R.C., Woods, S.A., Kryzanowski, L. and McKenzie, R.H. 1999. Fertilizer response of irrigated alfalfa in Alberta. *In* Proceedings, Western Nutrient Management Conference, Salt Lake City, Utah. March 1999. pp 49-56.

McKenzie, R.C. and Williams, P. 1998. Influence of irrigation on wheat strength. *In* Wheat Protein Production and Marketing. Ed. By D.B. Fowler, W.E. Geddes, A.M. Johnston and K.R. Preston. Pub. By Univ. of Sask. Extension Press. 278-280.

Campbell, C.A., Selles, F., Zentner, R.P., McConkey, B.G., McKenzie, R.C. and Brandt, S.A. 1997. Factors influencing grain N concentration of hard red spring wheat in the semiarid prairie. Can. J. Plant Sci. 77:53-62.

McKenzie, R.C., George, R.J., Woods, S.A., Cannon, M.E. and Bennett, D.L. 1997. Use of the electromagnetic induction meter as a tool in managing salinization. Hydrology Journal. 5. 1: 37-50.

Team Member 2	R. Colin McKenzie	Title	Soil & Water Agronomy Research Scientist
Signature	R. Colin McKenzie	Date	Jan 5 2000.
Name: Agency's Signing Authority	Alan Hall	Title	Director, Plant Industry Division, AAFRD
Signature		Date	Jan. 9, 2001

Team Member 3		Title	
Signature		Date	
Name: Agency's Signing Authority		Title	
Signature		Date	

Other Researchers

This personal information is being collected (under the authority of the ASRA Act) for the purpose of assessing the research teams' qualifications. It is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

Name	Lori Delanoy	Title	Potato Agronomist
Function in Project	Petiole Sampling	Organization	AAFRD
Signature	L.D. Delanoy	Telephone #	403-223-7915

Name	Cynthia Watson	Title	Gardener III
Function in Project	Field Supervision	Organization	Lethbridge Correctional Centre
Signature		Telephone #	403-317-7535

Name		Title	
Function in Project		Organization	
Signature		Telephone #	

Pd

Project 329015
New: x Renewal:_

MEMORANDUM OF UNDERSTANDING

Between: THE POTATO GROWERS OF ALBERTA

(hereafter referred to as "PGA")

and the

Alberta Agriculture, Food & Rural Development
(hereafter referred to as "AAFRD")

Project Title: " Influence of potassium fertilizer on specific gravity in Russet Burbank potatoes in Southern Alberta".

Objectives: 1. To determine the effect of three rates of potassium fertilization on yield, specific gravity, fry quality, and defects in Russet Burbank potatoes.
2. To correlate tissue potassium concentrations with potassium application rates and specific gravity.
3. To establish the feasibility of potassium fertilization for control of specific gravity.

STATEMENT OF WORK

Alberta Agriculture, Food & Rural Development is willing to undertake the study for PGA which hereby agrees to pay to contribute toward the costs of researching the information required as described.

PERIOD OF WORK

The research project will commence on April 01, 2001. A yearly report will be provided to PGA by Dec 30, 2001.

BASIS OF PAYMENT

The sponsor of the project, PGA will provide $2,000 upon finalization of the memorandum to AAFRD, to cover the following estimated yearly cost:

Casual Manpower (on an as need basis):	$
Materials & Supplies	$2,000.00

The Budget can be adjusted and used at the discretion of the project manager.

Payment of research project expenditures will be made from funds made available to AAFRD up to the maximum amount of funds received from the sponsor.

AAFRD will provide a record of revenue and expenditure upon project completion or depletion of funds. Any remaining funds after completion or termination of the project can be used for research at the discretion of the project manager.

RESPONSIBILITY OF PROJECT MANAGER

The project manager for this study is Michele Konschuh. She will provide all reports to AAFRD and the sponsor.

The project manager will authorize expenses and submit them to the appropriate AAFRD department for processing payment.

The project manager is not eligible for any manpower funds for herself.

AMENDMENTS OR TERMINATION

This Memorandum of Understanding may be amended by mutual consent of the parties as evidenced by an exchange of letters.

Either AAFRD or PGA may terminate this Memorandum of Understanding by providing two weeks notice in writing to the other party.

NOTICES AND REPRESENTATIVES

Notices for all purposes of or incidental to this Memorandum of Understanding shall be effectively given if delivered personally, or sent by registered or certified mail to the representatives of the parties designated as follows:

	Alberta Agriculture, Food & Rural Development:
Vern Warkentin Executive Director Potato Growers of Alberta 6008 - 46th Ave. Taber, AB T1G 2B1	Dr. Ron Howard Horticulture Unit Leader Crop Diversification Centre South S.S. #4, Brooks, AB T1R 1E6

Information generated from the project may be used by the Department of Agriculture, Food & Rural Development, and PGA.

The sponsor, PGA relinquishes ownership of any materials, supplies and assets purchased with the project funds to the AAFRD which assigns control to the project manager's departmental division.

The parties affirm their acceptance of the terms of this Memorandum of Understanding by signing below.
Copies bearing original signatures of this Memorandum will be kept by each party.

Michele Konschuh, Ph.D, Project Manager — Date: May 14, 2001

I agree that the project manager named above may supervise this project.

R.J. Howard
Ron Howard, Horticulture Unit Leader — Date: May 14'01

Vern Warkentin, Executive Director
Potato Growers of Alberta

Signature — Date: May 9/01

Project
New: **X** Renewal:

MEMORANDUM OF UNDERSTANDING

Between: Potato Growers of Alberta
(hereafter referred to as "PGA")

and

Alberta Agriculture, Food & Rural Development
(hereafter referred to as "AAFRD")

Project Title: Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta.

Objectives:
1. To determine the optimal petiole nutrient concentrations for Russet Burbank potatoes, specific to southern Alberta,
2. To determine the relationship, if any, between potato petiole nutrient concentrations and tuber specific gravity and
3. To compare these relationships to those found in field-scale petiole data.

STATEMENT OF WORK

Alberta Agriculture, Food & Rural Development is willing to undertake this study for the PGA, who hereby agrees to contribute toward the costs of researching the information required as described in the research proposal.

PERIOD OF WORK

The research project will commence in April, 2004. An interim update (poster format) will be provided at the November 2004 PGA meeting and a yearly report will be provided to the PGA by January 31, 2005.

BASIS OF PAYMENT

The sponsor of the project, the PGA, will provide $9,200 upon finalization of this memorandum to AAFRD, to cover the following estimated yearly costs:

Casual Manpower	$2,250
Travel	$ 800
Laboratory Analysis	$5,050
Materials	$ 100
Overhead (5%) and GST (7%)	$1,000
Total	**$9,200**

The Budget can be adjusted and used at the discretion of the project manager.

Payment of research project expenditures will be made from funds made available to AAFRD up to the maximum amount of funds received from the sponsor.

If requested, AAFRD will provide a record of revenue and expenditure upon project completion or depletion of funds. Any remaining funds after completion or termination of the project can be used for research at the discretion of the project manager.

RESPONSIBILITY OF PROJECT MANAGER

The project manager for this study is Shelley Woods, Soil and Water Research Scientist. She will provide all reports to AAFRD and the sponsor.

The project manager will authorize expenses and submit them to the appropriate AAFRD department for processing payment.

The project manager is not eligible for any manpower funds herself.

AMENDMENTS OR TERMINATION

This Memorandum of Understanding may be amended by mutual consent of the parties as evidenced by an exchange of letters.

Either AAFRD or the PGA may terminate this Memorandum of Understanding by providing two weeks notice in writing to the other party.

NOTICES AND REPRESENTATIVES

Notices for all purposes of or incidental to this Memorandum of Understanding shall be effectively given if delivered personally, or sent by registered or certified mail to the representatives of the parties designated as follows:

Potato Growers of Alberta

Mr. Vern Warkentin
Executive Director
Potato Growers of Alberta
6008 – 46th Avenue
Taber, AB T1G 2B1

Alberta Agriculture, Food & Rural Development:

Dr. Christine Murray
Branch Head, CDCS
Crop Diversification Centre South
S.S. #4
Brooks, AB T1R 1E6

Information generated from the project may be used by the Department of Agriculture, Food & Rural Development and the PGA.

The sponsor, the PGA, relinquishes ownership of any materials, supplies and assets purchased with project funds to the AAFRD which assigns control to the project manager's departmental division.

The parties affirm their acceptance of the terms of this Memorandum of Understanding by signing below.

Copies bearing original signatures of this Memorandum will be kept by each party.

Shelley Woods, Project Manager

April 23, 2004
Date

I agree that the project manager named above may supervise this project.

Dr. Christine Murray, Branch Head, CDCS

April 23, 2004
Date

Mr. Vern Warkentin, Executive Director
Potato Growers of Alberta

April 24/04
Date

Alberta
AGRICULTURE, FOOD AND
RURAL DEVELOPMENT

Crop Diversification Centre
South

S.S. #4
Brooks, Alberta
Canada T1R 1E6

Telephone 403/362-1300
Fax 403/362-1306

April 23, 2004

RECEIVED APR 2 8 2004

Potato Growers of Alberta
6008 – 46th Avenue
Taber, AB T1G 2B1

Attention: Vern Warkentin, Executive Director
Alfonso Parra, Technical Director

Re: MOU for research project "Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta" first year (2004)

Dear Vern and Alfonso,

Thank you for your April 16, 2004 e-mail, which indicated that the PGA approved funding for the project proposal entitled "Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta". I have been instructed to set up a Memorandum of Understanding (MOU) with each cooperator for externally funded projects. Please review the enclosed MOU. If the terms are acceptable, please sign both copies and return one original to me, the other is for your records. If you would prefer to propose alternate terms in the MOU, please contact me at 403-362-1352. An invoice will be issued under separate cover.

Thank you for funding this project. I am excited about the potential benefits of this research to members of the PGA and look forward to our collaboration.

Sincerely,

Shelley Woods
Soil and Water Research Scientist

POTATO GROWERS OF ALBERTA

Taber, April 16 2004.

Shelley Woods
Alberta Agriculture, Food and Rural Development
Crop Diversification Centre South
Brooks

Re: "Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes in southern Alberta"

Dear Shelley

We are pleased to advise that the Board of the Potato Growers of Alberta has approved your application for a three-year period in the amount requested, $9,200.00 per year, and the funds are available to meet the timelines specified in your application.

When requesting the funds for the project, please provide an invoice that specifies the amount, GST and to whom payable.

We appreciate your commitment and dedication to the potato industry.

Yours truly,

Alfonso Parra
Technical Director

Petiole Nutrient Recommendations for Russet Burbank Potatoes Grown in Southern Alberta

Researcher: Shelley Woods (AAFRD Brooks)
Term: 3 year
Objectives:

- To determine optimal petiole nutrient concentration for RB specific to Southern Alberta
- To determine the relationship if any, between petiole nutrient concentrations and tuber specific gravity.
- To compare these relationships to those in field-scale petiole data.

Cost: $9.200.oo (year).
Comments:

- Good project that fits into the PGA categories with high priority.
- Might be replicated on other commercial varieties in Alberta

Project Proposal

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

Prepared for:

Board of Directors
Potato Growers of Alberta
6008 – 46th Avenue
Taber, AB T1G 2B1

Prepared by:

Shelley Woods and Michele Konschuh
Alberta Agriculture, Food and Rural Development
Crop Diversification Centre South
SS #4, Brooks, AB T1R 1E6

March 17, 2004

I. 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 surplus 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 (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.

The purpose of this proposed research is to provide recommendations for critical petiole nutrient (N, P and K) concentrations for Russet Burbank potatoes, throughout the southern Alberta growing season. Russet Burbank has been chosen because it is the most commonly grown processing variety in southern Alberta.

References:

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

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

Gardner, B.R. and J.P. Jones. 1975. Petiole analysis and the nitrogen fertilization of Russet Burbank potatoes. Am. Potato J. 52:195-200.

Porter, G.A. and J.A. Sisson. 1991. Petiole nitrate content of Maine-grown Russet Burbank and Shepody potatoes in response to varying nitrogen rate. Am. Potato J. 68:493-505.

Schaupmeyer, C.A. 1999. Personal comments.

Westcott, M.P., V.R. Stewart and R.E. Lund. 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.

II. PROJECT OBJECTIVES

- **To determine the optimal petiole nutrient concentrations for Russet Burbank potatoes, specific to southern Alberta.** Petiole nitrate nitrogen, phosphorus and potassium will be assessed and expressed as a function of days after planting (DAP) for optimized potato yield.

- **To determine the relationship, if any, between potato petiole nutrient concentrations and tuber specific gravity.** Petiole nitrate nitrogen, phosphorus and potassium will be assessed.

- **To compare these relationships to those found in field-scale petiole data.** Suitable data from previous PGA-funded research projects will be analyzed and available processor data (where correlating yield values are available) will be assessed.

III. WORK PLAN

This two-part project will combine analysis of data from s plot-scale experiment with a review of southern Alberta field-scale data.

1. **Plot Measurements:** Ten rates of N, P and K fertilizers will be applied to a small portion of a field of grower-managed Russet Burbank potatoes. Between 75 and 100% of the fertilizer will be applied pre-plant and incorporated, with the remaining portion top dressed during the growing season. Each treatment plot will be 6 rows wide x 35 m long. Petiole samples will be collected and analyzed for each plot 6 times throughout the 2004 growing season, beginning approximately at the time of tuber initiation. Tuber samples (10 foot strips x 4 reps x 10 treatments) will be collected, graded and measured for total yield, <6 oz yield, 6-10 oz yield, >10 oz yield, mean tuber weight and specific gravity. Treatments will be applied at the following rates, which may be adjusted slightly to account for base fertility at the site.

	Rate (kg/ha)			Rate (lbs/ac)		
Treatment	**N**	**P**	**K**	**N**	**P_2O_5**	**K_2O**
1	0	50	100	0	102	107
2	100	50	100	89	102	107
3	200	50	100	179	102	107
4	300	50	100	268	102	107
5	200	0	100	179	0	107
6	200	25	100	179	51	107
(see #3)	200	50	100	179	102	107
7	200	100	100	179	204	107
8	200	50	0	179	102	0
9	200	50	50	179	102	54
(see #3)	200	50	100	179	102	107
10	200	50	200	179	102	214

2. **Data Review:** Previous PGA-funded projects, including phosphorus and compost on potatoes, precision farming of potatoes and potassium requirements of potatoes, will provide a database on nutrient concentrations and the corresponding tuber yield and specific gravity measurements. This database will be reviewed and summarized. Making further use of this data will add value to projects previously funded by the PGA. McCain's has expressed a willingness to contribute anonymous petiole analysis and correlating yield data. Other processors will be approached for their interest, and analysis of this data will be completed and compared to the controlled plot measurements.

It is recommended that the trial be conducted for 3 consecutive years to account for differences in climate, cropping and environmental conditions between years. In the second and third years, the trial may be fine-tuned and altered in response to first-year results. This project will address the needs for Russet Burbank potatoes. If the results prove to be satisfactory and useful, it may be beneficial to repeat the research on additional varieties in the future.

IV. TIME-FRAME AND REPORTING

Surface apply pre-plant fertilizer treatments	April-May 2004
Collect petiole samples (6 dates)	July-August 2004
Collect tuber samples	August-September 2004
Tuber grading and specific gravity	October 2004
Collect data from co-operating processors	October-November 2004
Analyze results	October-December 2004
Present poster at annual PGA meeting	November 2004
Prepare first-year summary report	January 2005

Interim progress will be reported verbally or by e-mail as requested by the PGA. Shelley Woods (Soil and Water Research Agronomist, CDCS) will act as project leader and Michele Konschuh (Potato Research Scientist, CDCS) will collaborate.

V. BUDGET

Description	*Cost*
Manpower:	
Petiole collection and processing (2 people x 0.5 days x 6 sampling dates x $125/day)	750
Tuber harvest (4 people x 2 days x $125/day)	1000
Grading and specific gravity analysis (2 people x 2 days x $125/day)	500
Travel:	
Plot set-up, petiole collection and harvest (including travel time, lunches and gas)	800
Services:	
Laboratory analysis of petiole samples (10 treatments x 4 reps x 6 dates x $20/sample)	4800
Laboratory analysis of soil samples (10 treatments x 5 foot depth x $5/sample)	250
Materials:	
Bags, tags, stakes and hand-held fertilizer spreader	100
Data analysis and report preparation and presentation (included)	0
Sub-total	8200
Overhead and GST (5% OH + 7% GST)	1000
Total requested for 2004	$9200

Note: The budget does not include compensation for time committed to the project by salaried professional AAFRD staff.

An invoice will be mailed out for the total cost of the project once a memorandum of understanding has been signed by both parties.

Contact Information:

Shelley Woods
Soil and Water Research Scientist
AAFRD, Crop Diversification Centre South
S.S. #4
Brooks, AB T1R 1E6
Ph. 403-362-1352; Fax 403-362-1306

Treatments and Layout

Ten rates of N, P and K fertilizers were applied (April 20/04) to a field of grower-managed Russet Burbank potatoes, near Taber, Alberta. Each plot was 8 rows wide (24 ft) and 115 ft long (see back of brochure).

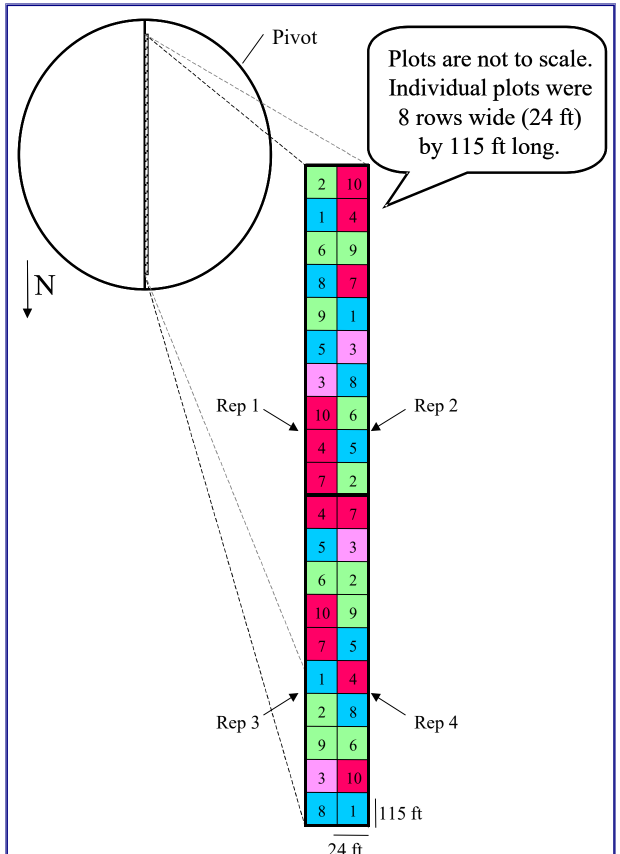
The potato crop was planted April 28/04 and was damaged by hail on July 7/04.

Petiole samples were collected and analyzed for each plot 7 times in the 2004 growing season.

Tuber samples (2x25 ft strips) were collected (Sept 22-23/04), graded for marketable yield (total yield minus smalls) and analyzed for specific gravity.

Fertilizer rates 2003-2004.

Treatment		Total N	Total P_2O_5	Total K_2O
Nitrogen	1	243	137	117
	2	255	137	117
	3	272	137	117
	4	367	137	117
Phosphorus	5	274	15	117
	6	272	72	117
	3	272	137	117
	7	268	246	117
Potassium	8	272	137	55
	9	272	137	84
	3	272	137	117
	10	272	137	238



2004 Plot layout.

Acknowledgements

This project was made possible with the financial support of the Potato Growers of Alberta (PGA), Alberta Agriculture, Food and Rural Development (Crop Diversification Centre South), McCain's and Sandberg Laboratories Ltd. Jerry Zeinstra hosted the trial.

This is year 1 of a 3-year study

A more detailed report is available upon request from the PGA office

Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta (2004)

S.A. Woods[1], L.E. Hingley[1] and M.N. Konschuh[2]

[1] Soil and Water Agronomy Program and
[2] Potato Agronomy Program
Crop Diversification Centre South
Brooks, Alberta

PGA

Alberta
AGRICULTURE, FOOD AND RURAL DEVELOPMENT
Crop Diversification Centre South

Background

The analysis of potato petiole samples is used to monitor the nutrient status of potato crops throughout the growing season. This can be a useful and timely technique for monitoring any nutrient deficiencies that may occur mid-season that were not identified in spring soil samples.

Petiole analysis results from previous Russet Burbank studies in southern Alberta indicated that the current recommendations (NW USA) may be somewhat high for phosphorus (P) and potassium (K), especially early in the growing season. Results also indicated that recommended nitrate nitrogen (N) concentrations may need fine-tuning to better suit southern Alberta growing conditions.

Objectives

Determine optimal petiole nutrient concentrations, throughout the growing season, for Russet Burbank potatoes, specific to southern Alberta.

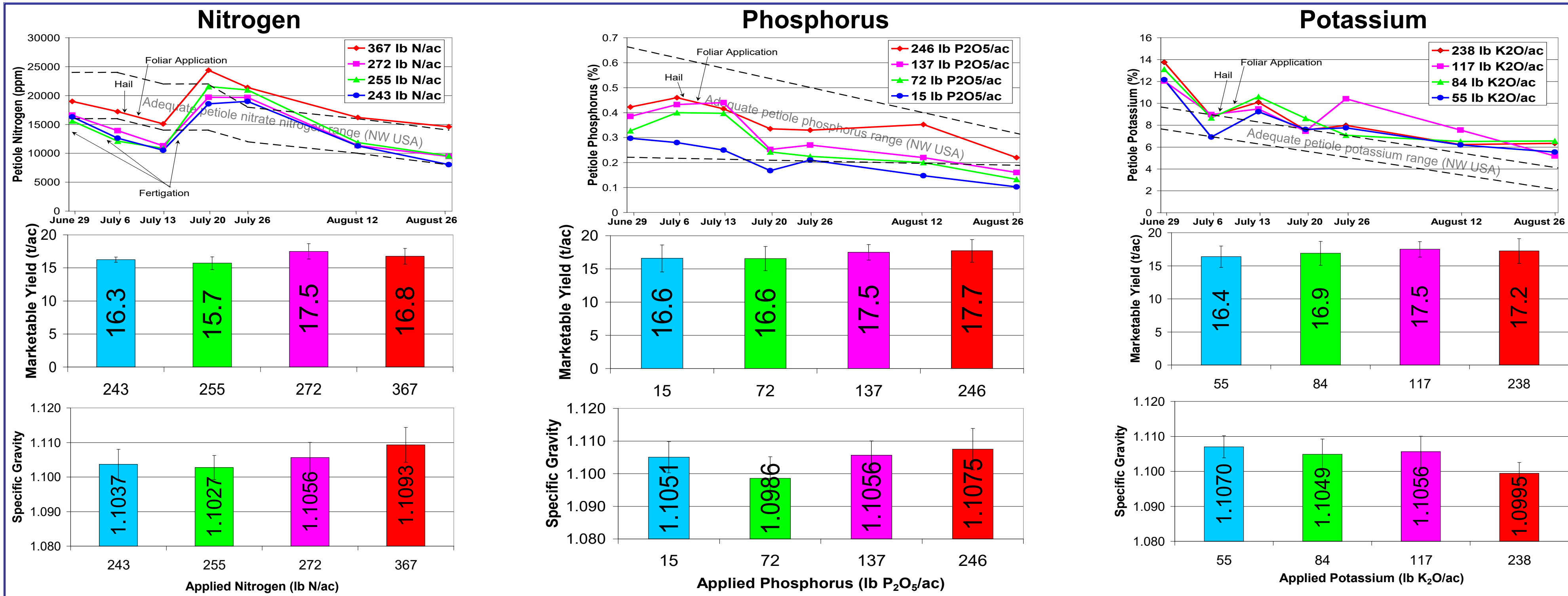
Determine the relationship between potato petiole nutrient concentrations and tuber specific gravity.

Results Summary (2004)

Nitrogen (N) Fertilizer Rates
• The highest N rate (367 lb/ac) consistently showed the highest **petiole N**. Petiole N declined from late June to mid-July but recovered quickly.
• Treatment 3 (272 lb N/ac) had the highest **yield**, but results were not significantly different.

Results (cont.)

Phosphorus (P) Fertilizer Rates
• Increasing rates of fertilizer P gave increasing amounts of **petiole P**.
• The two higher rates of fertilizer P had a slightly greater **yield** than the two lower rates of fertilizer P but results did not show significant differences.
Potassium (K) Fertilizer Rates
• Increasing rates of fertilizer K had no effect on **petiole K**. Initial soil K was high at the study site.
• There was a trend toward slightly increased **yield** with increasing fertilizer K with a small decrease for the highest rate.
• There was a trend toward decreasing **specific gravity** with increasing fertilizer K but differences were not statistically significant and all treatments gave acceptable values.



Potato petiole N, P, K content, marketable yield and specific gravity, for fertilizer rates (2004).

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

S.A.Woods[1], L.E. Hingley[2] and Michele Konschuh[3]
[1] Soil and Water Research Scientist, Irrigation Branch, AAFRD. Lethbridge, Alberta.
[2] Soil and Water Technologist, Irrigation Branch, AAFRD. Brooks, Alberta.
[3] Potato Research Scientist, Crop Diversification Centre South, AAFRD. Brooks, Alberta.

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.

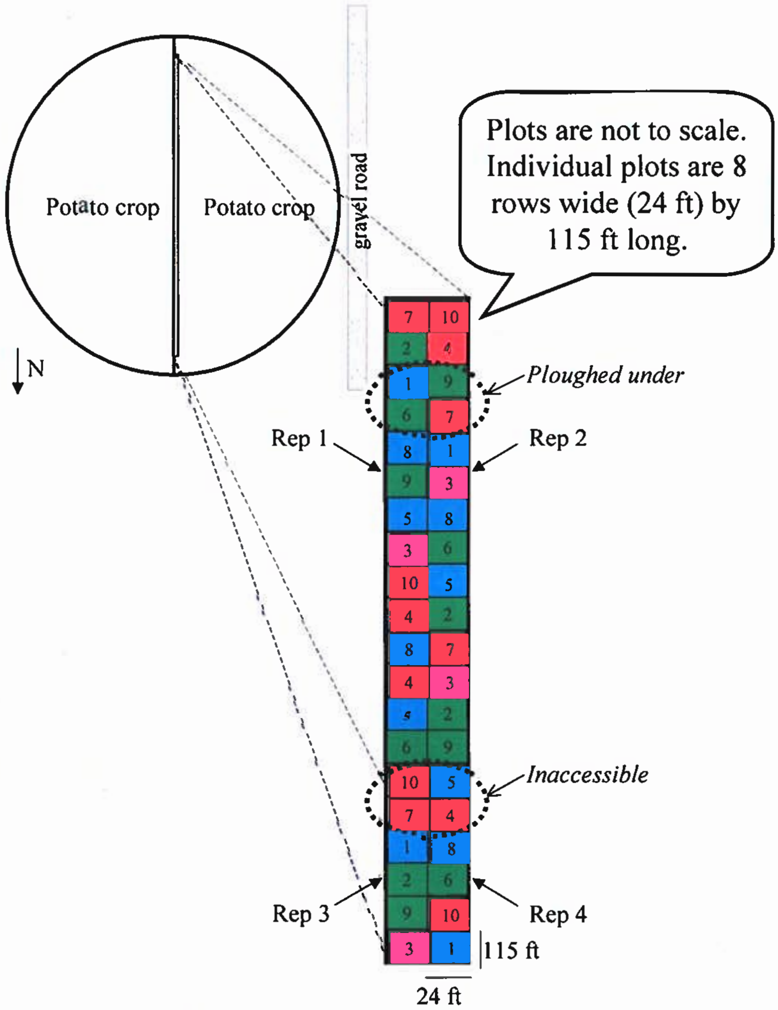
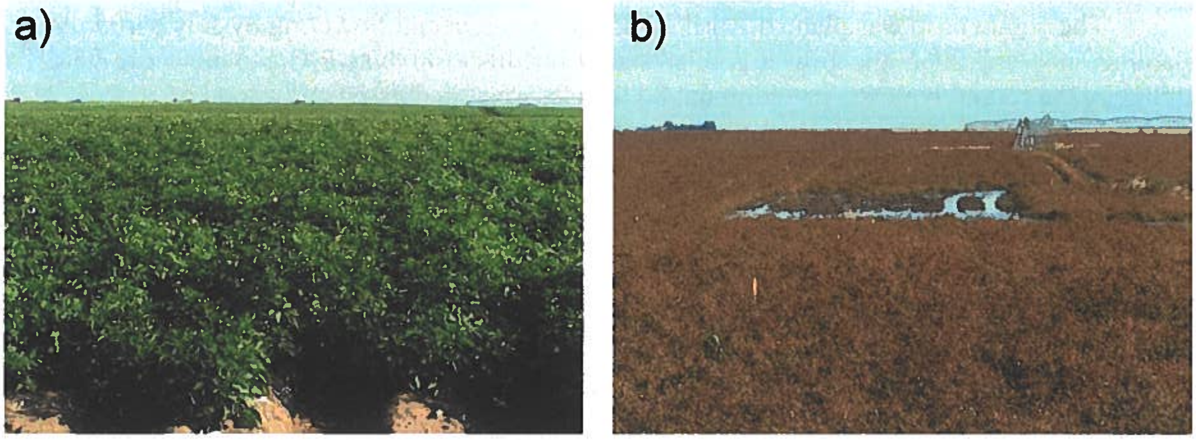


Figure 2. South end of research site looking north from edge of field, on a) July 20, 2005 and b) September 14, 2005, showing flooded portion of the field.



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).

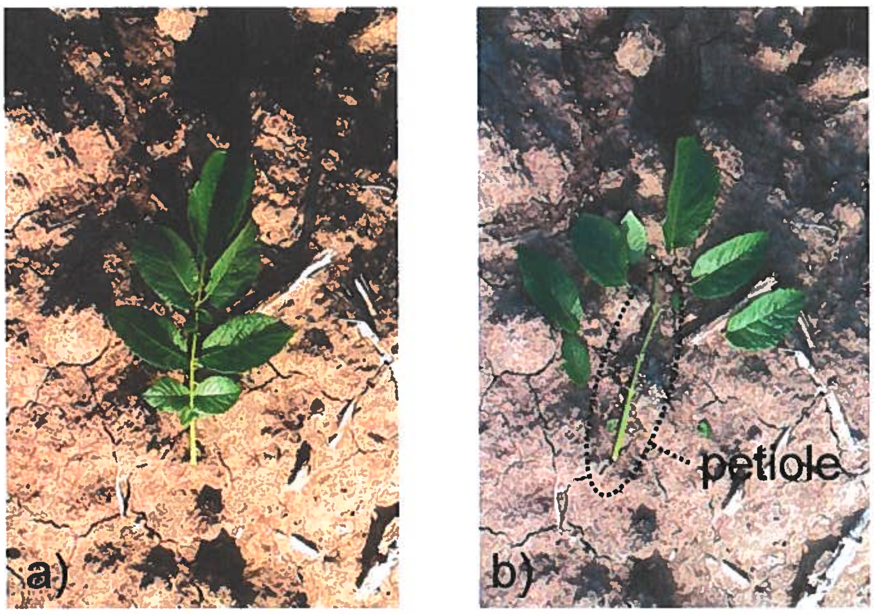
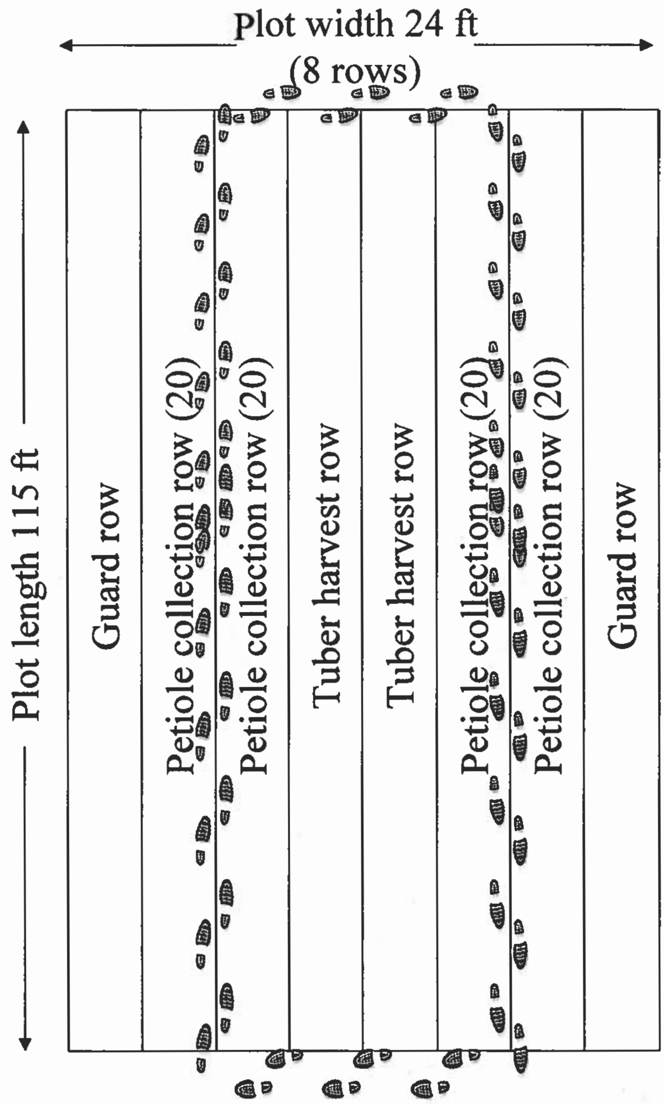


Figure 4. Map of individual 2005 plot, indicating guard rows, petiole collection rows, tuber harvest rows and staff walking paths.



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)

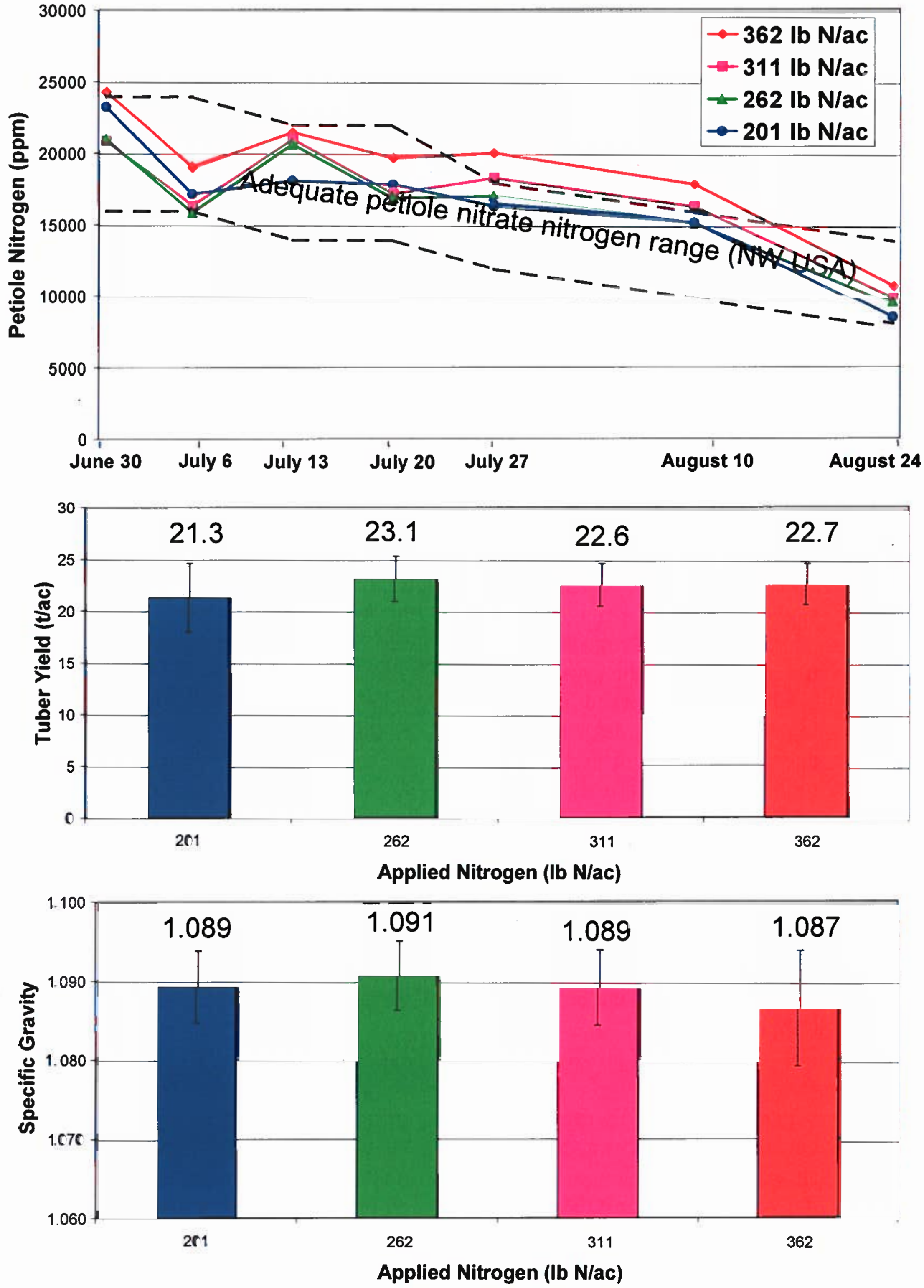
- The highest N rate (Treatment 4: 367 lb N/ac) consistently showed the highest petiole nitrate N (NO_3-N) concentration (Figure 6a) but not by a large margin. The lowest N rate (Treatment 1: 201 lb N/ac) actually had the second-highest average petiole N concentration for the first, second and fourth 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)

b)

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).

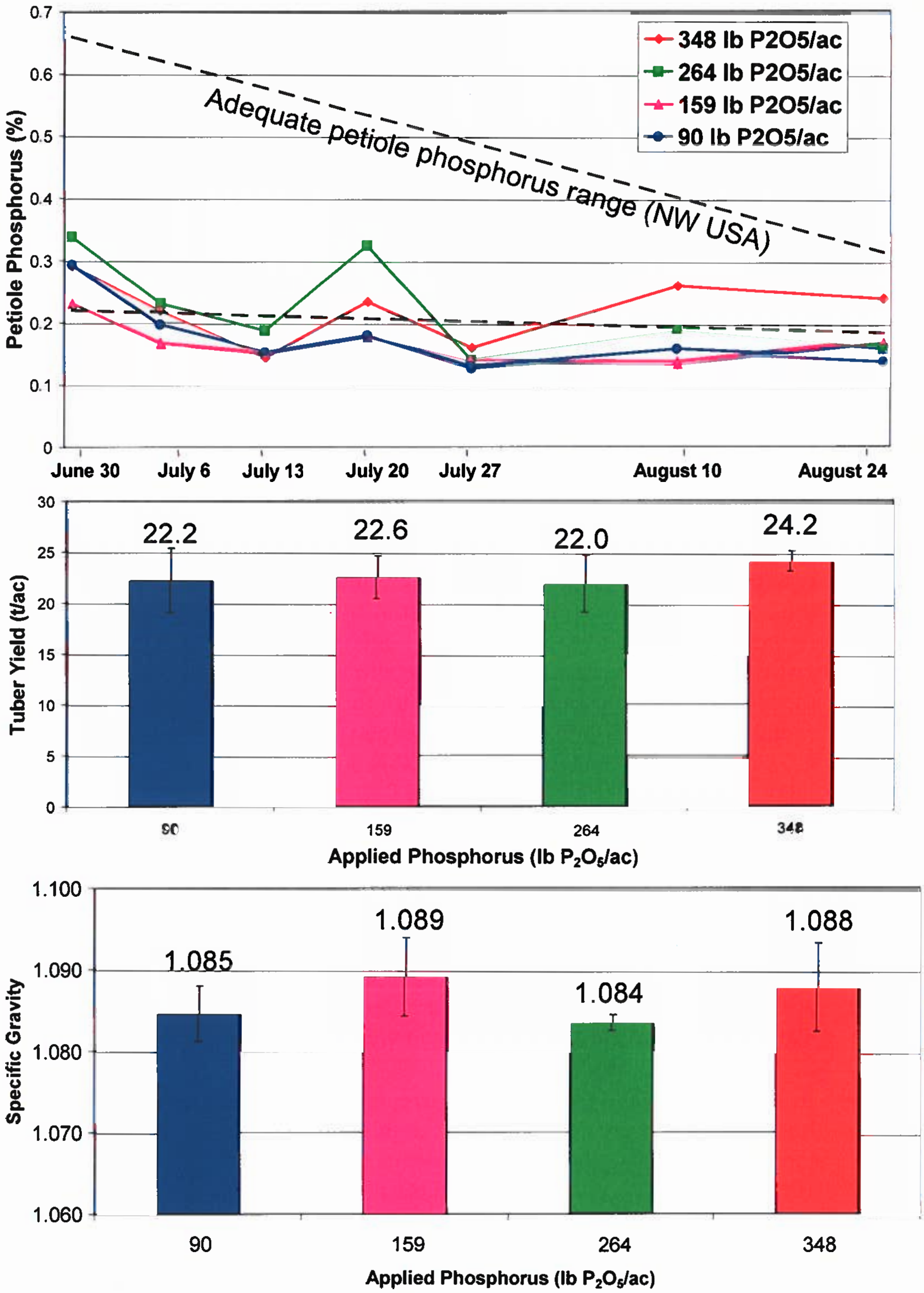
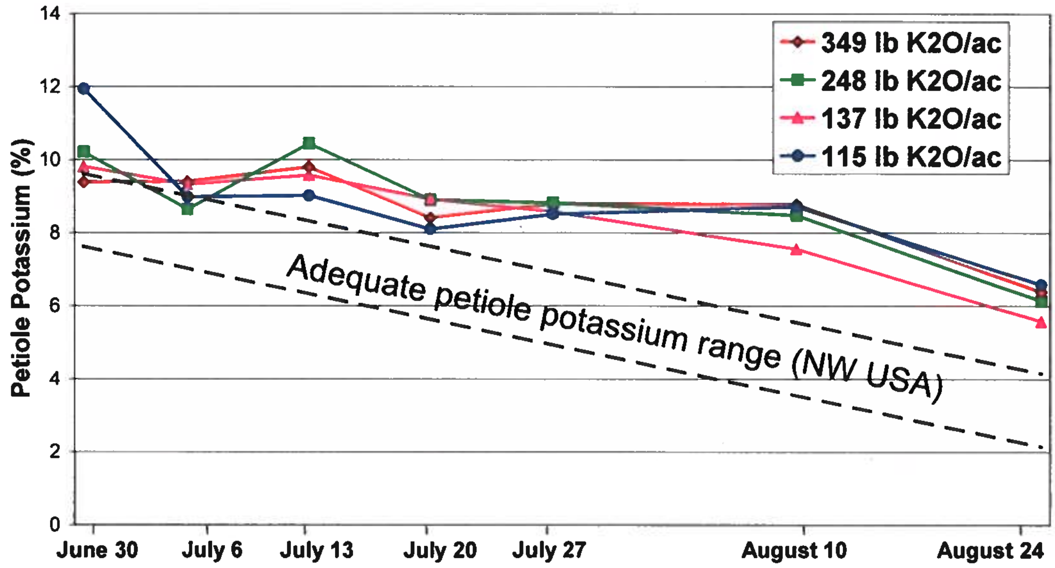
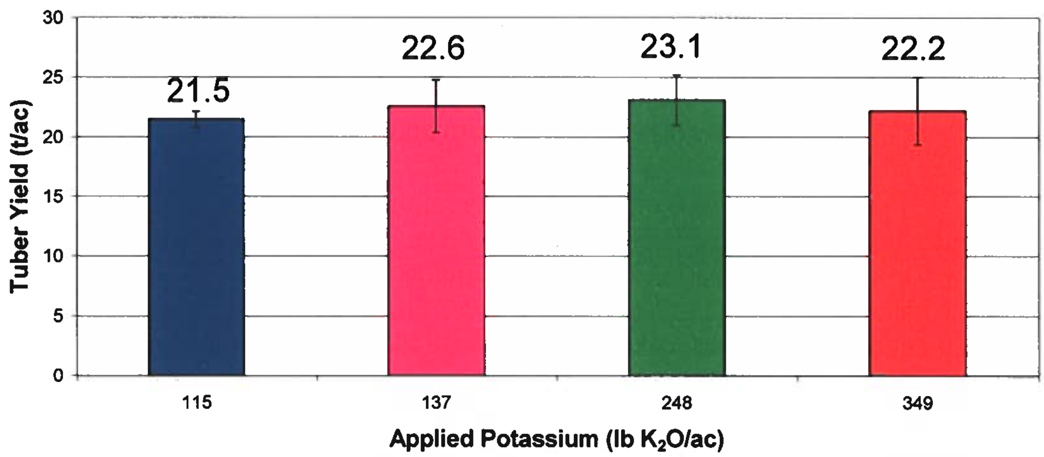


Figure 8. Potato petiole K, marketable yield and specific gravity for four different K fertilizer rates (2005).

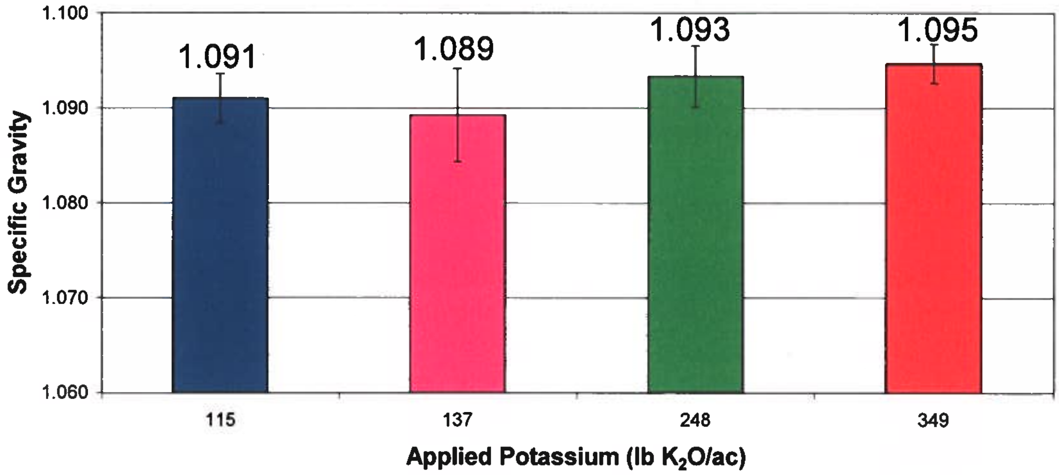
a)



b)



c)



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.

$$\textbf{Petiole } NO_3\textbf{-N (ppm)} = -153.7 * DAP + 32826 \qquad (r^2 = 0.43)$$

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.

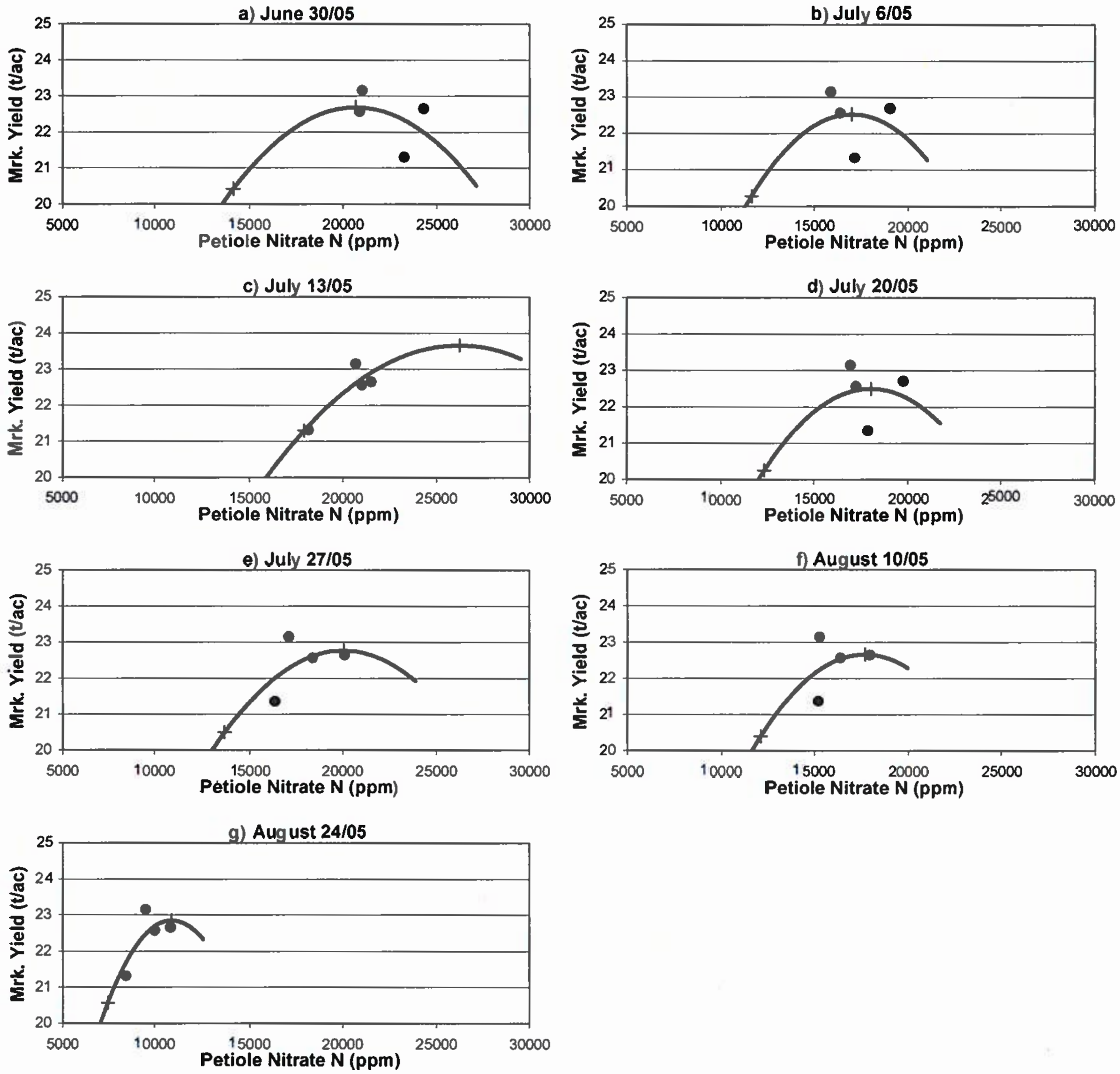


Figure 10. Russet Burbank potato tuber yield (t/ac) as a function of petiole phosphorus (%), showing data points, fitted second order curve and the 100%RY and 90%RY values, for seven 2005 petiole sampling dates.

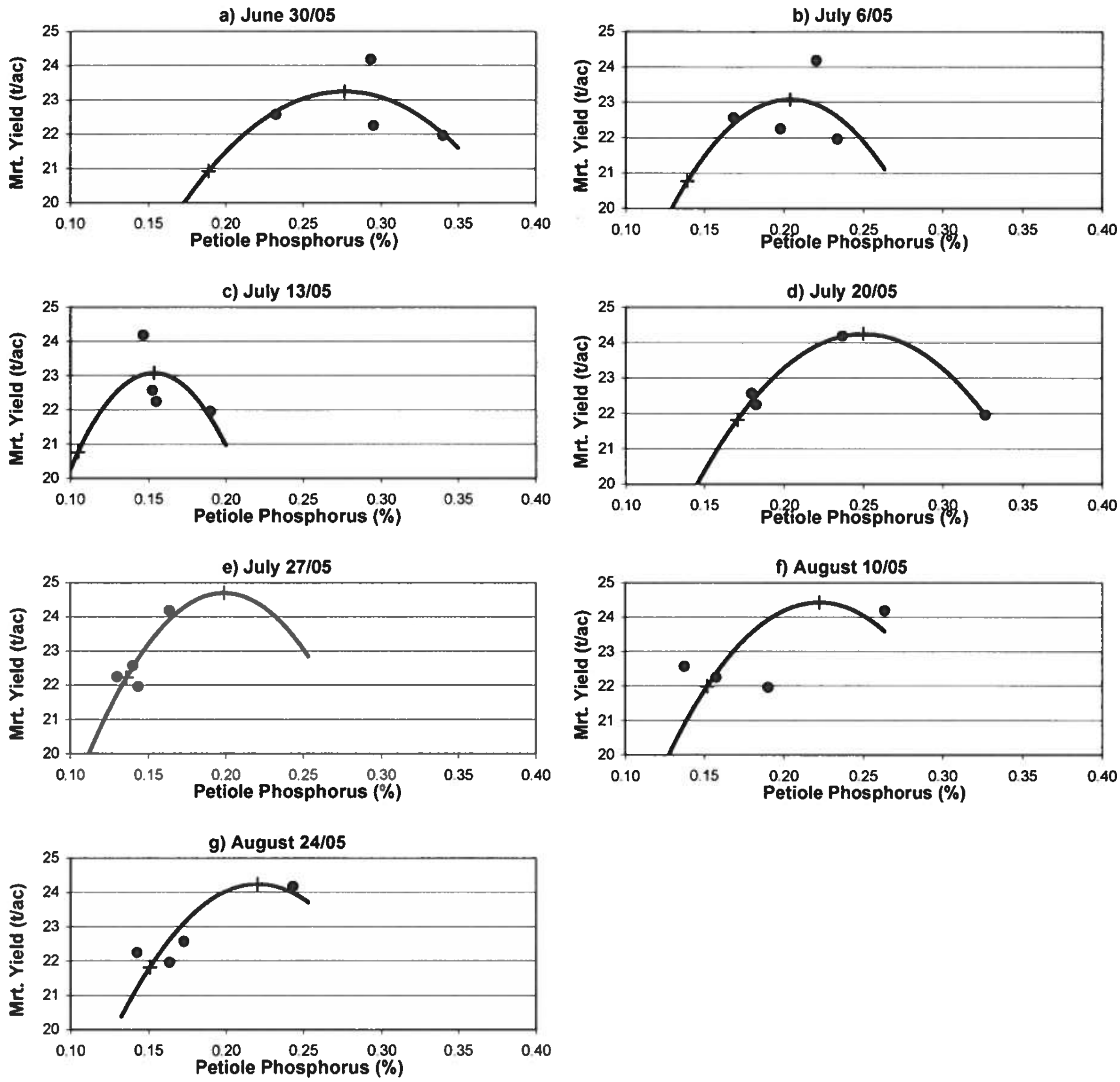


Figure 11. Russet Burbank potato tuber yield (t/ac) as a function of petiole potassium (%), showing data points, fitted second order curve and the 100%RY and 90%RY values, for seven 2005 petiole sampling dates.

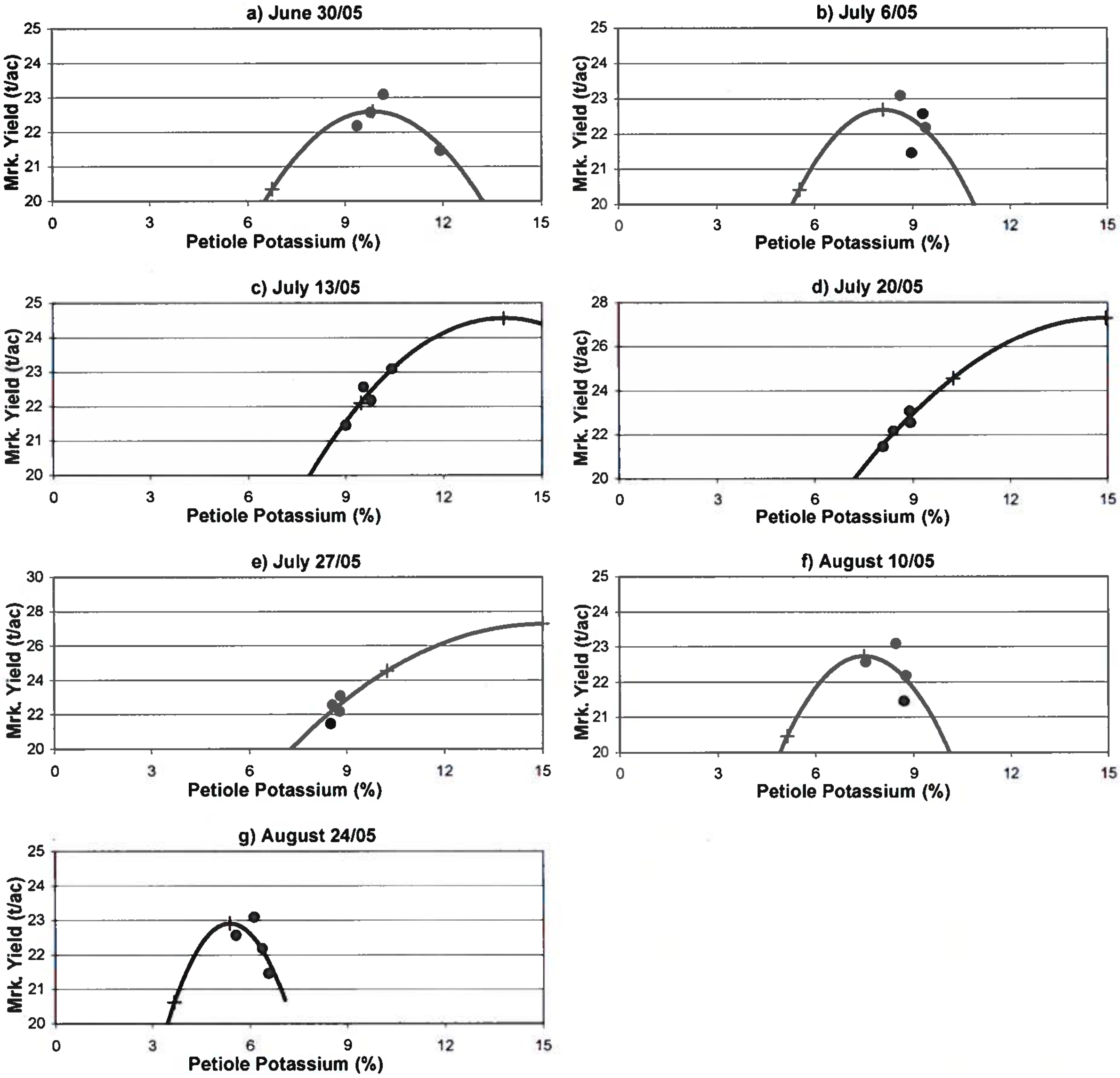
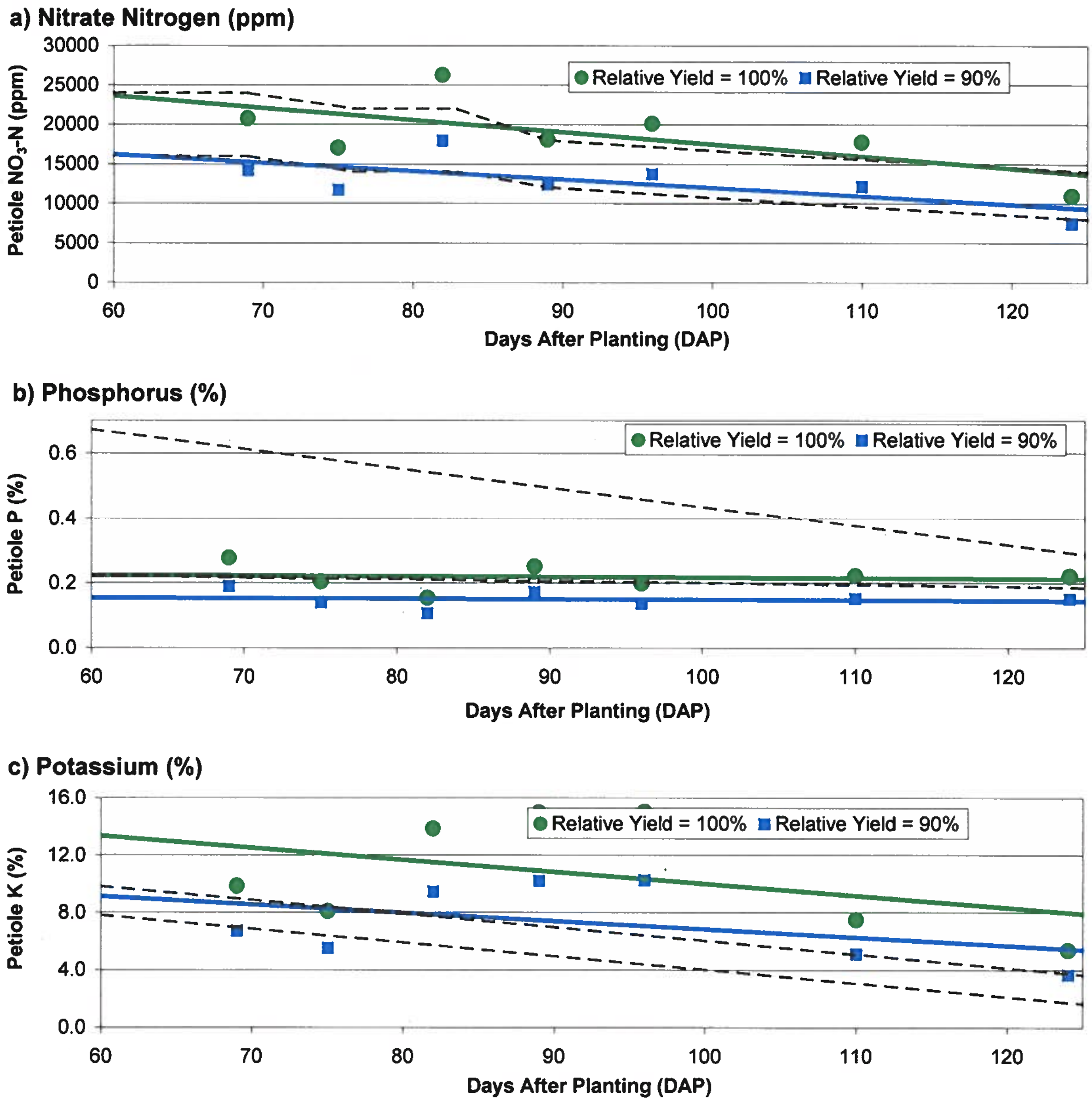
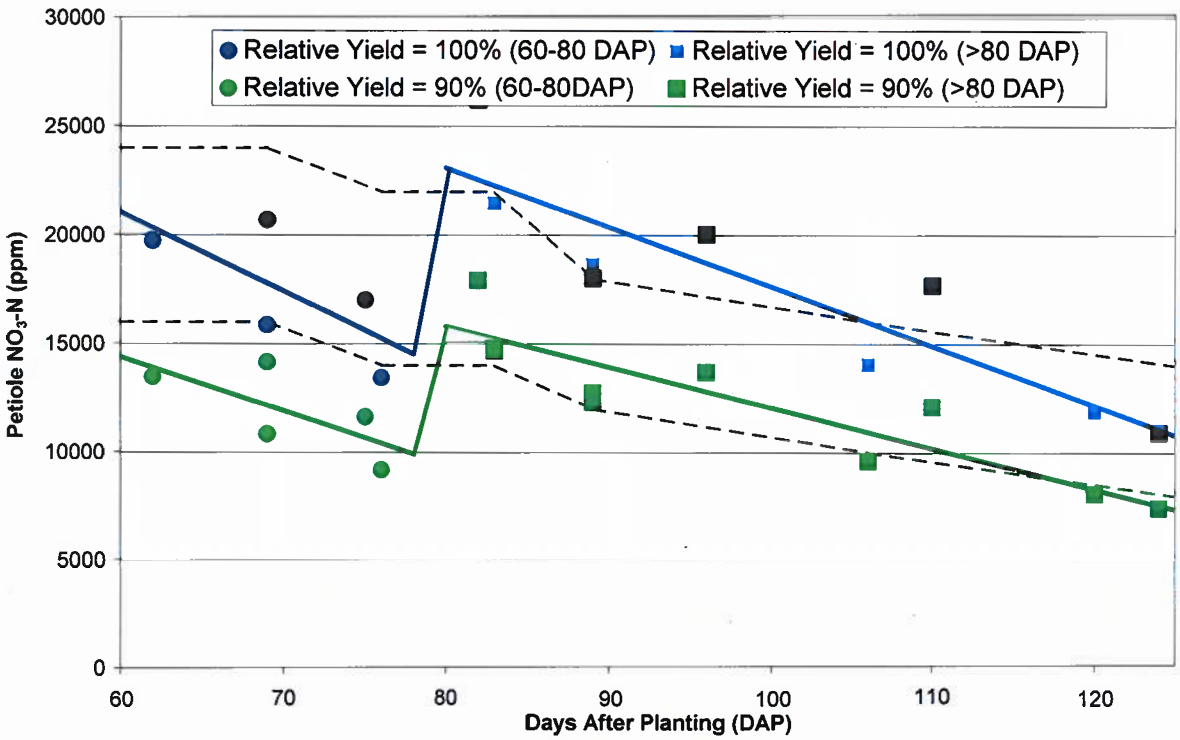


Figure 12. 100%RY and 90%RY petiole (a) nitrate nitrogen, (b) phosphorus and (c) potassium concentration as a function of days after planting, for the 2005 Taber site.





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**

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

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ABSTRACT

A 3-yr project was conducted by Alberta Agriculture and Rural Development (ARD) staff, with the financial support of the Potato Growers of Alberta (PGA). The goals of the project were to determine the optimal petiole nutrient concentrations for Russet Burbank potatoes, specific to 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 is 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 the 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 lower 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 higher 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.

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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

In 2004, a three-year research project was initiated by Alberta Agriculture and Rural Development (ARD), with the support of the Potato Growers of Alberta (PGA) to address the discrepancies between current petiole recommendations and previously-observed data. The project had the following goals. The main objective was to determine the optimal petiole nutrient concentrations for Russet Burbank potatoes, specific to 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 located approximately 15 km east of Taber, Alberta (Fig. 1) on a coarse-textured Orthic Brown Chernozem. In 2005, the project was conducted on a field 10 km south of Taber, Alberta (Fig. 1) on a medium-textured Orthic Brown Chernozem. 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 Chernozem.

Figure 1. Petiole study site locations (map created using the Alberta Soil Information Viewer, Alberta Agriculture and Rural Development, 2008).

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 was not collected for these.

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. 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. So, 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
Phosphoru	**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
Phosphoru	**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
Phosphoru	**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 seven times throughout the growing season, 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 sample date.

Within each plot, approximately 20 petioles each 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 not eight. This was because the cooperating grower utilizes 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.

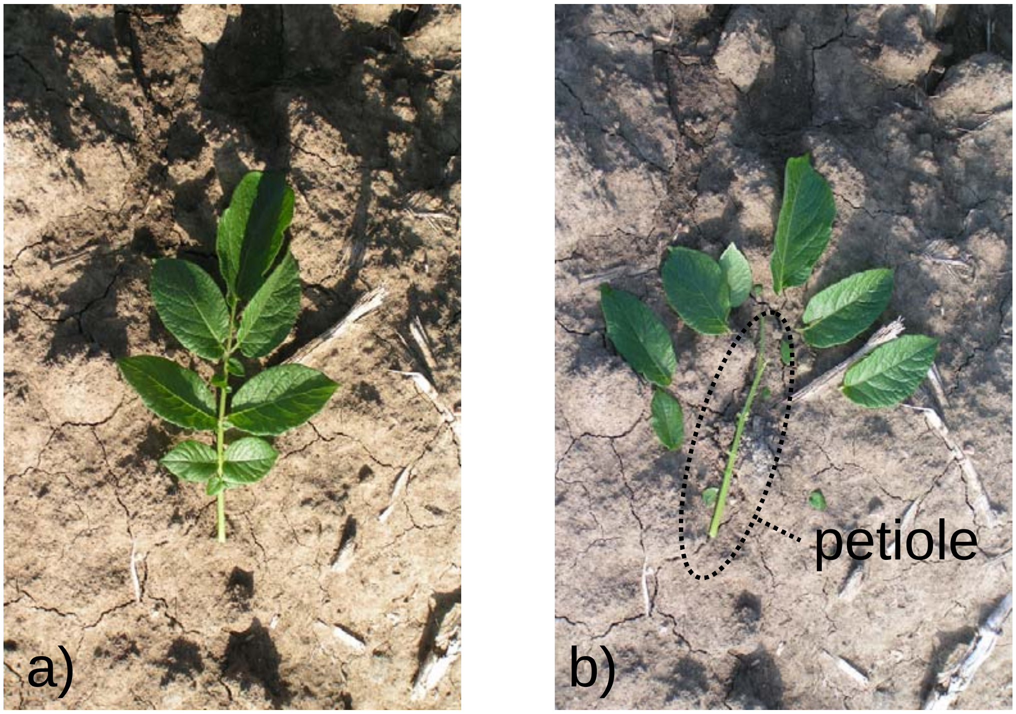

Figure 2. Russet Burbank fourth leaf stem a) before and b) after removal of leaves (petiole shown in dashed circle).

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 by the weight in air over 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.

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 forty 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. Taber monthly average temperature and rainfall for 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 of a hailstorm that 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 highest petiole NO_3-N concentration (Fig. 3a). Early in the growing season, petiole NO_3-N concentration in all but the highest 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 highest N rate (Treatment 4: 362 lb N/ac) in 2005 consistently showed the highest 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-highest 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 highest three 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 highest 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 highest overall yield; however, the treatments were not significantly different (Fig. 4b). Yield data for this treatment was 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 highest 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 higher two rates of N fertilizer (Treatments 3 and 4) had slightly higher 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.

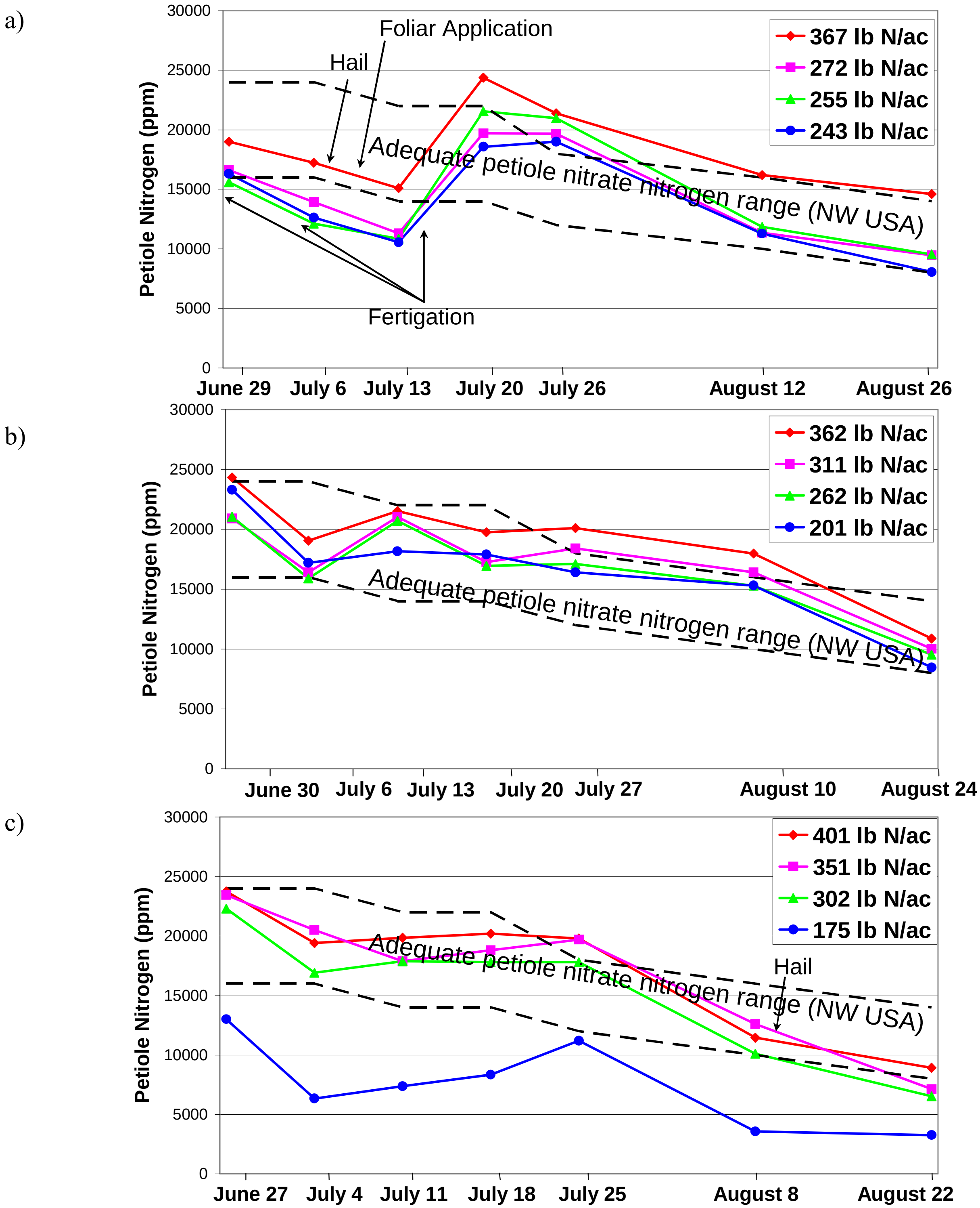

Figure 3. Russet Burbank potato petiole nitrate nitrogen (NO_3-N) concentrations (ppm) for four different N fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Dashed black lines correspond to upper and lower suggested limits used in the northwest USA.

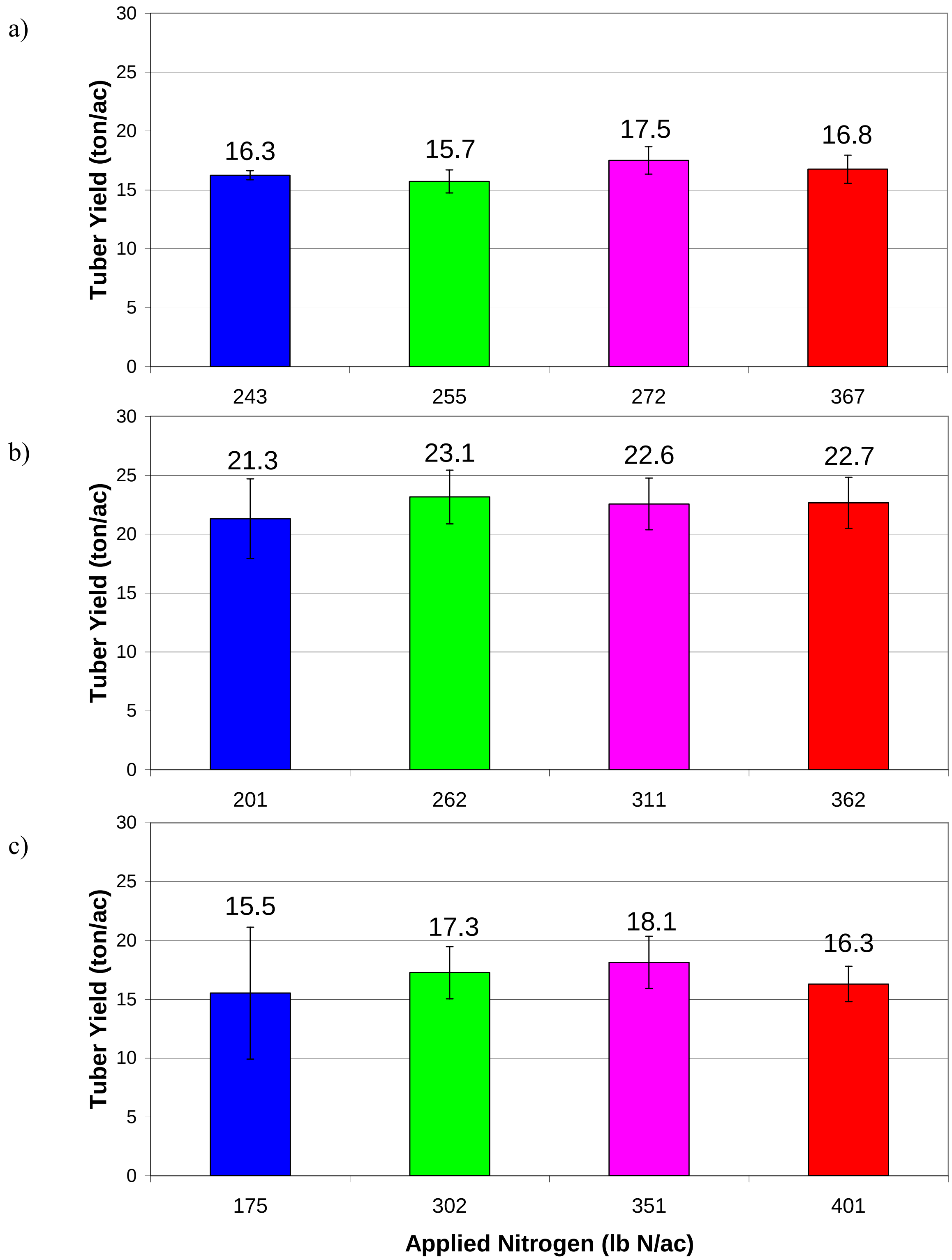

Figure 4. Russet Burbank potato marketable yield (ton/ac) for four different N fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Error bars indicate standard deviations. Differences among treatments for which error bars overlap are not statistically significant.

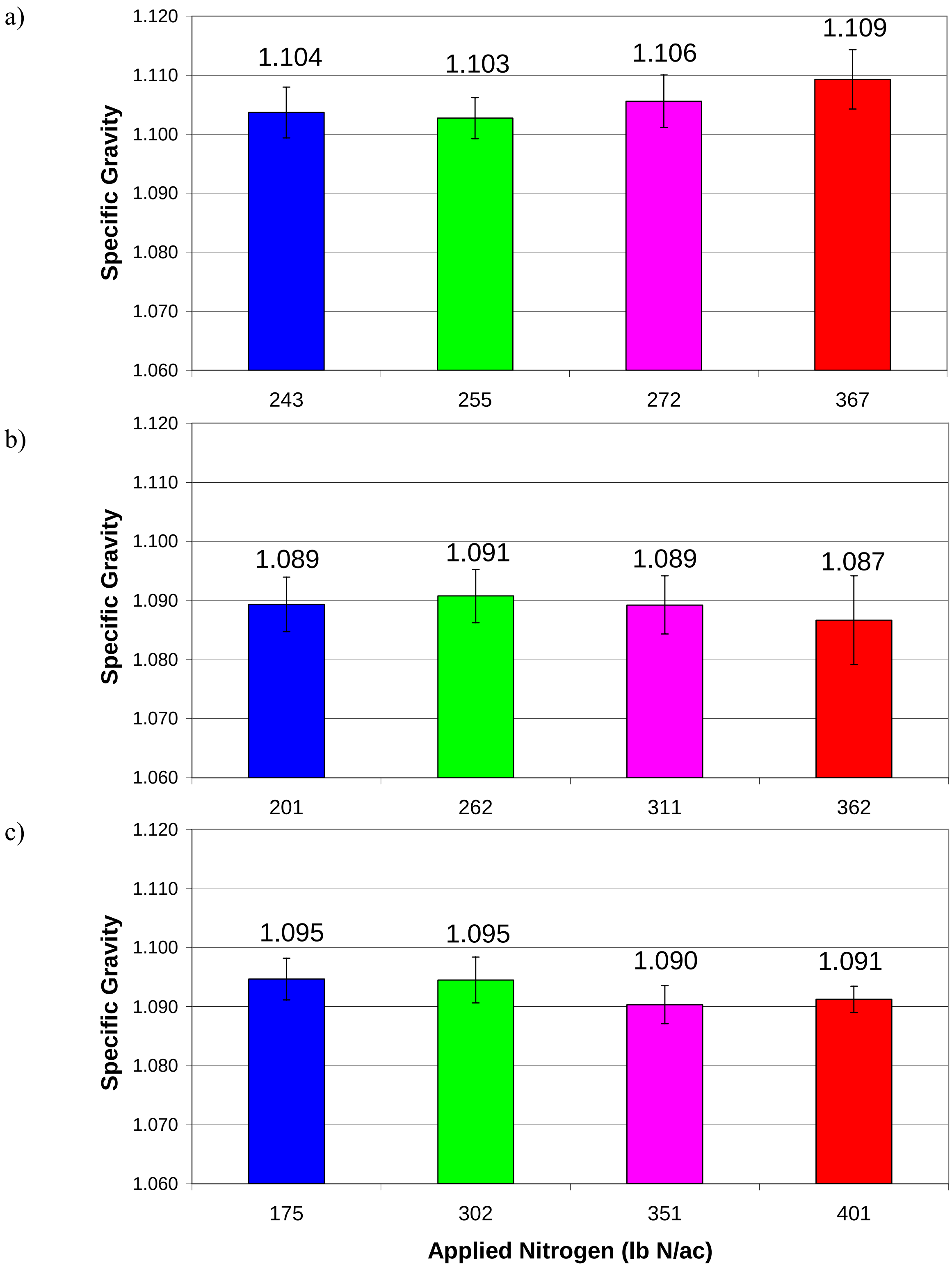

Figure 5. Russet Burbank potato tuber specific gravity for four different N fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Error bars indicate standard deviations. Differences among treatments for which error bars overlap are not statistically significant.

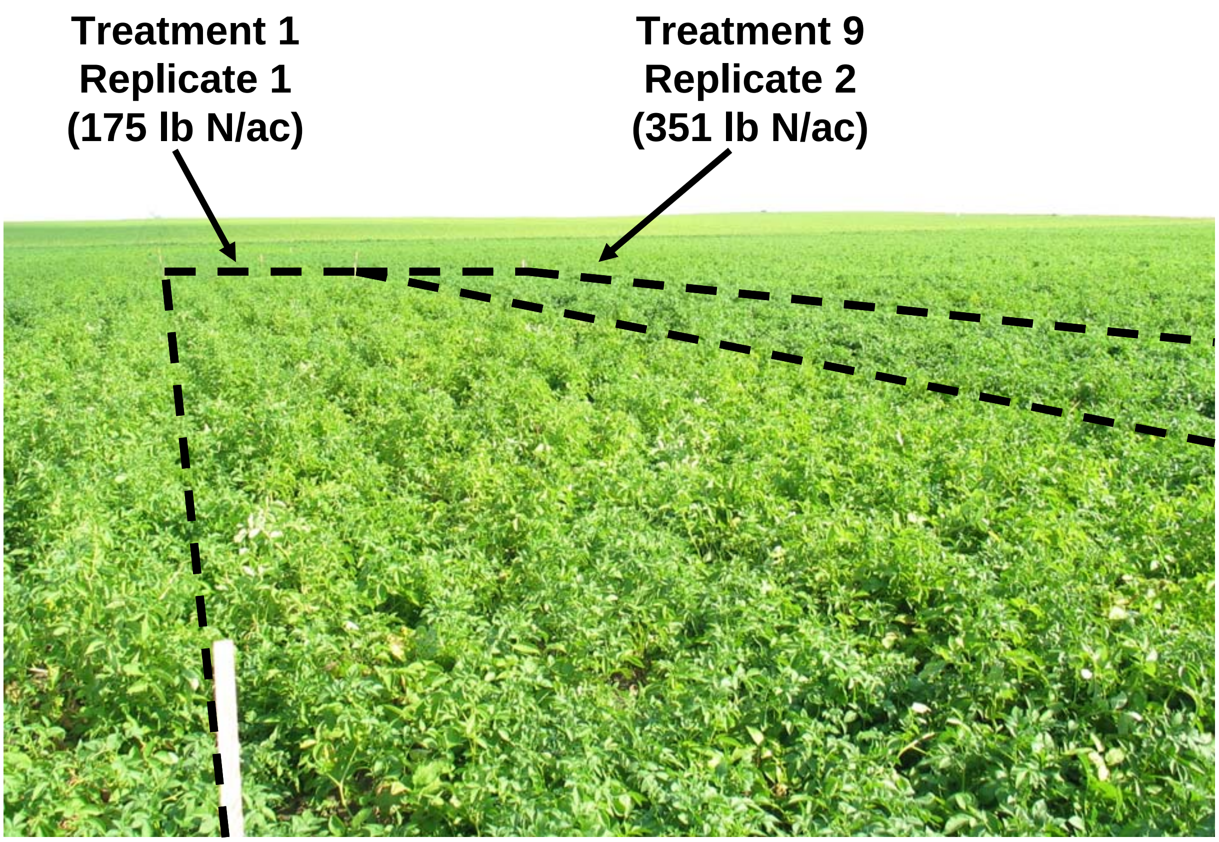

Figure 6. Visible difference in colour of Treatment 1, Rep 1 (175 lb/ac N fertilizer, including 24 lb/ac N added on April 17, 2007) compared to Treatment 9, Rep 2 (351 lb/ac N fertilizer, including 200 lb/ac N added on April 17, 2007), looking north on August 8, 2007 (photo courtesy of Gary Larson, AAFC).

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 higher 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 higher 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 highest 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).

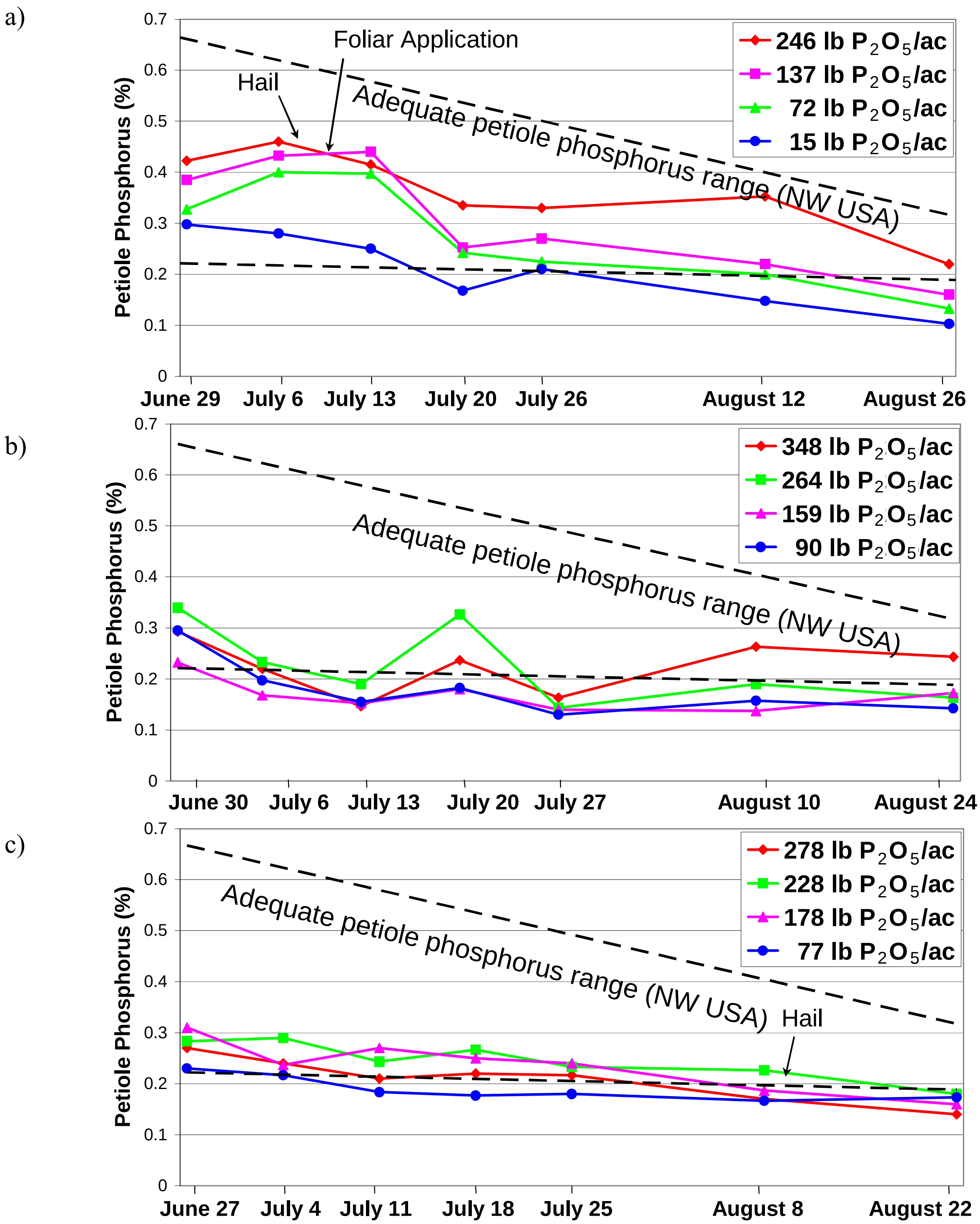

Figure 7. Russet Burbank potato petiole phosphorus concentrations (%) for four different P_2O_5 fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Dashed black lines correspond to upper and lower suggested limits used in the northwest USA.

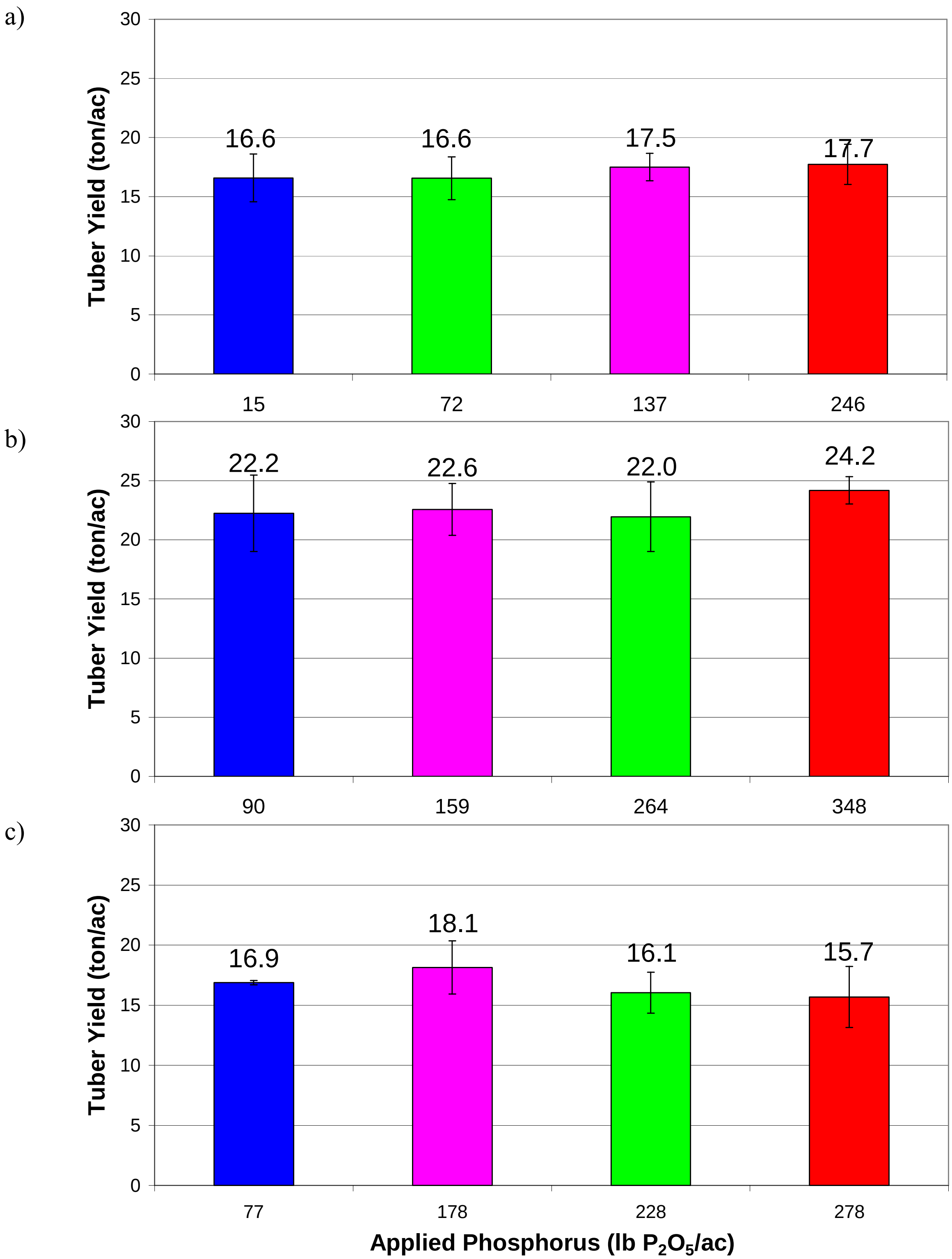

Figure 8. Russet Burbank potato marketable yield (ton/ac) for four different P_2O_5 fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Error bars indicate standard deviations. Differences among treatments for which error bars overlap are not statistically significant.

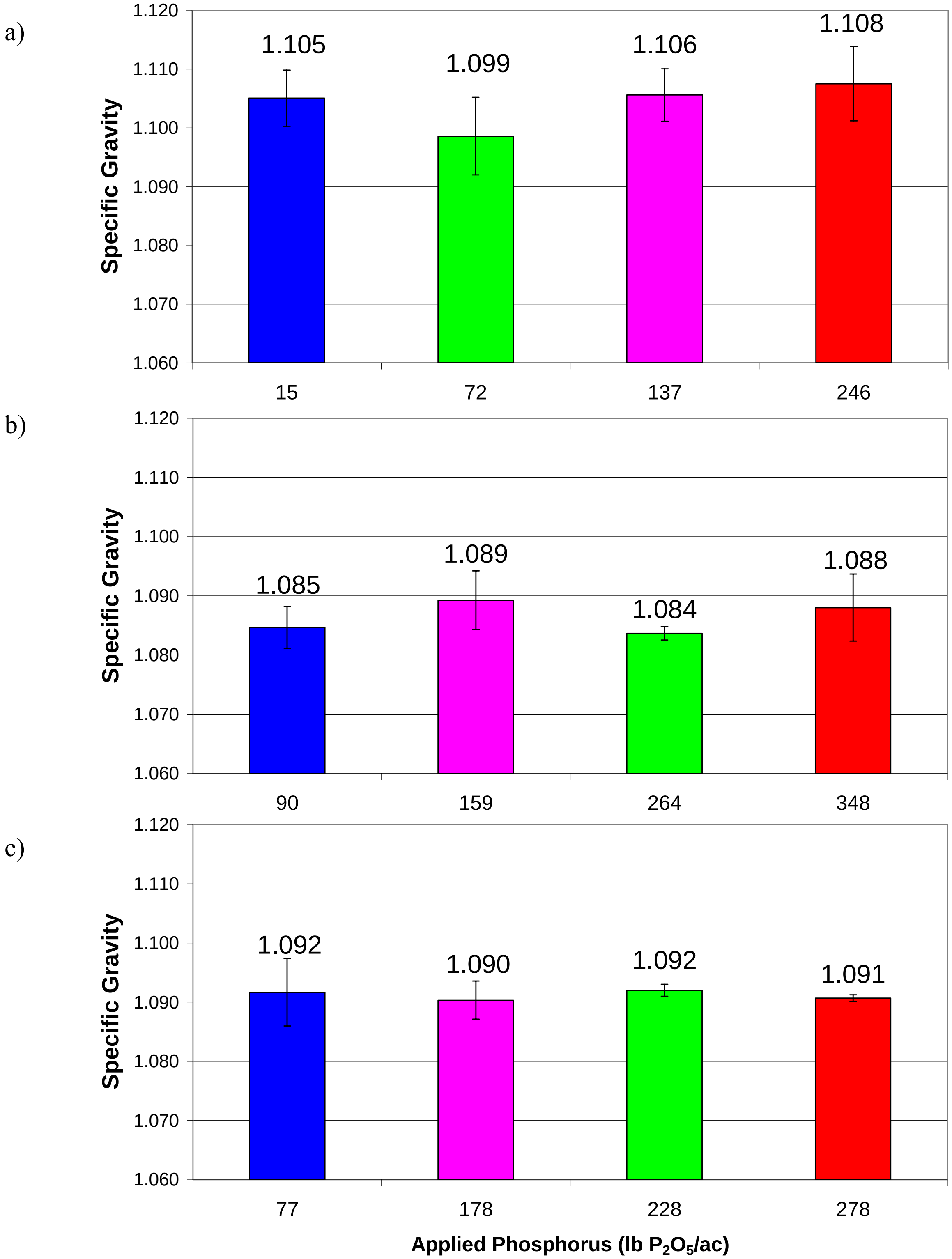

Figure 9. Russet Burbank potato tuber specific gravity for four different P_2O_5 fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Error bars indicate standard deviations. Differences among treatments for which error bars overlap are not statistically significant.

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, in 2007, petiole K results 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).

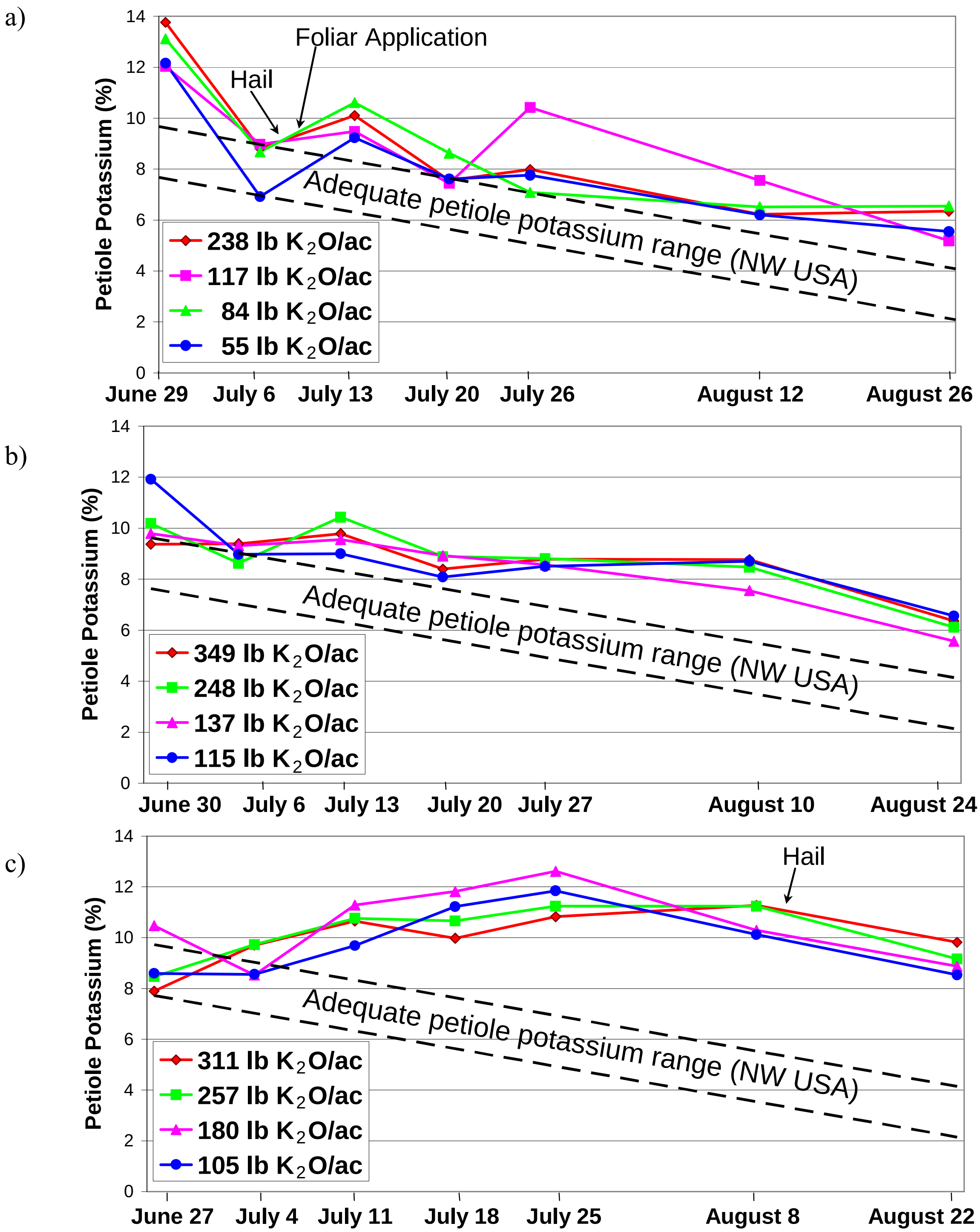

Figure 10. Russet Burbank potato petiole potassium concentrations (%) for four different K2O fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Dashed black lines correspond to upper and lower suggested limits used in the northwest USA.

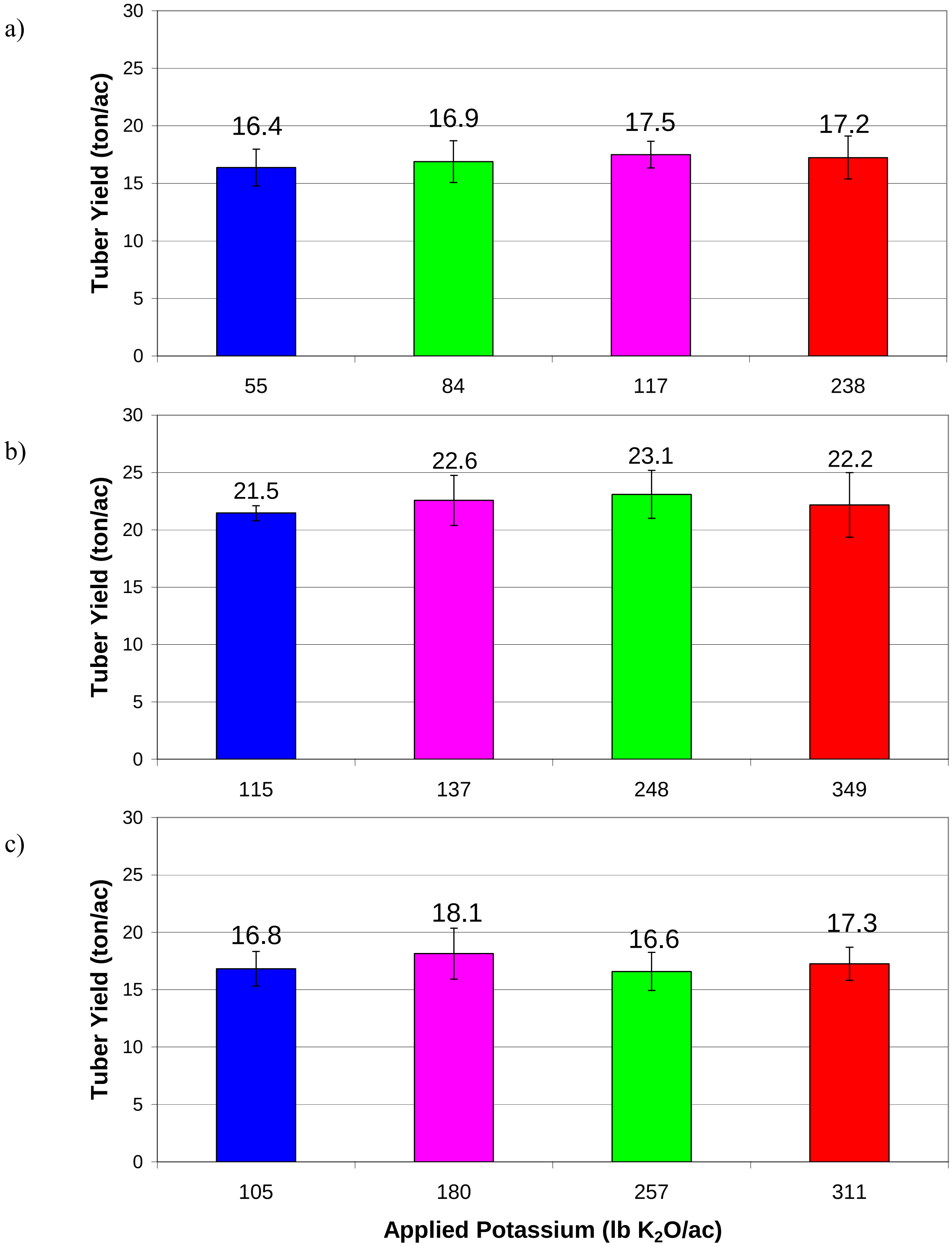

Figure 11. Russet Burbank potato marketable yield (ton/ac) for four different K_2O fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Error bars indicate standard deviations. Differences among treatments for which error bars overlap are not statistically significant.

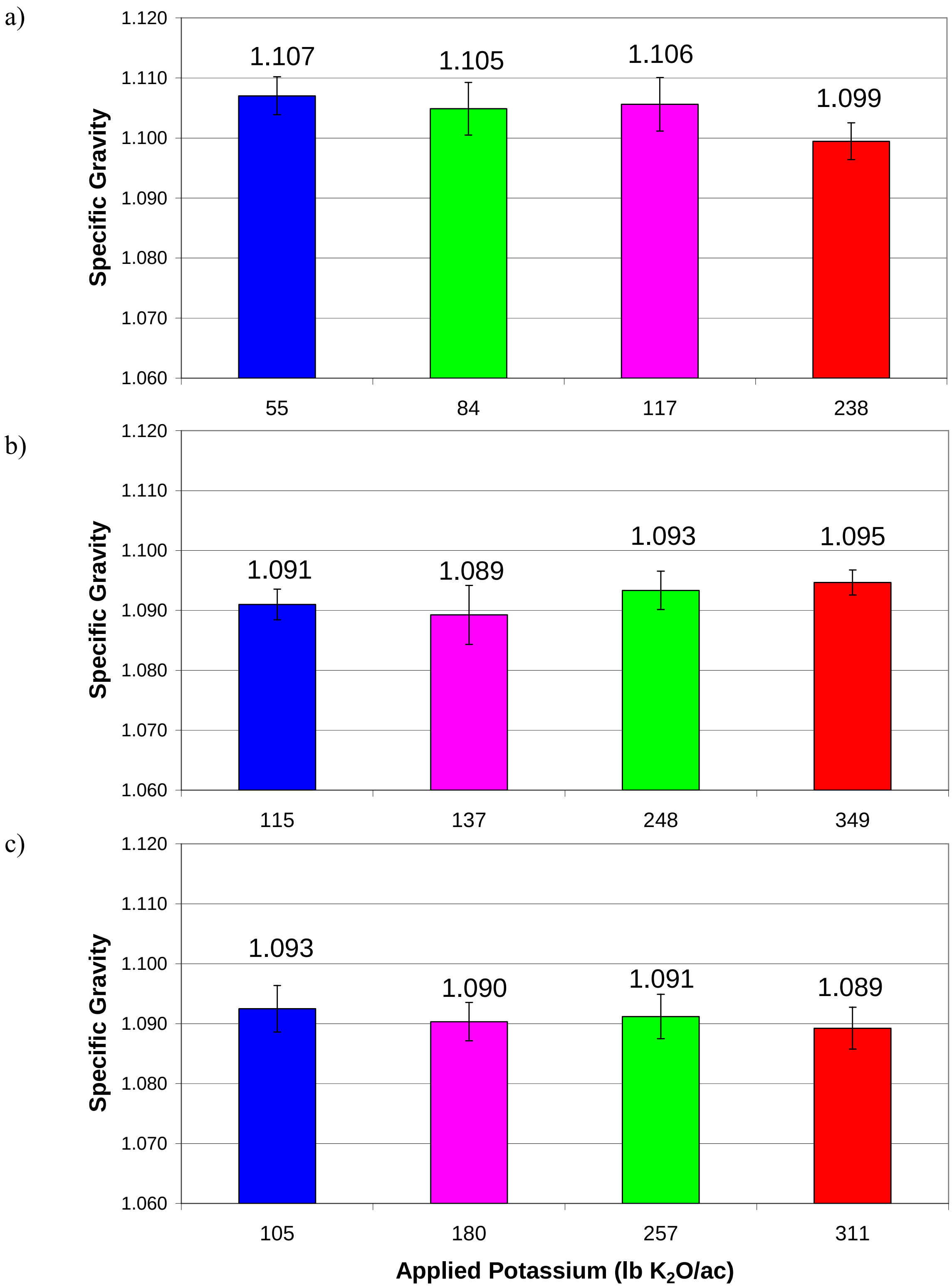

Figure 12. Russet Burbank potato tuber specific gravity for four different K_2O fertilizer rates, in (a) 2004, (b) 2005, and (c) 2007. Error bars indicate standard deviations. Differences among treatments for which error bars overlap are not statistically significant.

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 and 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 higher 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 ($r^2 = 0.73$)

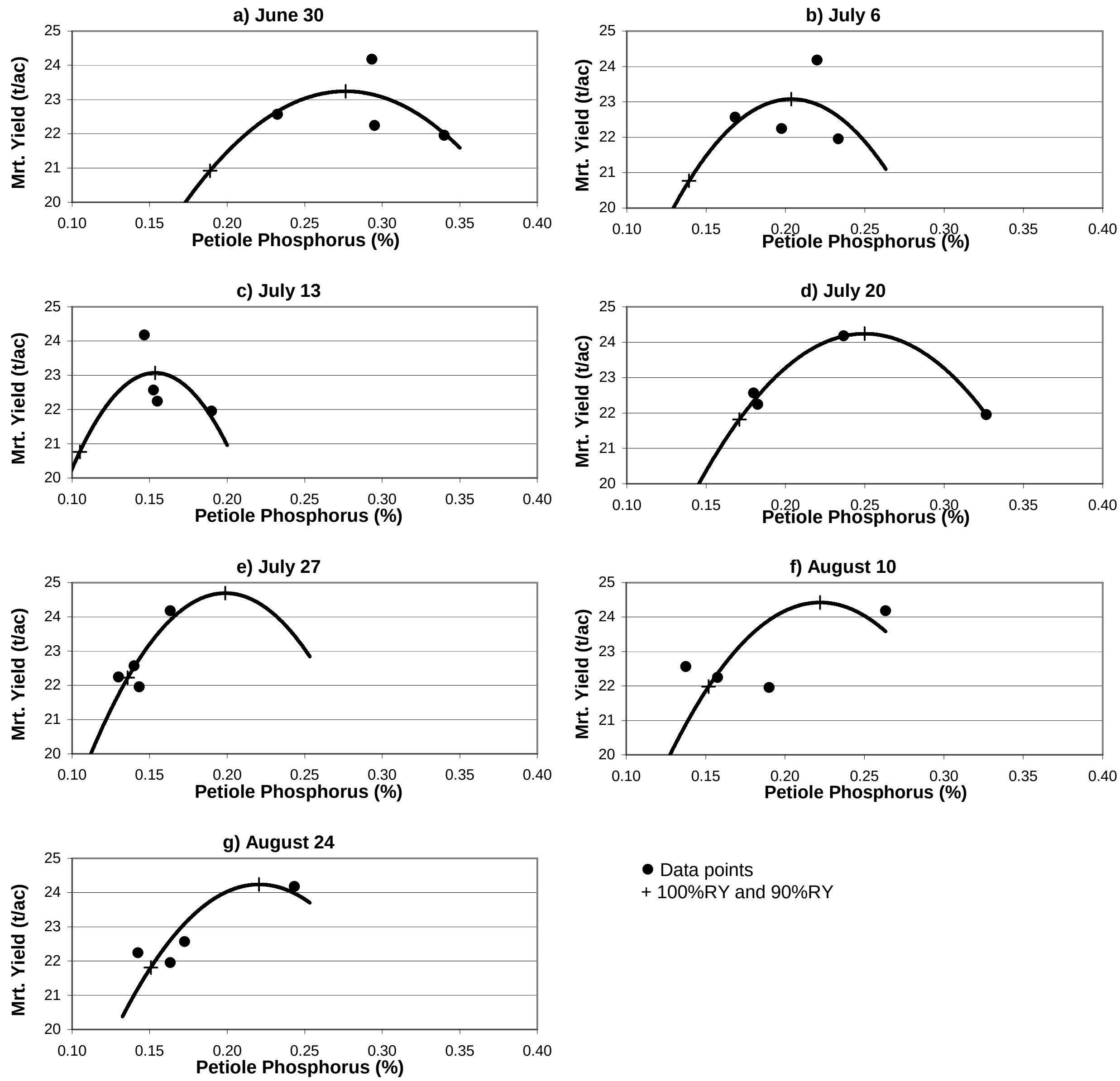

Figure 13. Russet Burbank potato tuber yield (ton/ac) as a function of petiole phosphorus (%), showing actual data points, the fitted second order curve, and the 100% relative yield (100%RY) and 90% relative yield (90%RY) values for seven petiole sampling dates in 2005.

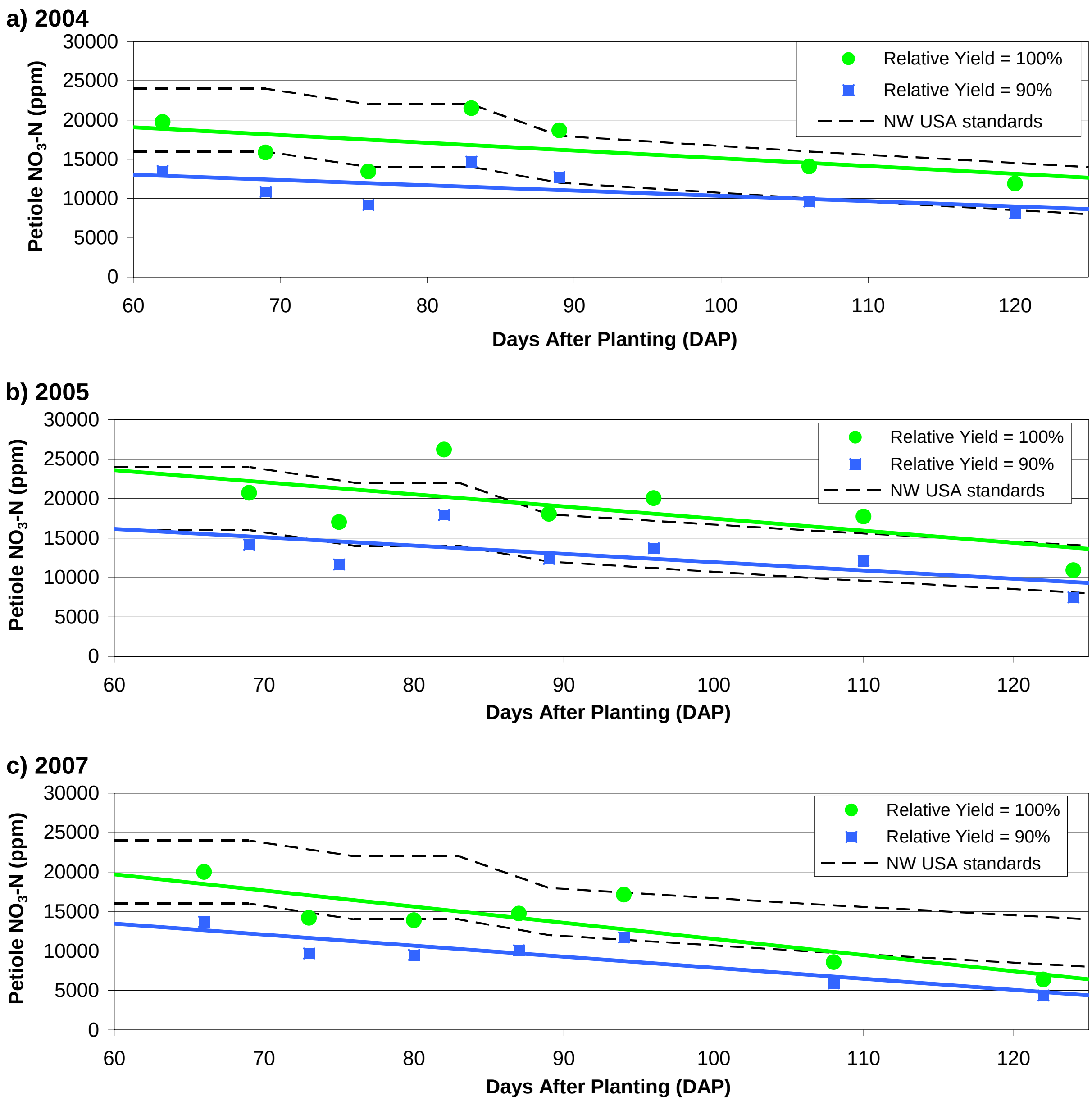

Figure 14. 100% relative yield (RY) and 90% relative yield petiole nitrate nitrogen (NO_3-N) concentration as a function of days after planting in (a) 2004, (b) 2005, and (c) 2007.

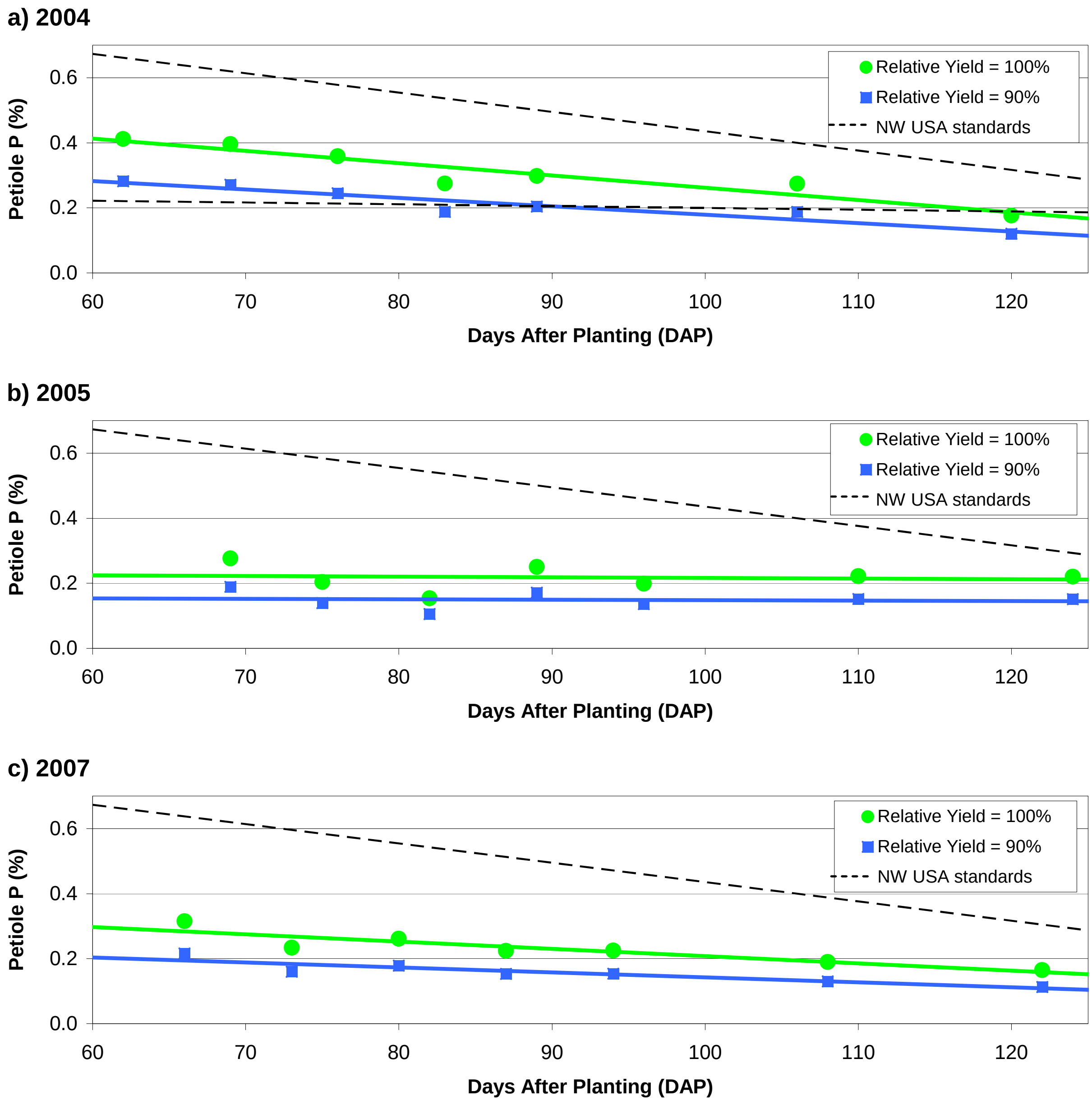

Figure 15. 100% relative yield (RY) and 90% relative yield petiole phosphorus concentration as a function of days after planting in (a) 2004, (b) 2005, and (c) 2007.

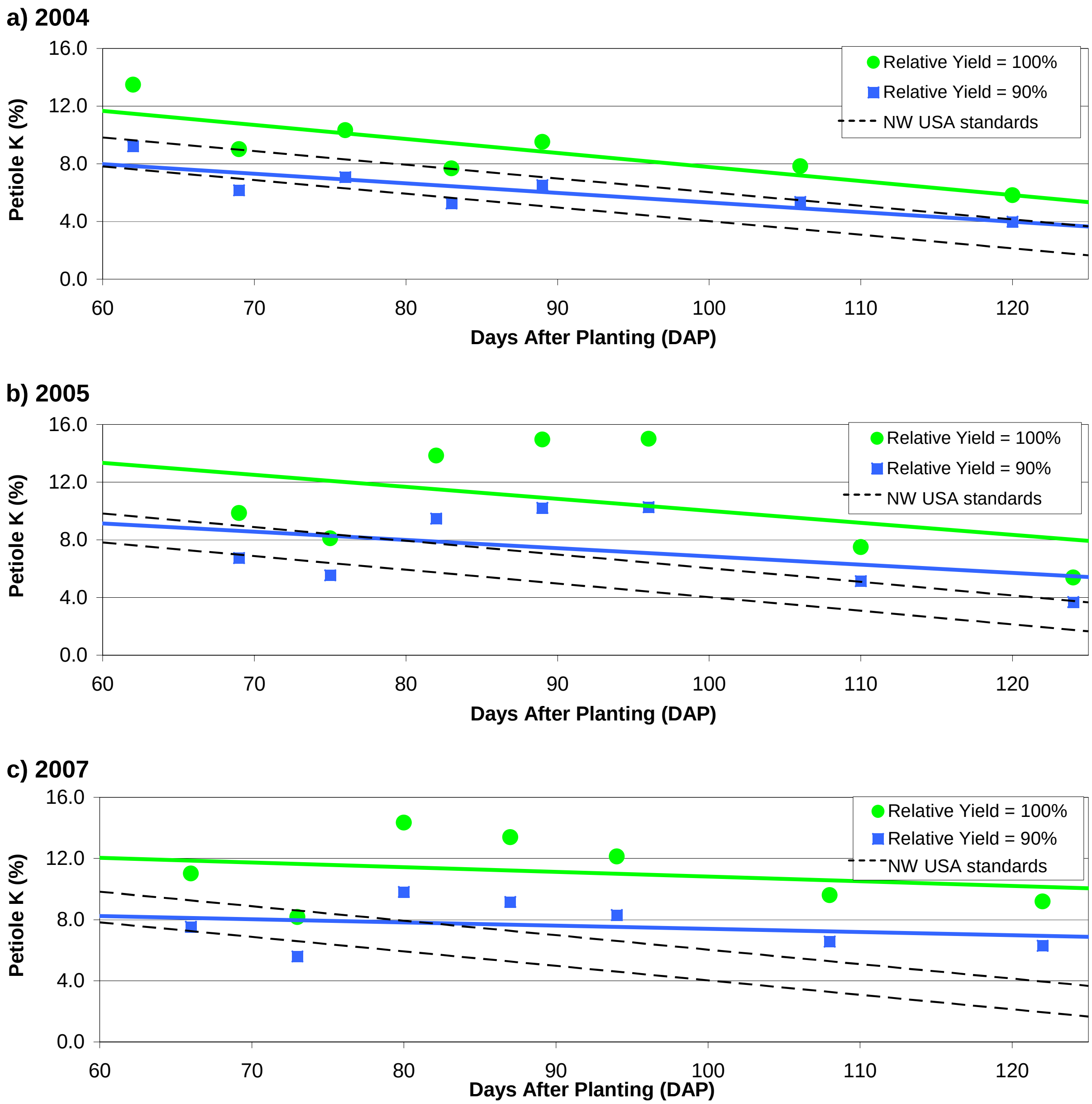

Figure 16. 100% relative yield (RY) and 90% relative yield petiole potassium concentration as a function of days after planting in (a) 2004, (b) 2005, and (c) 2007.

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 dates greater than 80 DAP (Fig. 17a). It is suggested that there should be two sets of ranges, one set for dates prior to and including approximately 80 DAP and another set for dates 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 dates 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 dates 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 dates prior to approximately 80 DAP and another set for dates 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 dates 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

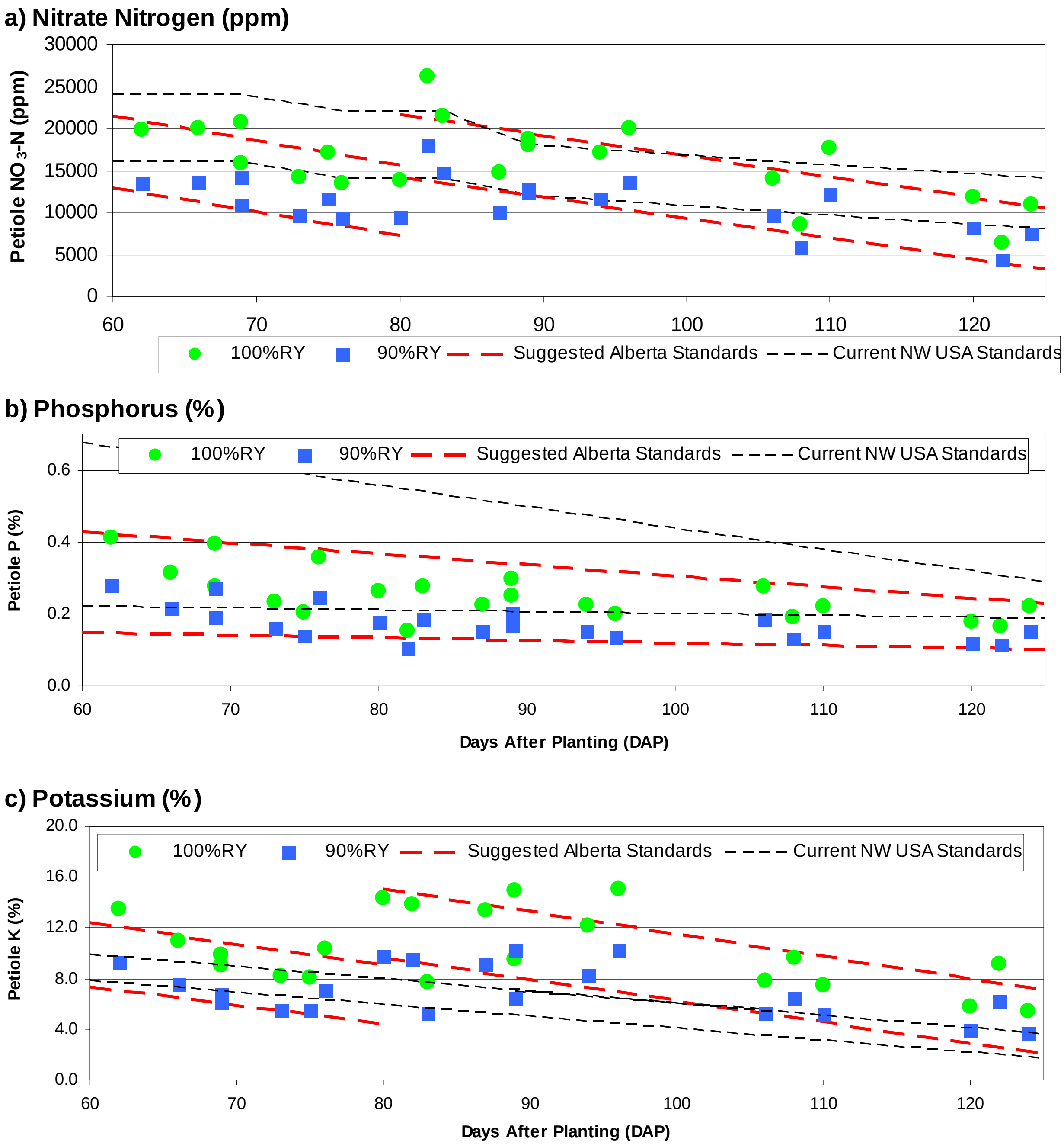

Figure 17. Suggested optimal petiole NO_3-N, P, and K concentrations for southern Alberta compared to current northwest USA recommendations and to the 100%RY and 90%RY data collected in 2004, 2005, and 2007.

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.

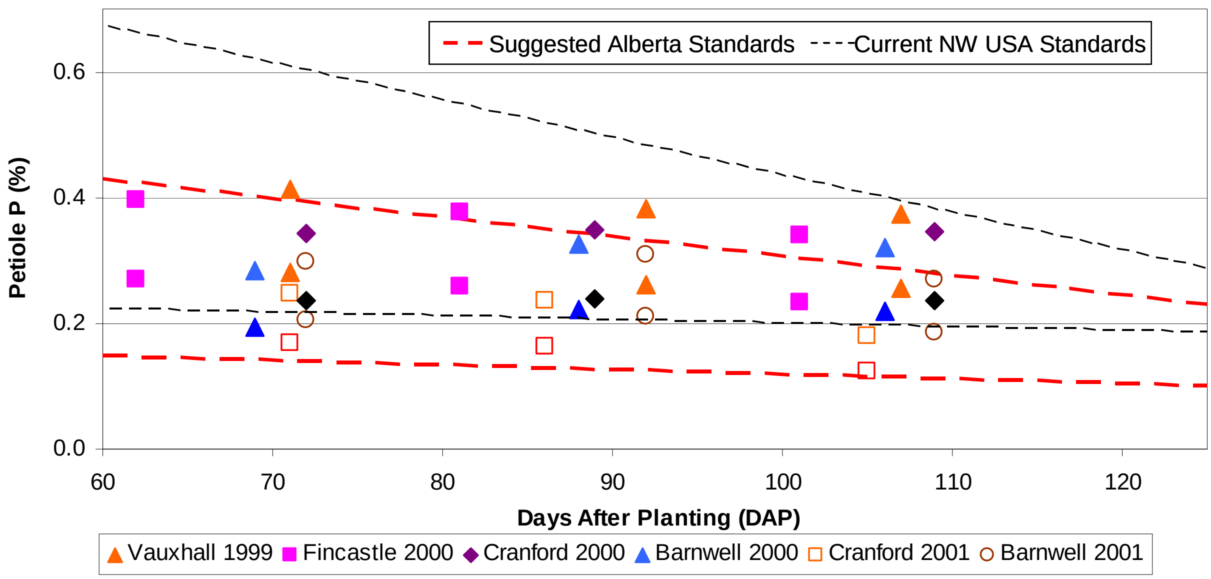

Figure 18. 100% relative yield (RY) phosphorus concentration as a function of days after planting, for six previously-completed PGA-sponsored studies.

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 (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 the 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.

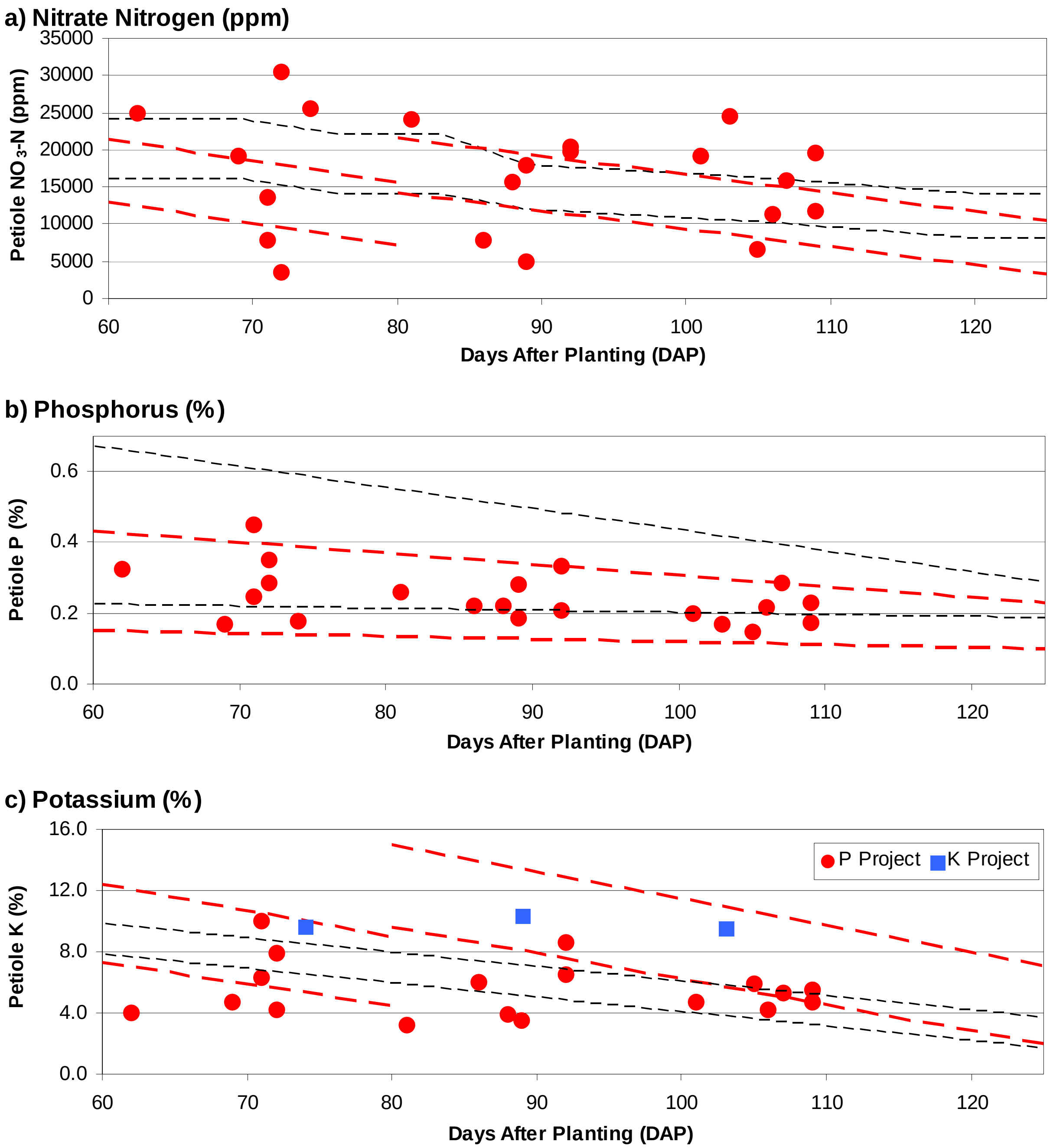

Figure 19. Petiole (a) nitrate nitrogen, (b) phosphorus, and (c) potassium concentration for treatment with highest yield as a function of days after planting for previously-completed PGA-sponsored studies.

The potential effects of climate reinforces 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.

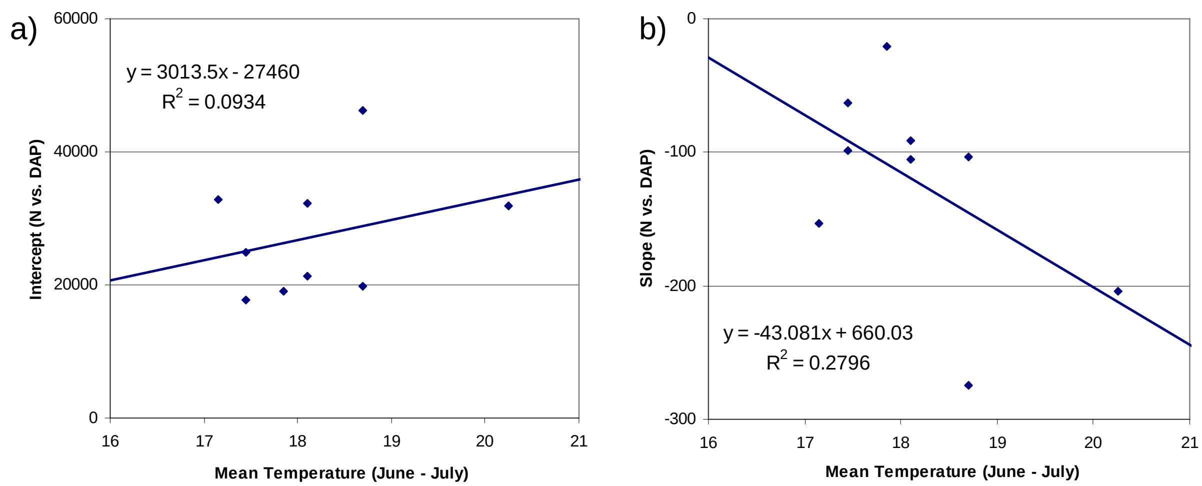

Figure 20. Climate effects on petiole nitrate nitrogen as exhibited by the relationship between the (a) intercept and (b) slope of the NO_3-N *versus* DAP best-fit lines as a function of mean temperatures in June and July for each year that data were available.

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.

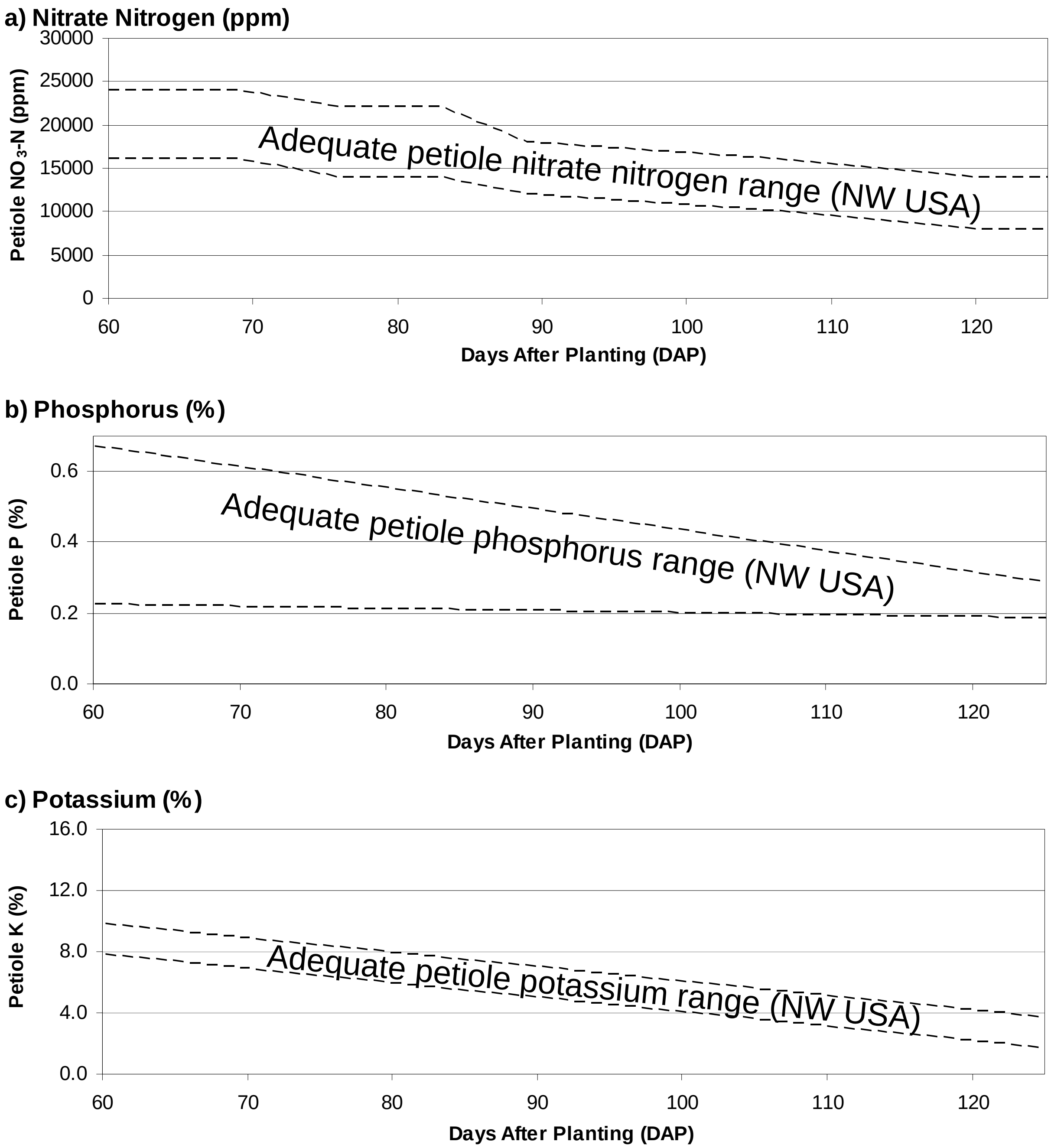

Figure 21. Current petiole nutrient (NO_3-N, P, and K) concentration recommendations based on information from the northwest United States (NW USA).

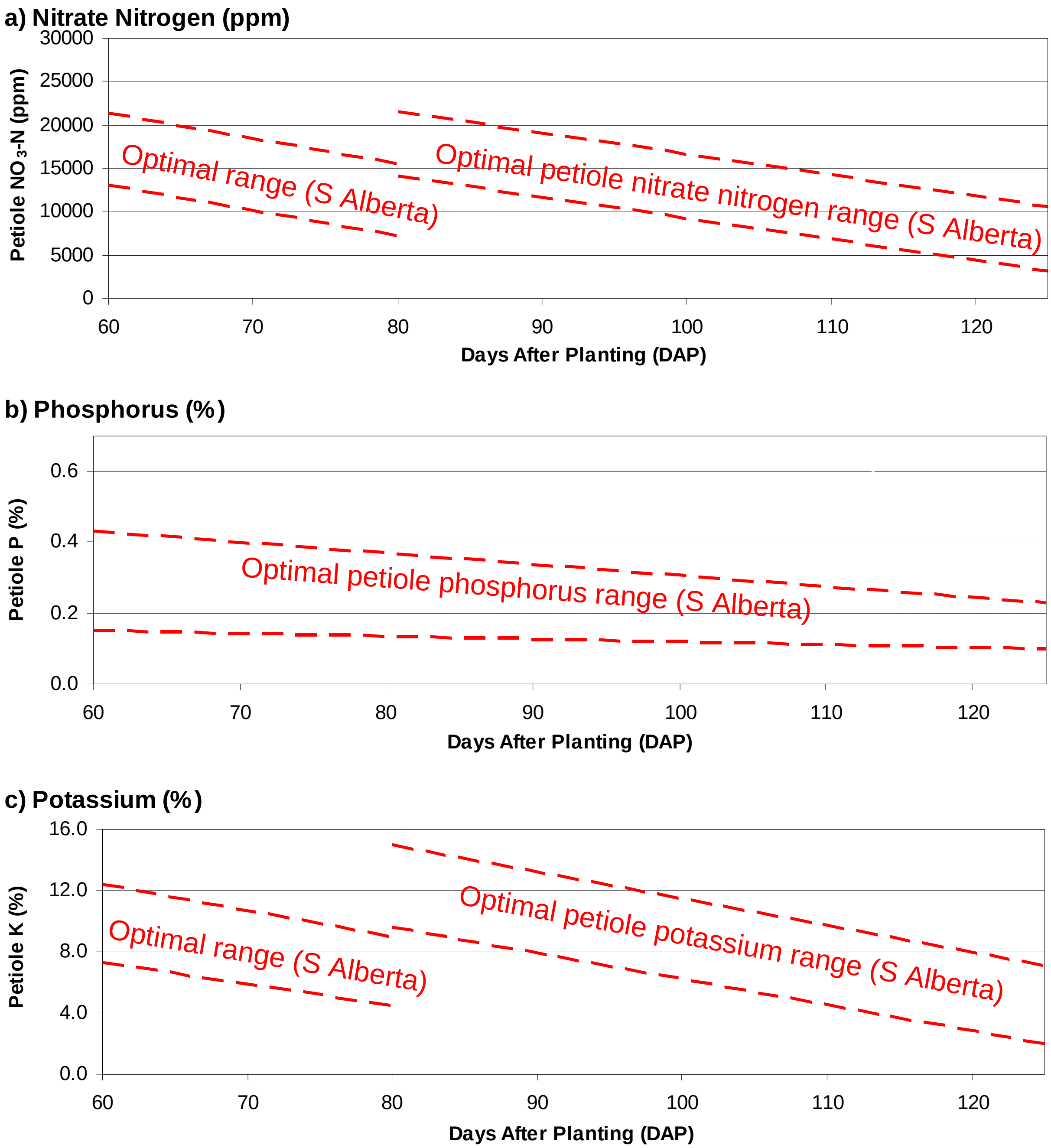

Figure 22. Suggested Russet Burbank petiole nutrient (NO_3-N, P, and K) concentration recommendations based on information from southern Alberta.

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 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.

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Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta (2007)

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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 petioles has been used to monitor nutrient status throughout the growing season; a useful and timely technique for monitoring mid-season nutrient deficiencies.
- Currently recommended petiole nutrient concentrations are from research conducted in the northwest United States, where longer growing seasons and different soil and climate conditions prevail.
- Results from previous studies in southern Alberta indicated that the current recommendations may be high for K and somewhat high for P, especially early in the growing season. Results also indicated that recommended NO_3-N concentrations may need fine-tuning to suit southern Alberta growing conditions.

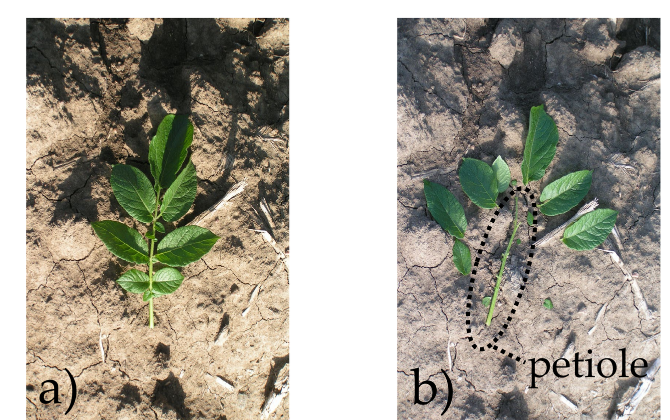

Figure 2. Russet Burbank 4th leaf stem before (a) and after (b) removal of leaves.

Figure 3. Hail damage Aug 2007.

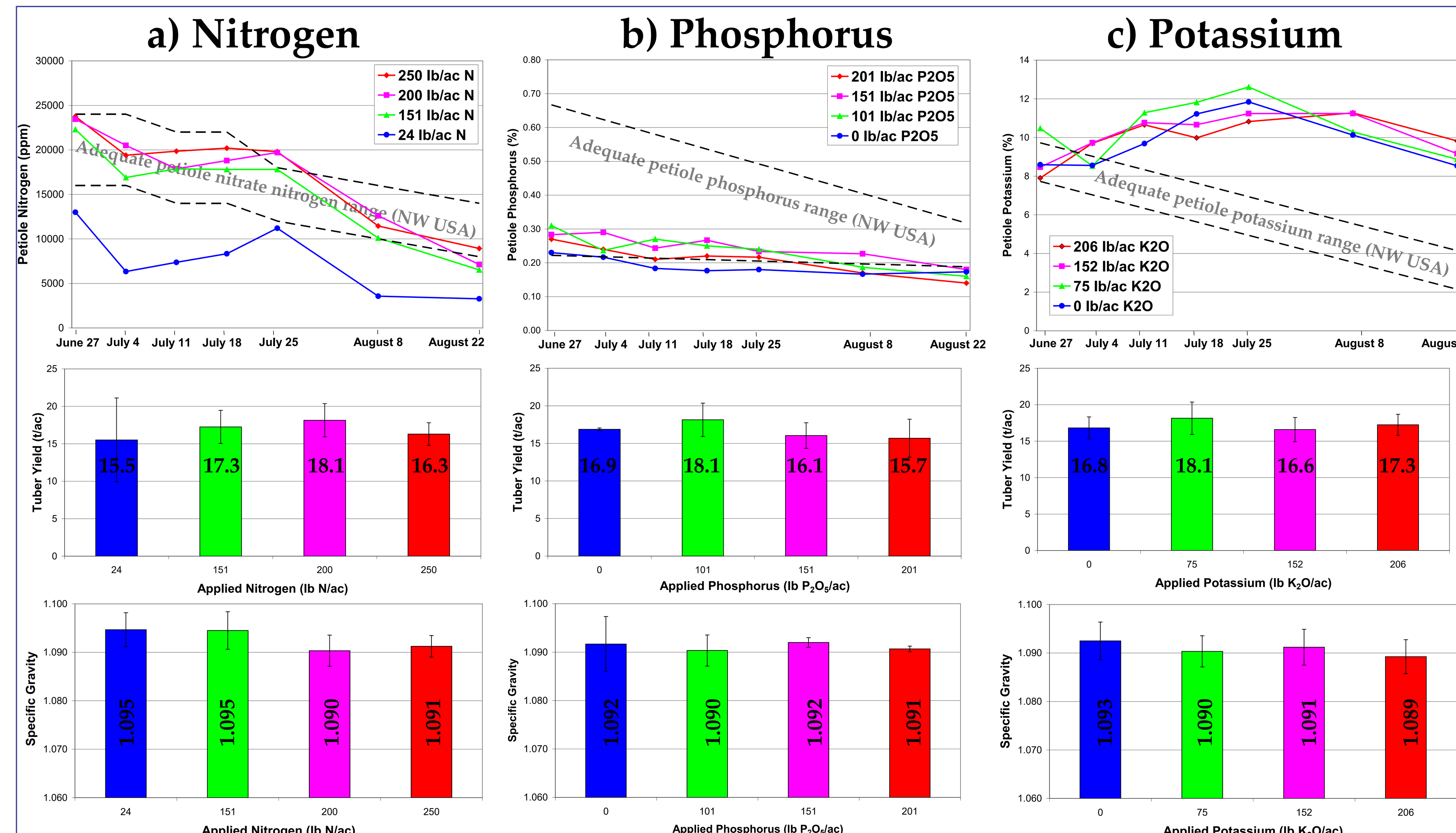

Figure 4. Potato petiole N, P, K content, marketable yield and specific gravity (2007).

Objectives

In 2004, a 3-year study was initiated. The objectives are to
- 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.

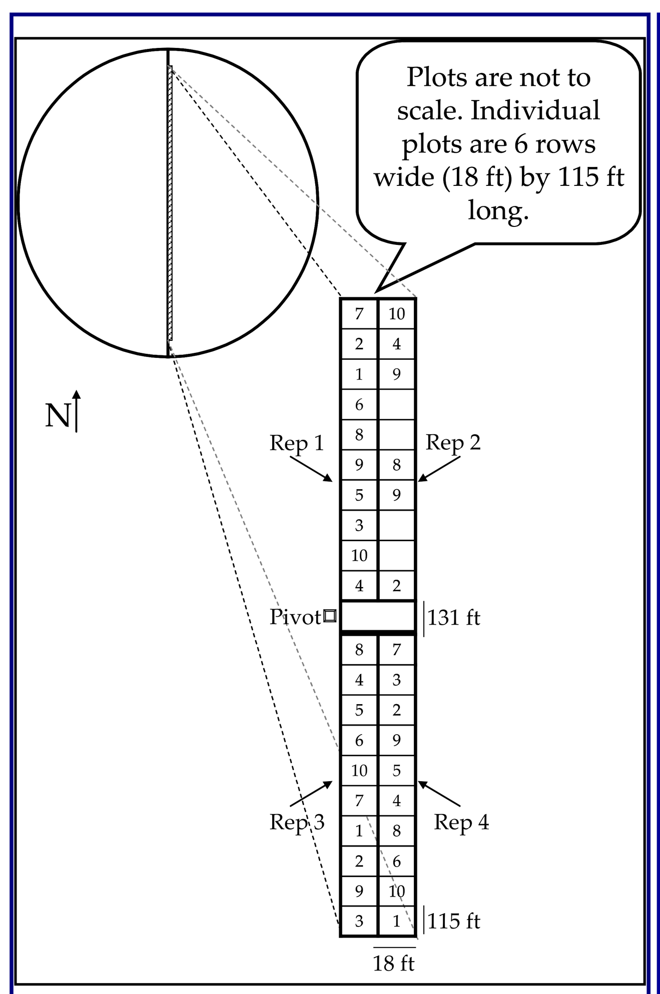

Figure 1. Plot layout 2007.

Table 1. Fertilizer rates 2007.

Treatment		Experiment Applied Apr 17/07 (lb/ac)		
		N	P_2O_5	K_2O
a) Nitrogen	1	24	101	75
	2	151	101	75
	3	200	101	75
	4	250	101	75
b) Phosphorus	5	200	0	75
	3	200	101	75
	6	201	151	75
	7	200	201	75
c) Potassium	8	200	101	0
	3	200	101	75
	9	200	101	152
	10	200	101	206

Project Treatments and Layout

Ten rates (Table 1) of N, P and K fertilizer were applied (April 17/07) to strips in a small portion of a field of grower-managed Russet Burbank potatoes, near Coaldale, Alberta. Each plot was 6 rows wide (18 ft) by 115 ft long (Figure 1) and there were 4 replicates. Due to an error in the application rate of K on several plots in Rep 2, data from 4 plots was not used in results calculations. Petiole samples (Figure 2) were collected and analyzed for each plot 7 times throughout the 2007 growing season. Tuber samples (2x25 ft strips) were collected (September 13-14/07), graded for marketable yield and analyzed for specific gravity.

The crop was planted April 22/07 and it had begun flowering by July 11/07. Grower fertilizer and fertigation amounts and dates have not yet been provided, however the plot area was avoided by the grower during the spring fertilizer application. The field was affected by a hail storm on August 10, 2007 (Figure 3). Crop damage was more extensive on the north half of the field.

Acknowledgements

This project was made possible with the financial support of the Potato Growers of Alberta and Alberta Agriculture and Food. McCain Foods provided funding to allow an additional date of petiole sampling to be added and Sandberg Laboratories provided a research rate for petiole analysis. Tony Bos is kindly acknowledged for hosting the trial. Lucinda Noronha managed the collection of petiole samples and Corrine Thiessen Hepher, Brent Nicol, Jonathan Peters, Darren Peterson and Rod Bennett assisted. Mitchell Froyman, Miranda Mathies, Ryan Moeller and Ralaina Virostek assisted with the tuber harvest.

Full reports of the 2004 and 2005 results are available on the PGA web site and a final report, consisting of the 2004-2007 results will be made available to the PGA in January 2008.

Results Summary

Nitrogen: There was an increasing concentration of petiole N with increasing fertilizer N and this was seen in all three years of the study. All but the lowest N fertilizer treatment fell within the USA standards. The highest three N treatments had very similar petiole N concentrations, despite representing a range in fertilizer N. There was no significant yield difference between treatments, however there was a trend to increasing yield with increased fertilizer, with a decreased yield at the highest rate of N. There was a slight trend to decreasing specific gravity with increased fertilizer N. A similar trend was also seen in 2005 but the opposite was seen in 2004.

Phosphorus: All petiole P results were in the low range, within and slightly below the USA standards, similar to both previous years. There was no relationship between fertilizer P and petiole P.

Potassium: Similar to previous years, petiole K results were above the USA adequate range and there was no relationship between fertilizer K and petiole K. There was no statistically significant trend in specific gravity with increasing fertilizer K.

PGA

Alberta Agriculture and Food

POTATO GROWERS OF ALBERTA

6008, 46th Avenue
Taber, Alberta T1G 2B1

Phone (403) 223-2262
Fax (403) 223-2268
e-mail: pga@albertapotatoes.ca
www.albertapotatoes.ca

April 20, 2007

Dr. Anne Smith
Agriculture and Agri- Food Canada
5403 - 1 Avenue South
PO Box 3000
Lethbridge, AB T1J 4B1

Re: Developing Diagnostic Tools for Nitrogen Management in Potatoes

Dear Anne:

We are pleased to advise that the Board of Directors of The Potato Growers of Alberta has reviewed and approved your research funding application.

The funding will be accessible for a one year period in the amount requested of $10,000. When requesting the funds for the project, please provide an invoice that specifies the amount, GST and to whom payable.

We appreciate your commitment and dedication to the potato industry.

Yours truly,

Vern Warkentin
Executive Director

/pl

Potato Growers of Alberta

Proposal application for Research funding 2007-2008

Instructions

To assess the proposals consistently, they must be completed according to the parameters contained in this form. Proposals may be rejected for incomplete information or lack of compliance with the instructions.

Please jump between boxes using the "Tab" key and avoid the use of the "enter" key. The PGA Research Committee will set dates for project proposal submissions, presentations and result reports.

This application could use other sources of forms only if they will be presented to other funding consortiums.

This proposal is confidential ☐

TITLE: Developing diagnostic tools for nitrogen management in potatoes.

Team Leader: Anne Smith		
Organization: Agriculture and Agri-Food Canada	Section/Department: Research Branch, Environmental Health	
Address: 5403 1st Avenue South	City: Lethbridge	Province: AB
Postal Code: T1J 4B1	E-mail: smitha@agr.gc.ca	
Phone Number (403) 317-2285	Fax Number (403) 317-2187	

Category of the project (Please check more than one box if necessary):

☐ Pest Management
☐ Water and Irrigation Management
☐ Potato Storage
☐ Potato Breeding
☐ Potato Plant Physiology
X Potato Fertility Plant
X Nutrition/Soil management
☐ Green House
☐ Environment
☐ Potato Marketing and Economics
☐ Potato Cultural Management

1. Project Information

Research Location (s): Lethbridge area
Duration (Y):1 Start Date (YY/MM):2007/05 Ending Date (YY/MM): 2007/12
Is the project linked to other applications / Research projects Y X N ☐ (Please identify related projects) 1.Project: Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta Team Leader: Shelley Woods Start Date: 2.Project: Team Leader: Start Date:

Background.
(Max 2000 characters)

Nitrogen (N) fertilization in annual cropping is key to maximizing yield and quality. In crops such as potatoes which is a high user of N, optimization of N application offers economic and environmental advantages. In-season application of N fertilizer whether through fertigation, banding or top-dressing is usually initiated following nitrate (NO_3-N) analyses of petiole samples (Zhang et al. 1996, Waterer and Heard 2005). Although petiole sampling is the "standard" for in-season monitoring of N levels in potato, there are some disadvantages to this technique. The NO_3-N levels can vary with the experience of the sampler, the time of day of sampling, the method of sampling, and the laboratory assay methods employed. There is also a delay between petiole sampling and obtaining the necessary information for management decisions.

In recent years, there had been considerable interest in the use of various hand held and tractor mounted instruments for"real-time" estimation of N deficiencies in a variety of crops including potatoes. A number of studies reported in the literature indicate the use of a chlorophyll meter or the Greenseeker which measure plant leaf chlorophyll content and canopy "greenness" respectively have potential for managing in-season N fertilization on potatoes (Olivier et al. 2006, Bowen et al. 2005). More recently investigations into the use of fluorescence excitation and the Dualex field portable instrument for N management have appeared in the literature (Cartelat et al. 2005). The Dualex offers a potential tool for in-season nitrogen management (Tremblay and Bélec 2006) but to date there is no data in potatoes. The use of these instruments has not to our knowledge been tested in southern Alberta conditions with varieties grown in this region. Ultimately, the use of hand held or tractor mounted tools may help producers achieve self-sufficiency and "real-time" results for N management.

POTATO GROWERS OF ALBERTA

Objectives (Measurable-Deliverables)

(Please use Bullets) (Max 1000 characters)

Objective

1. To conduct a preliminary evaluation of the use of the SPAD, Greenseeker and Dualex meters as alternative tools to petiole NO3-N sampling for in-season estimation of N-levels in potatoes.

Deliverable:

Report outlining the work undertaken, the relationship between the various instrument readings and (a) petiole N-samples and (b) final yield and the potential for further work to develop real-time diagnostic tools for N management in potatoes.

Methodology Description

(Please describe the scientific process you will follow to achieve project objectives).(Max 2000 Characters)

In 2007, we would propose that this study be be superimposed on the experiment of Shelley Woods of AAFRD to examine petiole nutrient recommendations for Russet Burbank potatoes. The on-going experiment, which has been established in collaboration with a grower, will employ 10 treatments involving four nitrogen levels (0, 150, 200 and 250 lb/ac) as well as four phosphate and four potassium levels. Petiole samples will be collected from each plot 7 times throughout the growing season and NO3-N measurements made to determine the optimal petiole nutrient concentrations for Russet Burbank potatoes, specific to southern Alberta. We propose that coincident to the collection of the petiole samples, our team will collect SPAD, Dualex and Greenseeker measurements in each plot. Multiple samples for each instrument will be taken in each plot, to provide a measure of variability within as opposed to across treatments. The values from the various instruments will be correlated with the petiole samples and also final yield. The preliminary data derived from this study will be evaluated to determine future directions and potential studies.

Economical/Environmental Benefits

(Please mention how the results of this project will benefit potato production economically and environmentally.(Max. 1000 characters) .

In potatoes, which are high cash value crop, N is the single most important nutrient for maximizing yield and quality. Excessive N reduces quality of the tubers thereby reducing economic returns. In addition over fertilization can potentially have a high environmental cost as a result of contamination of both surface and groundwater resources and contributing to greenhouse gas emissions. In contrast, too little N leads to stunted growth, premature death of the vines, increased susceptibility to diseases such as early blight or *Verticillium* and consequently reduced yields Ultimately, the idea would be to combine the information available from these sensor systems with that of field spatial variability to provide "real-time" information for N management strategies to maximize economic returns and enhance stewardship.

Technology Transfer Plan.
(Please describe the proposed method to communicate findings and results)
The results from the study will be communicated to the PGA directly through a written report and if desired an oral communication. The results will also be presented at local workshops or conferences where appropriate

3. Research Team Information

Team Member:Nicolas Tremblay		
Organization:AAFC	Section/Department:Environmental Health	
Address: 430 Gouin Blvd	City:, St-Jean-sur-Richelieu,	Province:QB
Postal Code:J3B 3E6	E-mail :tremblayna@agr.gc.ca	
Phone Number:450-515-2102	Fax Number:	

Team Member: Shelley Woods		
Organization: AAFRD	Section/Department: Irrigation Branch	
Address:100, 5401 1st Avenue South	City:Lethbridge	Province:AB
Postal Code: T1J 4V6	E-mail:Shelley.A.Woods@gov.ab.ca	
Phone Number (403) 381-5839	Fax Number (403) 381-5765	

Team Member:		
Organization:	Section/Department:	
Address:	City:	Province:
Postal Code:	E-mail address:	
Phone Number:	Fax Number:	

Team Member:		
Organization:	Section/Department:	
Address:	City:	Province:
Postal Code:	E-mail address:	
Phone Number:	Fax Number:	

3. Project Budget

		Year 1	Year 2	Year 3	**Total**
PGA	Cash	10,000			
	In-Kind				
	Total				
Other					
AAFC	Cash				
	In-Kind	20,000			
	Total				
Other					
AAFRD	Cash				
	In-Kind				
	Total				
Other					
	Cash				
	In-Kind				
	Total				
Other					
	Cash				
	In-Kind				
	Total				
Total					

Project Cost Distribution	Year 1	Year 2	Year 3	**Total**

Personnel	28,500			
Travel expenses				
Capital goods				
Materials				
TOT				
Overhead	1500			
Total	**30000**			

*TOT (Transference of Technology)

Research Project Manager
Anne M. Smith
Signature **Date**

Agriculture and Agri-Food Canada
Research Branch

Agriculture et Agroalimentaire Canada
Direction générale de la recherche

Office of Intellectual Property and Commercialization
Commercialization Officer: **Charmaine Ross**
Agriculture and Agri-Food Canada
Lethbridge Research Centre
5403 1st Avenue South
Lethbridge, Alberta T1J 4B1
Telephone: (403) 317-2214
Facsimile: (403) 317-2185
E-mail:rosscm@agr.gc.ca

June 1, 2007

Mr. Vern Warkentin
Executive Director
Potato Growers of Alberta
6008-46 Avenue
Taber, AB T1G 2B1

Dear Mr. Warkentin:

You will find enclosed **two** original copies of Research Support Agreement between Agriculture and Agri-Food Canada and the Potato Growers of Alberta for the Project, "Developing Diagnostic Tools for Nitrogen (N) Management in Potatoes". Please sign **both** copies, retain one for your records and return **one** copy to me for our records.

If you have any questions or concerns, do not hesitate to contact me at (403) 317-2214 or by email.

Sincerely,

Charmaine Ross
Office of Intellectual Property
& Commercialization

RECEIVED JUN 11 2007

Canada

Agriculture and Agri-Food Canada
Research Branch

Agriculture et Agroalimentaire Canada
Direction générale de la recherche

Protected Business Information

Office of Intellectual Property and Commercialization
Agriculture and Agri-Food Canada
Commercialization Officer: **Charmaine Ross**
Tel: **403-317-2214**
Fax: **403-317-2185**
Research Scientist: **Dr. Anne M. Smith**
Office of Intellectual Property File: **STAT 801821**

June 1, 2007

Mr. Vern Warkentin
Executive Director
Potato Growers of Alberta
6008-46 Avenue
Taber, AB
T1G 2B1

Dear Mr. Warkentin:

RE: Research Support Agreement
Between: Agriculture and Agri-Food Canada AND Potato Growers of Alberta ("Contributor")
Project: Developing Diagnostic Tools for Nitrogen Management in Potatoes

1. This is a Research Support Agreement (RSA) between the Contributor and Her Majesty the Queen in Right of Canada as represented by the Minister of Agriculture and Agri-Food ("AAFC") whereby the Contributor pays to AAFC cash support of **CDN $10,000** ("Contribution") for the Project detailed in Appendix "A" (Description of Research Project). The funds will be due upon the signing of this RSA.

2. The Contribution will be directed toward the Project conducted at the Lethbridge Research Centre, Lethbridge, Alberta and led by the Principal Investigator, Dr. Anne Smith.

3. The Contribution will assist in conducting the Project, and the AAFC research will be of direct or indirect benefit to the Contributor.

4. The Project will be conducted from May 8, 2007 to March 31, 2008, inclusive.

5. You, the Contributor, agree that:
   (a) The Contribution will be used to fund the Project as outlined in Appendix "A";
   (b) AAFC's only obligation is to use the Contribution for the Project mentioned above;
   (c) If appropriate, research results will be published, subject to any patent or trade secret concerns;
   (d) Any and all intellectual property arising from the Project is the sole property of AAFC;
   (e) The Contribution is irrevocable; and
   (f) There are no other understandings or agreements regarding this contribution or Project except as stated in this RSA.

Canada

If you find these terms and conditions acceptable, please have the appropriate authority in your organization date and sign both copies of this RSA (in any colour of ink other than black), keep one original for your records, and return the other to us for our files.

This Research Support Agreement has been executed, in duplicate, by duly authorized representatives of the parties and effective on the date of the last signature.

Yours truly,

John Culley, Ph.D.
Director, Office of Intellectual Property and Commercialization
Agriculture and Agri-Food Canada

For: Potato Growers of Alberta:

Mr. Vern Warkentin
Executive Director
Potato Growers of Alberta

Date: June 11/07

APPENDIX "A"
DESCRIPTION OF RESEARCH PROJECT:
Developing Diagnostic Tools for Nitrogen Management in Potatoes

Background:
Potatoes are a high user of N. Optimization of N application offers economic and environmental advantages. In-season application of N fertilizer whether through fertigation, banding or top-dressing is usually initiated following nitrate (NO_3-N) analyses of petiole samples. Although petiole sampling is the "standard" for in-season monitoring of N levels in potato, there are some disadvantages to this technique. The NO_3-N levels can vary with the experience of the sampler, the time of day of sampling, the method of sampling, and the laboratory assay methods employed. There is also a delay between petiole sampling and obtaining the necessary information for management decisions.
In recent years, there had been considerable interest in and potential for the use of a variety of hand held and tractor mounted instruments for "real-time" estimation of N deficiencies in a variety of crops including potatoes. These instruments include the SPAD, Greenseeker and more recently the Dualex field portable instrument which used fluorescence excitation. To date there is limited data in potatoes and to our knowledge these instruments have not been tested in southern Alberta conditions with varieties grown in this region. Ultimately, the use of hand held or tractor mounted tools may help producers achieve self-sufficiency and "real-time" results for N management.

Objectives:
To conduct a preliminary evaluation of the use of the SPAD, Greenseeker and Dualex meters as alternative tools to petiole NO3-N sampling for in-season estimation of N-levels in potatoes.

Various instruments will be used, along with traditional petiole sampling, to assess N sufficiency of the potato crop to determine their effectiveness in predicting the need for in-crop N applications to optimize yield. Ultimately, the use of these instruments, either hand held or tractor mounted, may offer the potential to reduce negative environmental effects from nutrients and improve the economics of production for the producer both of which are national Science priorities within Agriculture and Agri-Food Canada.

Impact/Benefits:
Nitrogen (N) fertilization in annual cropping is key to maximizing yield and quality. In crops such as potatoes which is a high user of N, optimization of N application offers economic and environmental advantages. Excessive N reduces quality of the tubers thereby reducing economic returns. In addition over fertilization can potentially have a high environmental cost as a result of contamination of both surface and groundwater resources and contributing to greenhouse gas emissions. In contrast, too little N leads to stunted growth, premature death of the vines, increased susceptibility to diseases such as early blight or *Verticillium* and consequently reduced yields. In-season application of N fertilizer whether through fertigation, banding or top-dressing is usually initiated following nitrate (NO_3-N) analyses of petiole samples (Zhang et al. 1996, Waterer and Heard 2005). Although petiole sampling is the "standard" for in-season monitoring of N levels in potato, there are some disadvantages to this technique. The NO_3-N levels can vary with the experience of the sampler, the time of day of sampling, the

method of sampling, and the laboratory assay methods employed. There is also a delay between petiole sampling and obtaining the necessary information for management decisions. In recent years, there had been considerable interest in the use of various hand held and tractor mounted instruments for"real-time" estimation of N deficiencies in a variety of crops including potatoes. A number of studies reported in the literature indicate the use of a chlorophyll meter or the Greenseeker which measure plant leaf chlorophyll content and canopy "greenness" respectively have potential for managing in-season N fertilization on potatoes (Olivier et al. 2006, Bowen et al. 2005). More recently investigations into the use of fluorescence excitation and the Dualex field portable instrument for N management have appeared in the literature (Cartelat et al. 2005). The Dualex offers a potential tool for in-season nitrogen management (Tremblay and Bélec 2006) but to date there is no data in potatoes. The use of these instruments has not to our knowledge been tested in southern Alberta conditions with varieties grown in this region. Ultimately, the use of hand held or tractor mounted tools may help producers achieve self-sufficiency and "real-time" results for N management.

Science Plan:
In 2007, this study will be superimposed on an on-going study being funded by the Alberta Potato Growers and led by Dr. Shelley Woods of Alberta Agriculture, Food and Rural Development to examine petiole nutrient recommendations for Russet Burbank potatoes. The on-going experiment, which has been established in collaboration with a grower, will employ 10 treatments involving four nitrogen levels (0, 150, 200 and 250 lb/ac) as well as four phosphate and four potassium levels. Petiole samples will be collected from each plot 7 times throughout the growing season and NO_3-N measurements made to determine the optimal petiole nutrient concentrations for Russet Burbank potatoes, specific to southern Alberta. Coincident with the collection of the petiole samples, our team will collect SPAD, Dualex and Greenseeker measurements in each plot. Multiple samples for each instrument will be taken in each plot, to provide a measure of variability within as opposed to across treatments. The values from the various instruments will be correlated with the petiole samples and also final yield. The preliminary data derived from this study will be evaluated to determine future directions and potential studies.

AAFC's Commitment and Role in the Project:
The objectives and work are consistent with those outlined by the lead AAFC scientist within the approved peer reviewed project entitled "Integrated Nutrient Management for Improved Productivity and Environmental Sustainability". As indicated AAFC will be responsible for acquiring the measurements with the various hand-held instruments, for analysis of the data and delivery of a report to the Potato Growers of Alberta outlining the work undertaken, the relationship between the various instrument readings and (a) petiole N-samples and (b) final yield and the potential for further work to develop real-time diagnostic tools for N management in potatoes. Agriculture and Agri-Food Canada will not be responsible for establishing the field sites.

Company's Commitment and Role in the Project:
The Potato Growers of Alberta will provide $10,000 in order for Agriculture and Agri-Food Canada to conduct the work outlined above.

Potato Growers of Alberta
Research Tracking

Title of Research Application: Petiole Nutrient (N,P+K) Rec. for RB grown in So. AB.

Name of Researcher: Dr. Shelley Woods

Employer: Ab Agriculture, Food & Rural Dev.

Date application was received by PGA ____

Date application was reviewed by PGA April 3, 2006

A) approved ✓ B) declined ____

Project start date: deferred to: Spring 2007 Project finish date: ____

Total amount requested: $ 9,200 - Amount requested per year: $ 9,200

MOU received and signed. Once copy returned to research agency, one copy filed in current year Research Binder

Date completed ____

Invoice received: # ____ Date funds advanced ____ Cheque# ____

Invoice received:# ____ Date funds advanced ____ Cheque# ____

Invoice received:# ____ Date funds advanced ____ Cheque# ____

Invoice received:# ____ Date funds advanced ____ Cheque# ____

Were reports received from the researcher? ____

What was done with the reports?

Presented at PGA meeting? ____ Put on PGA website? ____ Filed? ____

NOTES: ____

Alberta
GOVERNMENT OF ALBERTA

INVOICE

COPY

Page: 1 of 1

Payable to: Minister of Finance
Please Remit To:
Agriculture, Food & Rural Dev
7000 113 ST
EDMONTON AB T6H 5T6
Canada

Invoice: 011LA011762
Invoice Date: August/10/2007
Customer No: C031892
Payment Terms: Immediate
Period Covered -
Due Date: August/10/2007

Bill To:
POTATO GROWERS OF ALBERTA
6008 46 AVE
TABER AB T1G 2B1
Canada

AMOUNT DUE: **9,200.00 CAD**

Amount Remitted

Please cut along line and return top portion with payment

For billing questions, please call: **403-329-1212**

Invoice Number	Invoice Date	Customer Number	Payment Terms	Period Covered	Due Date
011LA011762	August/10/2007	C031892	Immediate	-	August/10/2007

Line	Description / Contract No.	Order No.	Quantity / Order Date	UOM	Unit Amt	GST Amt / PO Reference No.	Extended Amount
1	Research Project		1.00	EA	9,200.00	0.00	9,200.00

U for Research Project "Petiole Nutrient Recommendations for Russet Burbank Potatoes Grown in Southern Alberta "Final Year" 2007.

Subtotal: **9,200.00**

Total (GST):
Net Amount:

AMOUNT DUE: **9,200.00**

Government of Alberta - GST Registration Number: 124072513

Original

RECEIVED AUG 15 2007

Alberta Agriculture and Food

Technology and Innovation Branch

Agriculture Centre, 100, 5401 – 1 Avenue South
Lethbridge, Alberta, Canada T1J 4V6
Telephone: (403) 381-5839 Fax: (403) 381-5765
E-mail: shelley.woods@gov.ab.ca

June 20, 2007

Potato Growers of Alberta
6008 – 46th Avenue
Taber, AB T1G 2B1

Attention: Vern Warkentin, Executive Director

Re: MOU for research project "Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta" final year (2007)

Dear Vern,

Thank you for your phone call of April 19, 2007, indicating that the PGA is willing to fund the project entitled "Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta" for its third and final year. Please review the enclosed MOU. If the terms are acceptable, please sign both copies and return one original to me. The other is for your records. If you would prefer to propose alternate terms in the MOU, please contact me at 403-381-5839. I have also attached an invoice, which specifies the amount, GST and to whom payable.

Thank you for funding this project. I am excited about the potential benefits of this research to members of the PGA and look forward to our continued collaboration.

Sincerely,

Shelley Woods, Ph.D., P.Ag.
Soil and Water Research Scientist, Technology and Innovation Branch
100, 5401-1st Avenue South
Lethbridge, AB T1J 4V6

Project
New: Renewal: **X**

MEMORANDUM OF UNDERSTANDING

Between: Potato Growers of Alberta
(hereafter referred to as "PGA")

and

Alberta Agriculture and Food
(hereafter referred to as "AF")

Project Title: Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta.

Objectives:
1. To determine the optimal petiole nutrient concentrations for Russet Burbank potatoes, specific to southern Alberta,
2. To determine the relationship, if any, between potato petiole nutrient concentrations and tuber specific gravity and
3. To compare these relationships to those found in field-scale petiole data.

STATEMENT OF WORK

Alberta Agriculture and Food is willing to undertake this study for the PGA, who hereby agrees to contribute toward the costs of researching the information required as described in the research proposal.

PERIOD OF WORK

The research project will commence in April 2007. An interim update (poster format) will be provided for the November 2007 PGA meeting, if requested, and a final report will be provided to the PGA by January 31, 2008.

BASIS OF PAYMENT

The sponsor of the project, the PGA, will provide $9,200 upon finalization of this memorandum to AF, to cover the following estimated yearly costs:

Casual Manpower	$2,680
Travel	$ 500
Laboratory Analysis	$5,200
Materials	$ 300
GST (6%)	$ 520
Total	**$9,200**

The Budget can be adjusted and used at the discretion of the project manager.

Payment of research project expenditures will be made from funds made available to AF up to the maximum amount of funds received from the sponsor.

If requested, AF will provide a record of revenue and expenditure upon project completion or depletion of funds. Any remaining funds after completion or termination of the project can be used for research at the discretion of the project manager.

RESPONSIBILITY OF PROJECT MANAGER

The project manager for this study is Shelley Woods, Soil and Water Research Scientist. She will provide all reports to AF and the sponsor.

The project manager will authorize expenses and submit them to the appropriate AF department for processing payment.

The project manager is not eligible for any manpower funds herself.

AMENDMENTS OR TERMINATION

This Memorandum of Understanding may be amended by mutual consent of the parties as evidenced by an exchange of letters.

Either AF or the PGA may terminate this Memorandum of Understanding by providing two weeks notice in writing to the other party.

NOTICES AND REPRESENTATIVES

Notices for all purposes of or incidental to this Memorandum of Understanding shall be effectively given if delivered personally, or sent by registered or certified mail to the representatives of the parties designated as follows:

Potato Growers of Alberta

Mr. Vern Warkentin
Executive Director
Potato Growers of Alberta
6008 – 46th Avenue
Taber, AB T1G 2B1

Alberta Agriculture and Food:

Mr. Rick Atkins
Head, Technology and Innovation Branch
Agricultural Technology Centre
3000 College Drive South
Lethbridge, AB T1K 1L6

Information generated from the project may be used by the Department of Agriculture and Food and the PGA.

The sponsor, the PGA, relinquishes ownership of any materials, supplies and assets purchased with project funds to the AF, which assigns control to the project manager's departmental division.

The parties affirm their acceptance of the terms of this Memorandum of Understanding by signing below.

Copies bearing original signatures of this Memorandum will be kept by each party.

Shelley S. Woods.
Shelley Woods, Project Manager

August 7, 2007
Date

I agree that the project manager named above may supervise this project.

Mr. Rick Atkins, Head,
Technology and Innovation Branch

3/8/07
Date

Mr. Vern Warkentin, Executive Director
Potato Growers of Alberta

Aug 7/07
Date

AGRICULTURE, FOOD AND
RURAL DEVELOPMENT

Irrigation Branch

Agriculture Centre, 100, 5401 - 1 Avenue South
Lethbridge, Alberta, Canada T1J 4V6
Phone: (403) 381-5839 Fax: (403) 381-5765
E-mail: shelley.woods@gov.ab.ca

May 9, 2006

Potato Growers of Alberta
6008 – 46th Avenue
Taber, AB T1G 2B1

Attention: Alfonso Parra; Technical Director, Potato Growers of Alberta

Re: Research project "Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta": request for deferral of the third year of funding

Dear Alfonso,

Thank you for funding the 2004 and 2005 project titled "Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta". I am writing to request that funding for thē final year of the project be deferred until the 2007 growing season. We were unable to find a suitably nutrient-deficient field for the 2006 growing season. In order to ensure the best possible results for the final year of the study, we hope to work with Mr. Jerry Zeinstra in the fall of 2006 to set aside an unfertilized portion of one of his potato fields for our research plots.

Due to my recent change of job, the 2007 plot set-up, sampling (petiole and tuber) and handling of funds will be conducted by staff from the Potato Program at CDC South, under the supervision of Dr. Michele Konschuh. However, I will remain responsible for data analysis and preparation of the final report.

Sincerely,

Dr. Shelley Woods
Soil and Water Research Scientist
Irrigation Branch, 100, 5401 – 1 Avenue South
Lethbridge, AB T1J 4V6

POTATO GROWERS OF ALBERTA

April 20, 2007

Ms. Shelley Woods
Alberta Agriculture, Food & Rural Development
A256 Agriculture Centre
100, 5401 - 1 Avenue S
Lethbridge, AB T1J 4V6

Re: Petiole Nutrient Recommended for Russet Burbank Potatoes in Southern Alberta

Dear Shelley:

We are pleased to advise that the Board of Directors of The Potato Growers of Alberta has reviewed and approved your research funding application.

We are aware that this is a one year project; the total funding of $9200 is available immediately. When requesting the funds for the project, please provide an invoice that specifies the amount, GST and to whom payable.

We appreciate your commitment and dedication to the potato industry.

Yours truly,

Vern Warkentin
Executive Director

/pl

Potato Growers of Alberta
Research Tracking

Title of Research Application: Application of Polymer-Coated Urea (ESN) in Potato Prod in So. AB

Name of Researcher: Michele Konschuk

Employer: AAFRD

Date application was received by PGA ____________________

Date application was reviewed by PGA ____________________

A) approved ✓ B) declined ________

Project start date: ____________________ Project finish date: ____________________

Total amount requested: $ 6360.00 Amount requested per year: ____________________

MOU received and signed. Once copy returned to research agency, one copy filed in current year Research Binder

Date completed ____________________

Invoice received: # ____________ Date funds advanced ____________ Cheque# ____________

Invoice received: # ____________ Date funds advanced ____________ Cheque# ____________

Invoice received: # ____________ Date funds advanced ____________ Cheque# ____________

Invoice received: # ____________ Date funds advanced ____________ Cheque# ____________

Were reports received from the researcher? ____________________

What was done with the reports?

Presented at PGA meeting? ________ Put on PGA website? ________ Filed? ________

NOTES: ____

Alberta Agriculture and Food

Crop Diversification Centre South
301 Horticultural Station Road East
Brooks, Alberta, Canada T1R 1E6
Telephone (403) 362-1300, Fax (403) 362-1306
ext 1302

June 25, 2007

Mr. Vern Warkentin, Executive Director
Potato Growers' of Alberta
6008 – 46th Ave
Taber, Alberta T1G 2B1

Dear Mr. Warkentin,

Enclosed is your duly executed copy of the memorandum of agreement that was created to acknowledge your collaborative support on our application of polymer-coated urea (ESN) in potato production in southern Alberta.

As indicated in the agreement, your payment of $6,360.00 can be made payable to the Minister of Finance and can be forwarded to my attention.

Thank you for your continued support in our research projects.

Yours truly,

PAID

Anna Moeller
Centre Administrator

/alm

enclosure (1)

RECEIVED JUN 28 2007

Project # 819194

MEMORANDUM OF AGREEMENT

Between:
Potato Growers of Alberta
(Hereafter referred to as "**PGA**")

And

Her Majesty, the Queen, in right of the Province of Alberta as represented by the Minister of Agriculture and Food
(Hereafter referred to as "**AF**")

Project Title: Application of polymer-coated urea (ESN) in potato production in southern Alberta

Objectives:
1. To determine the effect of combinations of urea and polymer coated urea on yield, specific gravity and quality of Russet Burbank potatoes; and
2. To determine whether polymer coated urea can replace the need for in-season N applications (top-dressing, side-dressing or fertigation), and
3. To determine whether polymer coated urea reduces the risk of nitrate leaching in irrigated potato production; and
4. To determine whether polymer coated urea can be used as a tool for better nitrogen management in Alberta potato production.

SCOPE OF WORK

1. **AF** will conduct the Research Project according to the research plan, which is attached to and forms part of this Agreement.

PERIOD OF WORK

2. This Agreement will commence on 04/01/2007 and will terminate on 12/31/2009 unless extended upon agreement of both parties.

BASIS OF COSTS and PAYMENT

3. **PGA's** total contribution for this Research Project is $6,360 to cover the following estimated total costs:

Labour, materials, & technology transfer	$6,000
GST	$360
Total Cost	$6,360

The budget may be adjusted and used at the discretion of the project manager.

4. **PGA** will provide to **AF**, upon execution by both parties of this Agreement, the sum of $6,000 plus GST. This represents three annual contributions of $2,000 paid in one lump sum.

Cheques shall be made payable to **"Minister of Finance"** and forwarded to:

Attention: Anna Moeller
Alberta Agriculture and Food
Crop Diversification Centre South
302 Horticultural Station Road East
Brooks, AB T1R 1E6

5. **AF** will use the funds paid by **PGA** only for the purpose of conducting the Research Project. **AF** will provide, upon request, a record of revenue and expenditure to **PGA** upon completion of the Research Project or depletion of funds.

RESPONSIBILITY OF PROJECT MANAGER

6. The project manager for this Research Project is Dr. Michele Konschuh of **AF** who will supervise the Research Project and provide all reports to **PGA** and other sponsors. The project manager will authorize expenses and submit them to the appropriate **AF** office for payment to be processed.

AMENDMENTS OR TERMINATION

7. This Agreement may only be amended upon mutual consent of the parties and evidenced in writing.

8. Either **AF** or **PGA** may terminate this Agreement in the event of a material default or breach of a substantive term, condition or provision of this Agreement, by providing two weeks notice in writing to the other party. In such event if **AF** is in default then any and all amounts of the funds advanced by **PGA** hereunder that represent payment for work or services hereunder that have not been performed by AF up to the date of termination shall be refunded to **PGA.**

NOTICES AND REPRESENTATIVES

9. Notices for all purposes of or incidental to this Agreement shall be effectively given if delivered personally, or sent by registered or certified mail to the representatives of the parties designated as follows:

PGA:
Vern Warkentin
Executive Director
6008 – 46th Avenue
Taber, AB T1G 2B1

Agriculture and Food:
Dr. Cornelia Kreplin
Director, Agriculture Research Division
204 J.G. O' Donoghue Building
7000 – 113 Street
Edmonton, AB T6H 5T6

AF, **PGA,** and other sponsors may use information generated from the project. The sponsor, **PGA**, relinquishes ownership of any materials, supplies and assets purchased with the project funds to **AF** who assigns control to the project manager's branch.

Agriculture and Food

Michele Konschuh, Project Manager	May 8, 2007 Date
Henry Najda, Branch Head, Food Crops Branch	May 9, 2007 Date
Cornelia Kreplin, Director, Agriculture Research Division	Date

PGA

Vern Warkentin, Executive Director	June 11/07 Date

Name	Application of polymer-coated urea (ESN) in potato production in southern Alberta
Abstract	Nitrogen (N) management is a crucial agronomic tools used by potato producers to achieve the yield, quality and consistency required by the processing industry. Environmentally Smart Nitrogen (ESN) is a polymer-coated urea fertilizer with peak N release around 45 days after application depending on soil temperatures. Zvomuya and Rosen (2001) reported that a synchronous association between availability and demand of N could be achieved with just one fertilizer application of a polymer-coated urea at potato planting. Recent work in other potato production areas with polymer-coated urea products, has demonstrated that strategies that match crop N needs with N applications during key stages of plant development improved N-use efficiency and decreased nitrate leaching. The proposed research will determine the effect of combinations of urea and polymer-coated urea fertilizers for potato production in Alberta. Spring applied ESN could potentially be used to reduce total N applied, or to replace the need for N applications during the growing season. Products need to be evaluated under local conditions to identify combinations that match the uptake patterns for processing potato crops in Alberta.
Keywords	potato, nitrogen, controlled-release, urea, specific gravity, fertilizer, polymer-coated urea, production
Team Leader Name:	Michele Konschuh
Team Leader Organization:	AAFRD
Project Duration (Yrs)	3
Project Start Date	04/01/2007
Project End Date	12/31/2009
Stand-Alone Project	Yes
Application Linked	No
Background	Potatoes managed for maximum productivity exert a heavy demand on soil fertility (8). Nitrogen (N) management affects vine and tuber biomass production as well as tuber size, grade, specific gravity and internal and external quality (6). Insufficient available N leads to poor canopy establishment, decreased yield, and early crop senescence. Excessive N before tuber formation can delay tuber bulking and reduce yield, while excessive late-season N usually reduces specific gravity and skin set (6). Potato producers use a number of tools to manage N such as soil sampling, fertilizer formulations, timing and placement of fertilizer, and in-season crop monitoring through tissue testing. In recent years, split or periodic N application procedures have become common in many potato-producing regions (2). Strategies that match crop N needs with applications during the first 60 days of emergence, improve N-use efficiency (7). The potential for leaching is closely related to the efficiency of the N management program (6). Splitting the N application is an effective strategy to increase fertilizer use efficiency while limiting nitrate leaching (8). Another tool that is becoming available for N management is polymer-coated urea fertilizers.

Urea is an economical source of N that is converted by soil microbes to ammonium nitrogen. Ammonium forms of N become available to plants as microbes then convert it to nitrate forms. Coated urea products are part of a larger group of controlled-release fertilizers (CRF's), but the release rate is mostly influenced by soil temperature and is less affected by soil moisture than other CRFs. Earlier versions of controlled release fertilizers did not closely match N release with plant demand and resulted in less than satisfactory results. This coupled with higher costs of CRFs has limited their use to high value greenhouse and nursery crops (5).
Environmentally Smart Nitrogen, ESN, is a made in Alberta polymer-coated urea fertilizer (44-0-0). ESN provides a steady N supply for the growing plants demand while reducing losses due to leaching and denitrification. Zvomuya and Rosen (2001) reported that a synchronous association between availability and demand of N could be achieved with just one fertilizer application of a polymer-coated urea at potato planting. Recent work in other potato production areas with polymer-coated urea products, have demonstrated improved N-use efficiency and decreased nitrate leaching (1,4,10). Coated urea products range in their peak release dates, but ESN releases N approximately 45 days after application. Results from Alberta petiole-N research indicate that N uptake by the potato crop increases dramatically as potatoes switch from tuber initiation to tuber bulking around 75 to 80 days after planting (Shelley Woods, pers. comm., 2004). Spring applied ESN could potentially be used to replace broadcast fertilizer at the time of hilling or replace the need for in-season fertigation applications. Products need to be evaluated under local conditions to identify products or blends that match the uptake patterns for potato plants.

Objectives and Deliverables

The purpose of the proposed research is to determine whether ESN can be used in potato production to improve nitrogen use efficiency while maintaining yield and quality.

The use of polymer coated urea in potato production could potentially increase nitrogen use efficiency and reduce the total amount of nitrogen required to grow a high quality processing potato crop.

Potatoes produced for processing must be relatively consistent in size, shape, and other characteristics, such as fry color and specific gravity. In Alberta, it is quite common to have potatoes with higher than desirable specific gravity. Preliminary results have shown that the timing, quantity and the form of N fertilizer may impact specific gravity in the tubers. There is potential for ESN to be used as a tool to maintain yield and optimize specific gravity for processing potatoes.

Objectives:
1. To determine the effect of combinations of urea and polymer coated urea on yield, specific gravity and quality of Russet Burbank potatoes; and
2. To determine whether polymer coated urea can replace the need for in-season N applications (top-dressing, side-dressing or fertigation), and
3. To determine whether polymer coated urea can be used as a tool for better nitrogen management in Alberta potato production.

Deliverables:
1. Recommendations for potato growers regarding the use of polymer coated urea for potato production in Alberta.
2. Improved competitiveness of Alberta's potato industry.

Project Design and Methodology

Munoz et al. (2005) identified two key aspects of the use of CRFs in potato production that would benefit from further study: 1) fertilization scheduling and the application of polymer coated urea with other fertilizer sources to synchronize N release with plant demand; and 2) placement of CRF related to root distribution in order to optimize uptake. Polymer-coated fertilizers could be placed closer to the potato seed piece with less risk of damage than occurs with soluble fertilizers. The proposed research addresses the first of these identified needs for irrigated potato production in Alberta.

A preliminary trial with urea and ESN combinations was conducted at CDCS, Brooks, AB in 2006. Results from this preliminary trial indicated that a 50:50 split of urea and ESN at planting resulted in the greatest marketable yield. These results and a recent decision by CFIA to accept the use of ESN in potato production has piqued the interest of potato growers in Alberta.

The proposed work would be conducted on Russet Burbank potatoes at two southern Alberta research stations to ensure that background N is low and that N applications can be controlled. One set of replicated plots will be established at CDCS, Brooks and the other with be etablished each year at the AAFC Substation, Vauxhall, AB. A portion of a commercial field near Taber has also been set aside for a potential demonstration-scale trial within range for the PGA field day and tour. The trial is planned for 3 years to determine the impact of the treatments under a variety of environmental conditions. A total of 6 site years of data will be generated and should provide sufficient information to develop recommendations for incorporating ESN as part of an N management strategy for potato producers.

Various combinations of urea and ESN (polymer-coated urea) will be used pre-plant and compared with urea at planting followed by top-dressing at emergence to determine if ESN could be used to replace a nitrogen applciation in-season. Each treatment will be 4 rows wide and 6m long. The centre two rows will be harvested for yield estimates and tuber evaluations. Each treatment will be replicated 6 times to reduce some of the variability inherent in small plot research.

Proposed treatments include:
1. No nitrogen - check
2. Urea at 180 kg/ha (100% - 0%; pre-plant incorporated
3. Urea at 120 kg/ha plus 60 kg/ha coated urea (ESN); (67% - 33%); pre-plant incorporated
4. Urea at 90 kg/ha plus 90 kg/ha ESN (50% - 50%); pre-plant incorporated
5. Urea at 60 kg/ha plus 120 kg/ha ESN (33% - 67%); pre-plant incorporated
6. ESN at 200 lbs/ac (0% - 100%); pre-plant incorporated
7. Urea 120 kg/ha pre-plant incorporated plus 60 kg/ha top-dressed at emergence
8. Urea 120 kg/ha pre-plant incorporated plus 40 kg/ha top-dressed plus 2 x 9 kg/ha simulated fertigation

Petiole samples will be taken three times during the season (late June, early July and mid July)to ascertain when N from the coated urea becomes available. Yield, grade, specific gravity and defects will be measured after harvest. Fry color may be evaluated if large differences in specific gravity are observed.

Contributions to Alberta's Agriculture and Agri-Food Knowledge

There is no regional information available to Alberta potato producers on the use of polymer coated urea in potato production. Controlled release fertilizers (CRF's) such as polymer coated urea have been used successfully in other potato production areas, but our climate and the nature of our industry is unique. Areas such as Idaho, Florida, Colorado and Minnesota are including CRF products in the development of Best Management Practices (BMP) for potato production. There are also environmental benefits to using CRF's such as reduced nitrogen losses to denitrification or leaching.

Potato production involves significant crop inputs and the timing and quantity of nitrogen used contribute to the quality and yield of processing potatoes. Until recently, most controlled release fertilizers were much more expensive than traditional fertilizers, and the supply was somewhat limited. Adoption by Alberta growers has also been delayed because of the lack of information for this area and because approval of the polymer coating by CFIA only occurred very recently.

Preliminary results have shown that the timing, quantity and the form of N fertilizer may impact specific gravity in the tubers. For example, ammonium nitrate applications resulted in much lower tuber specific gravity than urea applications. There is potential for ESN to be used as a tool to maintain yield and optimize specific gravity for processing potatoes.

The anticipated results from the proposed work will:
- be included in BMP development for potato production in Alberta
- determine whether polymer coated urea can reduce total nitrogen applied or reduce the number of in-season nitrogen applications required for optimal potato yield and quality
- provide gross economic evaluations of the use of polymer coated urea
- potentially reduce nitrogen losses to leaching and denitrification processes
- will have more relevance than studies conducted in other potato production areas, because soil type and environmental conditions are unique in Alberta

The only IP expected from the outcome of this project is knowledge and information. The knowledge and information generated by this project will be available to the sponsors, cooperators and the general public through the provincial and federal governments.

Benefits to Alberta's Agriculture and Agri-Food Industry

In Alberta, potatoes are grown in a short, but intensive growing season. Growers are continually challenged to produce consistent potato yield and quality while limiting cost of production figures. Recently a stronger Canadian dollar put pressure on an export market already soft from decreased demand for potato products. Energy costs have increased and impact processors as well as producers. In order to remain competitive, producers need to realize greater returns on investment or reduce costs of production. With fertilizer and fuel costs on the rise, it is becoming even more important to improve nitrogen-use efficiency and reduce costs associated with additional field operations.

Heavy rainfall in Alberta in the the spring of 2004 and 2005 rendered some nitrogen applications inefficient, due to denitrification and leaching. Although Alberta's potato producers are not yet facing scrutiny over nitrate leaching, the costs (financial and environmental) and the logistics of replacing lost N impact profitability.

Polymer-coated urea products such as ESN are less subject to N losses in the soil. N is released later in the growing season when the N uptake of the plant is at its peak. ESN may increase N-use efficiency, ensure that N is available at key times in plant growth and development, and eliminate the need for top-dressing and possibly fertigation. This would potentially save on one or more field operations.

Potatoes produced for processing must be relatively consistent in size, shape, and other characteristics, such as fry color and specific gravity. In Alberta, it is quite common to have potatoes with higher than desirable specific gravity. Preliminary results have shown that the timing, quantity and the form of N fertilizer may impact specific gravity in the tubers. There is potential for ESN to be used as a tool to maintain yield and optimize specific gravity for processing potatoes

Some potential benefits include:
- Maintaining or reducing costs of production by increasing N-use efficiency and reducing one or more in-season N applications
- Reducing N losses due to denitrification and leaching
- Reducing potential for nitrate contamination of surface and ground water supplies
- Providing a fertility-based approach to capping specific gravity in the optimal range for processing

For ESN to be a useful tool for potato N management in Alberta, local information for producers is essential. We need to determine the best approach to optimize potato yield and quality without significantly increasing costs of production.

Knowledge

Preliminary results from the 2006 trial at CDCS will be presented at the Annual General Meeting

Transfer Plan of the Potato Growers of Alberta (PGA). The results will generate interest in the potential use of polymer-coated urea products as a nitrogen management tool.

In 2007, a grower cooperator has agreed to host a field-scale demonstration in a commercial Russet Burbank field. The PGA field day may include a field tour of the site. This will increase awareness and provide an opportunity for growers to provide feedback and ask questions.

Results from 2007, 2008 and 2009 will be presented at the PGA annual meeting each year in the form of oral or poster presentations.

Progress reports will be generated each year and provided to sponsors and cooperators.

Articles will be prepared for Agri-News and the PGA newsletter once data starts coming in (2008+).

There is potential for a scientific publication to be produced based on the information generated by the project.

Agrium has already developed information brochures for the ESN product. The polymer coating has been accepted by CFIA for use in Canadian potato production. As demand for the product increases, an economy of scale may be realized and the price differential between urea and coated urea should become smaller. Agrium will receive information related to the trial that will help them scale production to meet anticipated demand for the product.

Project Team Qualifications The research team is strong. Each member of the team has worked previously with polymer-coated urea. Two of the team members have worked with potato, while the other team member has extensive experience on other irrigated crops in southern Alberta.

Soil fertility advice will be provided by Dr. Ross McKenzie. Fertilizer applications will also be supervised by Dr. McKenzie to ensure that rates and incorporation methods are appropriate.

Seed preparation, planting and potato crop management will be provided by Dr. Michele Konschuh and staff at CDCS and at the Vauxhall station. Petiole sampling will be coordinated by Dr. Michele Konschuh. Harvest will be conducted by technical staff at CDCS and Vauxhall. Grading will be completed by McCain or by technical staff at CDCS and Vauxhall.

Dr. Zvomuya will provide valuable insight when results are interpreted. Dr. Zvomuya has worked with ESN on potato in other potato production areas.

Individually, each member of the team has demonstrated success with projects of this size and scope. The team leader has a track record of success leading potato projects and has worked successfully on similar projects in the past. The team leader has also had experience working with individual members of the team on other projects. This represents the first time this particular group of people have been assembled for a project. The team composition brings together the potato, agronomy and fertility expertise required for this project.

Ability to Complete Individual members of the team have access to equipment and facilities at CDCS and the AAFC Substation at Vauxhall required for the work proposed. The work requires access to land suitable for potato production, fertilizer application equipment, irrigation infrastructure, potato equipment, and grading and storage facilties. In some cases, there may be opportunities to share facilities between team members, but this need is not anticipated.

McCain Foods Canada, a commercial processor, was involved with grading potatoes in the preliminary ESN trial conducted in 2006. We have anticipated a similar level of in-kind contribution for this three year trial. In the event that they are unable to commit this in-kind contribution, adequate facilities are available through AAFRD and AAFC.

We have one grower cooperator willing to provide a demonstration site in 2007 and there is strong interest in this project from the potato industry

As with any project on crops, there remains some uncertainty with respect to the weather. We have tried to address this uncertainty by including two locations per year for three years.

The team should be well able to meet the specified objectives in a cost-effective manner.

Literature Cited

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2. Love, S.L., J.C. Stark and T. Salaiz. 2005. Response of four potato cultivars to rate and timing of nitrogen fertilizer. Amer. J. Potato Res. 82: 21-30.
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9. Zvomuya, F. and C.J. Rosen. 2001. Evaluation of polyolefin-coated urea for potato production on a sandy soil. HortSci. 36: 1057-1060.
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Budget Commentary

Personnel costs will cover the costs of employing seasonal workers to cut and treat seed, plant potatoes, irrigate and weed plots, collect petiole samples, harvest and assess potatoes.

In-kind government contributions represent manpower committed to the project by technical, professional and field staff. I have also tried to estimate in-kind contributions provided such as access to suitable land, land preparation, irrigation infrastructure and water supply, protectant pesticides as required, field equipment, fuel, grading equipment and storage facilties.

In-kind industry contributions include fertilizer products supplied by Agrium and assistance with potato grading and evaluations by McCain Foods. McCain foods offered the use of their culinary staff and lab for grading potatoes from the preliminary trial in 2006. A similar level of contribution is anticipated over the next 3 years.

The Potato Growers of Alberta typically conduct a research funding process in February each year. An application will be submitted to try to secure the PGA portion of the industry commitment. Research decisions are generally available by the end of March.

Travel includes trips to Vauxhall and the commercial demonstration site to stake plots, apply treatments, plant potatoes, petiole sample and harvest plots. Lunches for staff travelling off-site have been included as well as mileage charges to defray fuel costs.

Materials and supplies for the project include seed potato, costs for soil sample analyses, costs for petiole sample analyses, and stakes, bags and tags required to conduct the work. Sample analyses are the largest part of the estimated cost of supplies.

CDL costs include partial coverage to attend one industry conference per year. In the third year of the trial, aniticpated page charges for a scientific publication have been included.

Anticipated Budget By Year

Year 1

Source	Type	Personnel	Travel	Capital Assets	Supplies	CDL*	Overhead	Total/Year
Funding Consortium	Cash	$8,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$8,000.00
Gov't	Cash	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Gov't	In-Kind	$20,000.00	$0.00	$0.00	$4,000.00	$0.00	$0.00	$24,000.00
Industry	Cash	$7,000.00	$1,500.00	$0.00	$5,000.00	$500.00	$0.00	$14,000.00
Industry	In-Kind	$2,000.00	$0.00	$0.00	$500.00	$0.00	$0.00	$2,500.00
	Total:	$37,000.00	$1,500.00	$0.00	$9,500.00	$500.00	$0.00	$48,500.00
*Communication, Dissemination, and Linkage								

Year 2

Source	Type	Personnel	Travel	Capital Assets	Supplies	CDL*	Overhead	Total/Year
Funding Consortium	Cash	$8,500.00	$0.00	$0.00	$0.00	$0.00	$0.00	$8,500.00
Gov't	Cash	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Gov't	In-Kind	$20,000.00	$0.00	$0.00	$4,000.00	$0.00	$0.00	$24,000.00
Industry	Cash	$7,000.00	$1,500.00	$0.00	$5,000.00	$500.00	$0.00	$14,000.00
Industry	In-Kind	$2,000.00	$0.00	$0.00	$500.00	$0.00	$0.00	$2,500.00
	Total:	$37,500.00	$1,500.00	$0.00	$9,500.00	$500.00	$0.00	$49,000.00
*Communication, Dissemination, and Linkage								

Year 3

Source	Type	Personnel	Travel	Capital Assets	Supplies	CDL*	Overhead	Total/Year
Funding Consortium	Cash	$8,500.00	$0.00	$0.00	$0.00	$500.00	$0.00	$9,000.00
Gov't	Cash	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Gov't	In-Kind	$20,000.00	$0.00	$0.00	$4,000.00	$0.00	$0.00	$24,000.00
Industry	Cash	$7,000.00	$1,500.00	$0.00	$5,000.00	$500.00	$0.00	$14,000.00
Industry	In-Kind	$2,000.00	$0.00	$0.00	$500.00	$0.00	$0.00	$2,500.00
	Total:	$37,500.00	$1,500.00	$0.00	$9,500.00	$1,000.00	$0.00	$49,500.00
*Communication, Dissemination, and Linkage								

Budget Grand Total

Personnel	Travel	Capital Assets	Supplies	CDL*	Overhead	Grand Total
$112,000.00	$4,500.00	$0.00	$28,500.00	$2,000.00	$0.00	$147,000.00
*Communication, Dissemination, and Linkage						

Total Amount Requested from Members of the FC

Year	Amt Requested From FC
Year 1	$8,000.00
Year 2	$8,500.00
Year 3	$9,000.00
Year 4	$0.00
Year 5	$0.00
Total Amount Requested From FC:	$25,500.00

Funding Contribution and Sources

Source	Amount	Percentage of Total
Funding Consortium Cash	$25,500.00	17.35%
Gov't Cash	$0.00	0%
Gov't In-Kind	$72,000.00	48.98%
Industry Cash	$42,000.00	28.57%
Industry In-Kind	$7,500.00	5.10%
Total Project Cost:	$147,000.00	100%

Government Sources

Name	Amount Cash	Amount In-Kind	Confirmed
Alberta Agriculture Food and Rural Development	$0.00	$43,500.00	Yes
Agriculture and Agri-Food Canada	$0.00	$28,500.00	No

Industry Sources

Name	Amount Cash	Amount In-Kind	Confirmed
Agrium	$36,000.00	$1,500.00	Yes
McCain Foods	$0.00	$6,000.00	No
Potato Growers of Alberta	$6,000.00	$0.00	No

Approvals and Permits

Approval/Permit	Status
Canadian Environmental Assessment Act	N/A
Alberta Environment Act	N/A
Human Ethics Approval	N/A
Animal Care Approval	N/A
Transgenic Crop Permit	N/A
Other	N/A

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Ph.D. Developmental Plant Physiology University of Calgary 1995
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Publications and Patents:
7 refereed papers, 2 published conference proceedings, 14 posters at potato conferences and presentations at potato industry meetings, >12 project reports to project sponsors and funding agencies.

Calpas, J, MN Konschuh, S Lisowski and H Ono (2006) The Canadian Entomologist. Submitted.
Calpas, JT, MN Konschuh, CC Toews and JP Tewari (2006) Can. J. Plant Pathol. 28: 109-124.
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DR Lynch, LM Kawchuk, Q Chen, M Konschuh, J Holley, DK Fujimoto, D Driedger, H Wolfe, L Dunbar, D Waterer, P Bains, J Wahab, and P McAllister (2004) Alta Russet: An early maturing, high quality russet cultivar for wedge cut French fry production. Am. J. Potato Res. 81:195-201.
Miranda, J, MN Konschuh, EC Yeung & CC Chinnappa (1999) In vitro plantlet regeneration

from hypocotyl explants of Stellaria longipes (Caryophyllaceae). Can. J. Bot. 77: 318 – 322.
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Konschuh MN & TA Thorpe (1997) Metabolism of 14C-aspartate during shoot bud formation in cu

Other Evidence of Productivity:
2001 – Present Secretary, Cultivar Registration Committee, Western Potato Council
2001 – Present Chair, Research Priorities Committee, Western Potato Council

Konschuh, MN, RJ Howard, R McKenzie, J Thomson, L Kawchuk, SA Woods, and D Waterer (2006)Use of green manure crops to reduce soil-borne pests and diseases of Alberta potato crops. ACIDF and AFC Grant 2006F052R
Konschuh, MN, P. McAllister, and D Drierger (2005) Lutein content of yellow-fleshed potatoes grown in Alberta. ACAAF Grant #AB0001

D. Driedger & MN Konschuh (2002) Yellow discoloration of potato flesh Phase II: Chemical differences between yellow and white Russet Burbank potatoes and effect of temperature stress on Russet Burbank flesh color. ACIDF Project Report 2002C112N.
MN Konschuh & AM Johnson-Flanagan (2002) Characterization and production of consistent, and reliable Echinacea. AARI Project Report #98P009.

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Degrees Certificates/Diplomas:
University of Alberta - 1975 - B.Sc. Soil Sci. & Plant Sci.

University of Alberta - 1982 - M.Sc. Soil Science (Physics)

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Publications and Patents:
Papers accepted for publication:
McKenzie, R.H., Bremer, E., Middleton, A.B., Pfiffner, P.G. and Dowbenko, R.E. 200x. Controlled-release urea for winter wheat in southern Alberta. Can. J. Soil Sci. (Accepted).
McKenzie, R.H., Bremer, E., Middleton, A.B., Pfiffner, P.G. 200x. Efficacy of high seeding rates to increase grain yield of winter wheat and winter triticale in southern Alberta. Can. J. Plant Sci. (Accepted).

Published papers in the past five years:
McKenzie, R.H., Middleton, A.B. and Bremer, E. 2006. Fertilizer and rhizobial inoculant responses of chickpea on fallow and stubble sites in southern Alberta. Can. J. Plant Sci. 86:685-692.
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the Canadian prairies. Can. J. Soil Sci. 86:565-572.
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O'Donovan, J., Blackshaw, R.E., Harker, K.N., Clayton, G.W. and McKenzie, R.H. 2005. Variable crop establishment contributes to differences in competitiveness with wild oat among cereal varieties. Can. J. Plant Sci. 85:771-776.
McKenzie, R.H., Middleton, A.B. and Bremer, E. 2005. Fertilization, seeding date, and seeding rate for malting

Other Evidence of Productivity:
University of Lethbridge:
Adjunct professor at the University of Lethbridge. Instruct two forth year courses Geog 4760 - Agricultural Soil Management and Geog 4770 - Irrigation Science; teach independent study classes for individual students.

Recent Awards:
Received the Distinguished Agrologist Award from the Alberta Institute of Agrologists
U of L Agricultural Student Society - Distinguished Teaching Award - 2005

Present Major Research Activities:
Optimizing water use, nitrogen use and agronomic practices for irrigated grain and oilseed crop production in Alberta; ACIDF Project F017R
Optimizing marketing and production of irrigated soft white spring wheat in Alberta; ACIDF Project C011R
Effect of irrigation and nutrient management on yield and quality of timothy hay; ACIDF Project A158R

Optimizing nitrogen fertilizer management for winter cereal production;RT Linkages and Duck's Unlimited project
Manipulation of malt barley quality characteristics through optimization of agronomic , genetic, and environmental factors; various funding agencies.
Evaluation of new crops such as winter canola, winter pea; winter lentils; and mung bean potential or southern Alberta; various funding agencies.

Extension Activities:
Lead the organization of the Agronomy Update Conference held every second year in Lethbridge

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Degrees Certificates/Diplomas:
University of Zimbabwe – 1987-1990: B.Sc. Agriculture (Soil Science)
University of Reading (England) - 1992-1993: M.Sc. Soil Science (Soil Fertility/Chemistry)
University of Minnesota – 1996-2000: Ph.D. Soil Science (Soil Fertility/Chemistry)

Publications and Patents:
Zvomuya, F., F.J. Larney, O.O. Akinremi, R.L. Lemke, and V.E. Klaasen. 2006. Topsoil replacement depth and organic amendment effects on plant nutrient uptake from reclaimed natural gas wellsites. Canadian Journal of Soil Science: 86 (in press).
Charmley, E., D. Nelson, and F. Zvomuya. 2006. Nutrient cycling in the vegetable processing industry: Utilization of potato by-products. Canadian Journal of Soil Science 86:621-629.
Zvomuya, F., B.L. Helgason, F.J. Larney, H.H. Janzen, O.O. Akinremi, and B.M. Olson. 2006. Predicting phosphorus availability from soil-applied composted and non-composted cattle feedlot manure. Journal of Environmental Quality 35:928-937.
Zvomuya, F., C.J. Rosen, and S.C. Gupta. 2006. Phosphorus sequestration by chemical

amendments to reduce P leaching from wastewater applications. Journal of Environmental Quality 35:207-215.
Zvomuya, F., C.J. Rosen, and S.C. Gupta. 2006. Nitrogen and phosphorus leaching from growing season versus year-round application of wastewater on seasonally frozen lands. Journal of Environmental Quality 35:324-333.
Zvomuya, F., F.J. Larney, C.K. Nichol, A.F. Olson, J.J. Miller, and P.R. DeMaere. 2005. Chemical and physical changes following co-composting of beef manure with phosphogypsum. Journal of Environmental Quality 34:2318-2327.
Zvomuya, F., S.C. Gupta, and C.J. Rosen. 2005. Phosphorus Leaching in Sandy Outwash Soils Following Potato-processing Wastewater Application. Journal of Environmental Quality 34:1277-1285.
Gupta, S.C., E.l Munyankusi, J. Moncrief, F. Zvomuya, and M. Hanewell. 2004. Tillage and ma

Other Evidence of Productivity:
University of Zimbabwe: External examiner for Soil Chemistry/Fertility M.Sc. and Ph.D. candidates.

Present Major Research Activities:
Environmental impact of land-disposal of oil and natural gas drilling fluids. Study focuses on ecological implications on native prairie, including changes in soil properties, range condition, and species composition.
Reclamation of abandoned oil and natural gas wellsites using organic amendments such as manure, compost, and alfalfa hay.

Attached File (s) ESNMichele Konschuh.doc

Comments
No comments to load for this proposal.

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April 20, 2007

Dr. Michele Konschuh
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Re: Application of Polymer-coated Urea (ESN) in Potato Production in Southern Alberta

Dear Michele:

We are pleased to advise that the Board of Directors of The Potato Growers of Alberta has reviewed and approved your research funding application.

We are aware that this is a three year project; the total funding of $6000 is available immediately. When requesting the funds for the project, please provide an invoice that specifies the amount, GST and to whom payable.

We appreciate your commitment and dedication to the potato industry.

Yours truly,

Vern Warkentin
Executive Director

/pl

Potato Research Digest

2008-3

Nutrient Recommendations for Russet Burbank Potatoes in Southern Alberta

This research shows that optimal nutrient requirements for Russet Burbank potatoes, as measured in the plant petioles, may be different than traditionally recommended. The new recommended nitrate nitrogen range for southern Alberta is slightly lower than the northwest USA standard, both early and late in the growing season. Optimal phosphorus ranges are substantially less than the standard recommendation. The optimal potassium ranges are similar early in the season, but may be higher late in the growing season.

Why is this research important to potato growers?

The collection and analysis of potato petiole (leaf stem) samples can be a useful and timely technique for identifying crop deficiencies that may occur mid-season, however, the currently recommended petiole nutrient concentrations for Russet Burbank potatoes are based on data collected in the northwest United States. Previous studies in southern Alberta indicate these recommendations may be high for potassium (K) and slightly high for phosphorus (P), especially in the early part of the growing season. While sufficient nutrients are necessary to maximize tuber yield, quality, and uniformity, excess fertilizer is undesirable from both an economic and an environmental perspective.

A three-year project was conducted by Alberta Agriculture and Food, with financial support from the Potato Growers of Alberta, to determine the optimal petiole nutrient concentrations for Russet Burbanks grown in southern Alberta and the relationship, if any, between potato petiole nutrient concentrations and tuber specific gravity.

How was the research conducted?

Ten different rates of N, P, and K fertilizers were surface applied on replicated plots at three different sites in southern Alberta during three growing seasons. The plots were located on a coarse-textured Orthic Brown Chernozemic soil (2004), a medium-textured Orthic Brown Chernozemic soil (2005) and a medium-textured Orthic Dark Brown Chernozemic soil (2007). The fertilizer rates for the treatments were chosen to create four increasing amounts of one nutrient, while holding the other two constant.

Petiole samples were collected and analyzed for each plot on seven occasions, starting in late June and ending in mid-August, using the fourth petiole from the top of the main stem. Approximately 80 petioles were collected from each plot, at each sampling date. Samples were ground and sent to a laboratory for analysis of nitrate nitrogen (NO_3-N), phosphorus (P), and potassium (K). Tuber samples were collected in mid September, using the PGA two-row harvester. The samples were graded and weighed to calculate total yield (short tons per acre), marketable yield, mean tuber weight, and the percentage of smalls (potatoes less than $1^7/_8$ in. diameter). Marketable yield was defined as total yield minus the yield of undersize tubers. Specific gravity was calculated as the weight in air divided by the weight in water.

> Specific gravity is the most widely accepted measurement of potato quality. There is a high correlation between the specific gravity and the starch content and percentage of dry matter or total solids in the potato. Specific gravity is important to the processor because it affects the quality and yield of the processed product. Where potatoes are fried, it affects processing costs, as oil absorption rates are inversely related to dry matter levels.

What were the research findings?

The suggested petiole nitrate-nitrogen range is slightly lower than the northwest USA standards both at the beginning of the growing season and late in the growing season. The revised optimal petiole ranges for phosphorus are substantially lower than the northwest USA standards. The recommended potassium ranges are wider than the northwest USA standards overall. They are similar early in the growing season, but the upper limits of the new potassium recommendations are greater than for the northwest USA standards later in the growing season.

Recommended Russet Burbank
Petiole Nutrient (NO_3-N, P, and K) Concentrations for Southern Alberta

Days After Planting	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

NO3-N = nitrate nitrogen, P = phosphorus, K = potassium, RY = relative yield

Potato growers should determine petiole nutrient concentrations on a field-by-field basis, considering precipitation, soil texture, sampling technique, irrigation management, and other factors, and using the new recommendations as guidelines only.

Though many growers believe increased potassium applications have an effect on specific gravity, the researchers observed no consistent or significant relationship to exist.

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Developing diagnostic tools for nitrogen management in potatoes

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FINAL REPORT
to
Potato Growers of Alberta
May 2009

Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada

1.0 Background

Nitrogen (N) fertilization in potatoes, as in most annual crops, is key to maximizing yield and quality. Potatoes are high users of N, and optimization of N application can offer economic and environmental advantages. Excessive N can lead to delayed tuber set, increased incidence of deformed tubers, hollow heart, low specific gravity of the tubers, and physiologically immature tubers all of which can result in economic loss. In addition, over fertilization can potentially have a high environmental cost as a result of contamination of both surface and groundwater resources. The majority of potatoes are grown on coarse-textured soils and excessive irrigation or rainfall can result in N leaching. In contrast, too little N leads to stunted growth, premature death of the vines, increased susceptibility to diseases such as early blight or *Verticillium* and consequently reduced yields and economic return (Waterer and Heard, 2005).

Although N fertilizer is applied in the seeding preparations, in-season N fertilizer may also be required to maximize yield. Whether additional N is applied through fertigation, banding or top-dressing, it is usually initiated following nitrate (NO_3-N) analyses of petiole samples (Zhang et al. 1996, Waterer and Heard 2005). Guidelines for petiole NO_3-N levels, which vary with the age of the crop, are available (Figure 1) and currently undergoing review[1]. Although

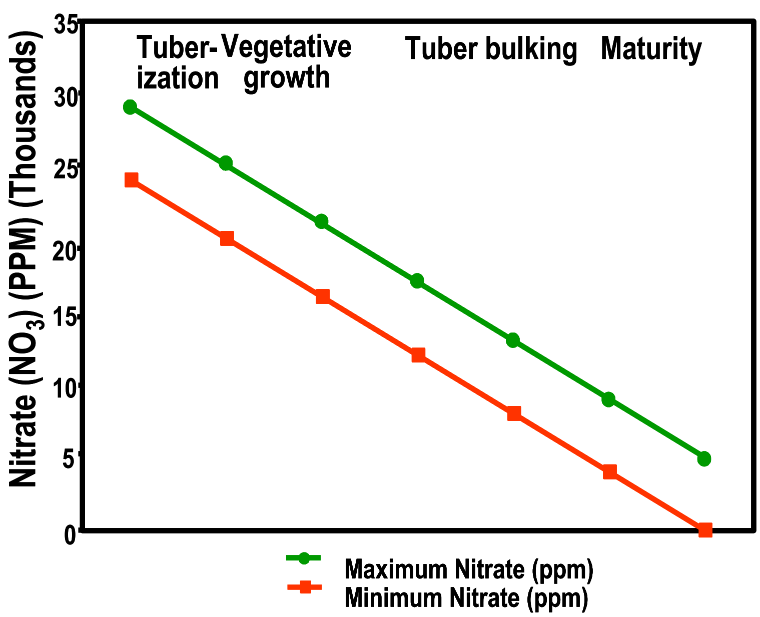

Figure 1: Target range for petiole NO3-N in potato petioles (Source: Waterer and Heard 2005).

petiole sampling is the "standard" for in-season monitoring of N levels in potato, there are some disadvantages to this technique. The NO_3-N levels can vary with the experience of the sampler, the time of day of sampling, the method of sampling, and the laboratory assay

[1] PGA Funded project. Woods S.A. Petiole Nutrient (N, P and K) Recommendations for Russet Burbank Potatoes Grown in Southern Alberta.

methods employed. There is also a delay between petiole sampling and obtaining the necessary information for management decisions.

In recent years, there had been considerable interest in the use of alternative "real-time" methods for estimating N levels in a variety of crops. These methods include the use of the Greenseeker, chlorophyll meter (SPAD-502 or Hydro-N Tester), and Dualex hand-held instruments (Figure 2). Depending on the crop, cost savings have been estimated at $10 to $20 per acres using in-season fertilization (Anon 2005).

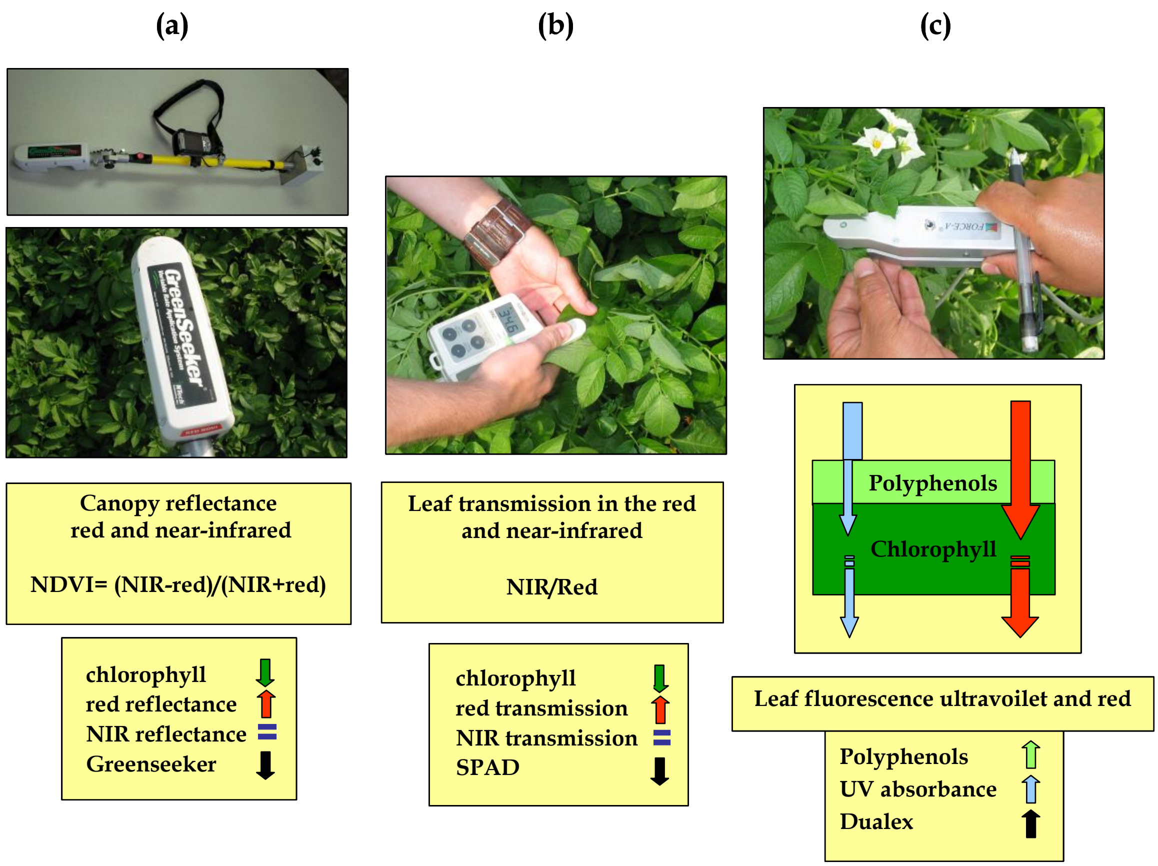

Figure 2: Greenseeker, SPAD 502 and Dualex pinciples of operation.

Research has been conducted on the use of the Greenseeker for improving N management in primarily wheat, forages and corn (Anon 2005). The Greenseeker consists of two diodes which emit energy in 671 and 780 nm wavelengths. The light reflected back from the crop is measured by a photodiode and the normalized difference vegetation index (NDVI) is computed ($[R_{780}-R_{671}]/[R_{780}+R_{671}]$). The principle is that NDVI relates to biomass and greenness (i.e. chlorophyll levels) and thus N management (Figure 2(a)). Studies suggest that the use of the Greenseeker may enable growers to optimize N use (Raun et al. 2001) and be useful in predicting in-season N requirements in potatoes (Bowen et al. 2005).

The chlorophyll meter is a hand held instrument which provides a simple, fast and non-destructive method for estimating relative amounts of chlorophyll. The chlorphyll meter measures transmittance of leaves in two wavelengths (650 and 940 nm) which are differentially absorbed by chlorophyll (Figure 2(b)). The chlorophyll meter readings can be related to chlorophyll levels and then indirectly to N management (Schepers et al. 1992, Varvel et al. 1997). This instrument has been widely used in N management research in a variety of crops (Wood et al. 1992, Follet et al. 1992, Sing et al. 2002) including potatoes (Vos and Bom 1993, Minotti et al. 1994, Denuit et al. 2002, Rodrigues 2004). A study in Belgium, involving field level production, indicated the potential use of a chlorophyll meter to monitor potato plant N status and aid in split applications of N fertilizer (Olivier et al. 2006).

More recently, investigations into the use of fluorescence excitation and the Dualex field portable instrument for N management have appeared in the literature (Cartelat et al. 2005). The Dualex (dual excitation) which measures leaf levels of polyphenolics and chlorophyll, operates in full daylight with an UV beam at 375 nm and a red reference beam at 650 nm (Figure 2(c)). Under conditions of N stress the concentration of polyphenolic compounds in leaves increases while chlorophyll content. The potential of this instrument as a tool for in-season nitrogen management in corn and wheat has recently been shown (Tremblay et al. 2007, Tremblay and Bélec 2006, Cerovic et al. 2005) but to date data for potatoes are very limited.

The use of the newly developed Dualex instrument in combination with a chlorophyll meter may offer even greater potential than either instrument individually to identify N stress due to measurement of both chlorophyll and polyphenolic compounds (Cartelat et al. 2005, Cerovic et al. 2005, Meyer et al. 2006).

Objective

(1) To conduct a second year pilot study to evaluate the use of the Greenseeker, SPAD, and Dualex meters for measuring in-season N deficiency in potatoes.
(2) To determine the relationship amongst the Greenseeker, SPAD and Dualex readings and petiole N values.

2.0 Methods

2.1. Experiment 1 and 2

2.1.1. Study sites

There were two study sites, Brooks (Experiment 1) and Vauxhall (Experiment 2), Alberta. The study sites were established and maintained by Dr. Michele Konschuh and were part of an on-going study into the effects of urea as opposed to ESN (slow release fertilizer) applications on potato productivity. There were 10 treatments in each trial of which only the five urea treatments were sampled (Tables 1 and 2, Figure X). The residual soil N level at both Brooks and Vauxhall resulted in a higher than anticipated N level in the check treatment. At Vauxhall, the residual N level was such that planned lowest N application of 115 kg/ha was not possible and the treatment was replaced by 123 kg/ha residue soil N. There were 5 replicates per treatments. Each plot consisted of two rows containing 20 Russett Burbank tubers per row (40 tubers per plot). The potato tubers were planted on May 13 at Vauxhall and May 14 at Brooks. Management of the plots is described in Konschuh (2009).

Table 1: Differential nitrogen fertilizer application (kg/ha N) in the five treatments at Brooks.

Trt #	Residual Soil N (top 60 cm)	Urea (Pre-plant)	Urea (Top-dressed)	Total N	% of STD
1*	92	0	0	92	71%
2	92	133	0	225	100%
3	92	78	0	170	75%
4	92	23	0	115	50%
10**	92	88	65	245	109%

* No N added, residual N in the soil from soil testing.
** Standard treatment

Table 2: Differential nitrogen fertilizer application (kg/ha N) in the five treatments at Vauxhall.

Trt #	Residual Soil N	Urea (Pre-plant)	Urea (Top-dressed)	Total N	% of STD
1*	123	0	0	123	54%
2	123	102	0	225	100%
3	123	47	0	170	75%
4	123	0	0	115	50%
10**	123	90	65	278	124%

* No N added, residual N in the soil from soil testing.
** Standard treatment

2.1.2. Petiole sampling

Petiole samples were taken three times during the 2008 season to determine NO_3-N. At Brooks samples were taken 44 (June 26), 66 (July 18) and 86 (August 8) days after planting (DAP) while at Vauxhall sampling was conducted 46 (June 27), 71 (July 22) and 85 (August 6) DAP. The July sampling at Vauxhall was delayed one week due to a hailstorm. The protocol used is described in Konschuh (2009).

2.1.3. Greenseeker, SPAD and Dualex measurements

Greenseeker, SPAD and Dualex measurements were taken 44 (June 26), 64 (July 16) and 87 (August 7) DAP at CDC South, Brooks and 44 (June 25), 64 (July 15), 71 (July 24) and 85 (August 5) DAP at Vauxhall. As there was a hail storm at Vauxhall 64 DAP (July 15) the plots were re-sampled 73 DAP (July 24) to provide closer sampling to the petiole NO_3-N measurements.

The Greenseeker NDVI measurements were taken over the area that included the 4th, 10th and 16th plant in each row. Particular attention was paid to keeping the sensor height in relation to the top of the crop canopy the same on each date. Six NDVI readings were recorded per plot to provide a measure of in-plot variability as well as between plot variability.

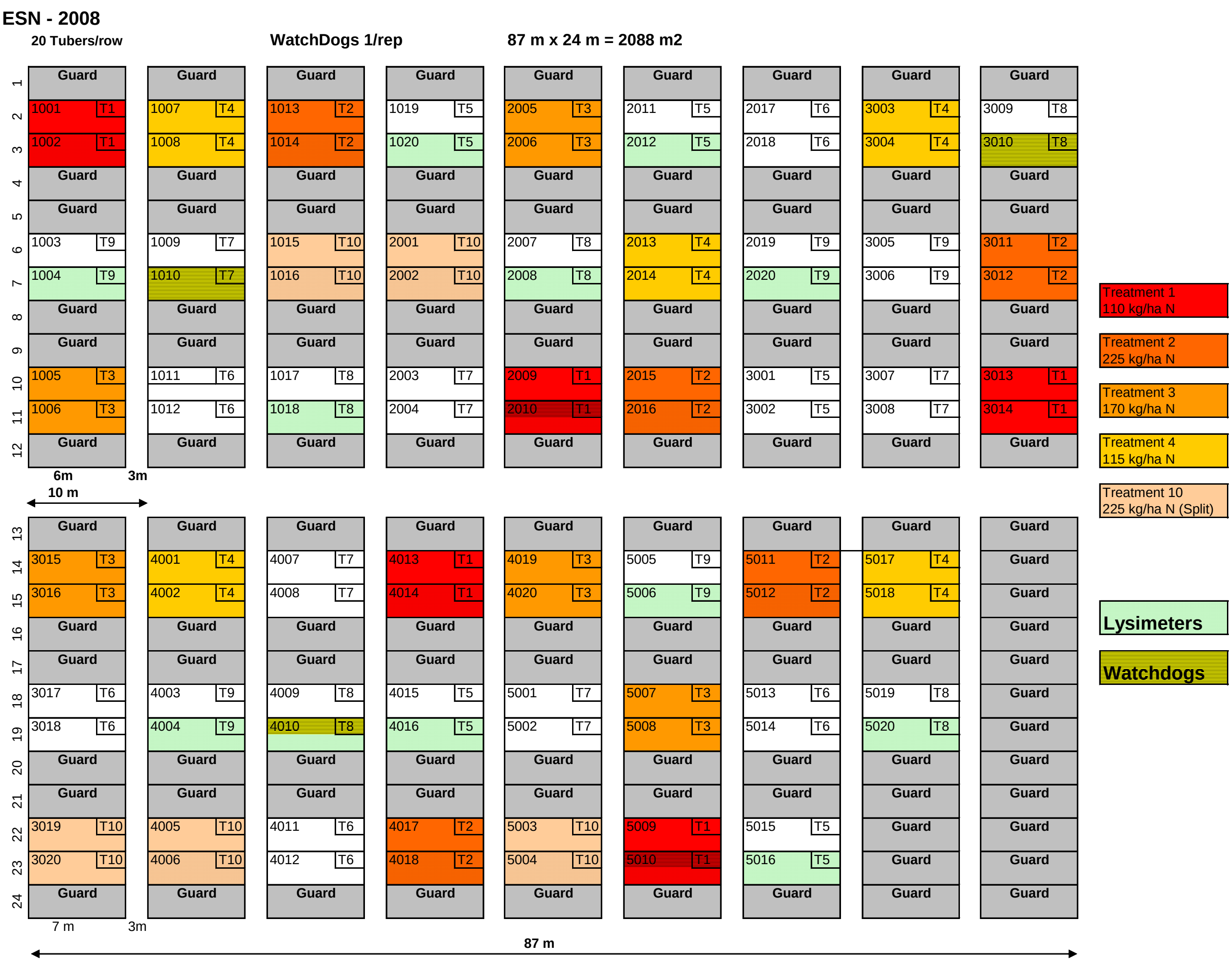

Figure 3: Plot layout at Brooks and Vauxhall.

Consistent with the Greenseeker measurements the SPAD and Dualex readings were taken at the midpoint of the terminal three leaflets on the 4th fully expanded compound leaf of the 4th, 10th and 16th plant of each row within a plot (Figure 4). The SPAD readings were taken on the upper surface of the leaflets while the Dualex readings were taken on both the upper and lower surface of the leaflets. The three SPAD and the six Dualex readings per plant were averaged as were the readings from the six plants per plot to provide a mean value per plot. In order that the SPAD and Dualex readings could be compared and used to create a SPAD/Dualex ratio, the measurements were always made in the same order (i.e. the 1st, followed by the 2nd followed by the 3rd leaflets).

Due to variations in the soil, water supply, growth stage, sampling protocols, variety, seasonal environmental conditions, and variations amongst the machines themselves, it is generally accepted that absolute values for Greenseeker, SPAD and Dualex are unsuitable. Accordingly, it is generally accepted that the values measured with these instruments are ratioed to those obtained from plants within a nutrient rich reference area (Tremblay and Bélec 2006). The results for the Greenseeker, SPAD and Dualex measurements are expressed as a ratio where the denominator is the mean value obtained in the 245 and 278 kg/ha split N application treatment at Brooks and Vauxhall respectively, as these treatments were deemed to be nutrient rich.

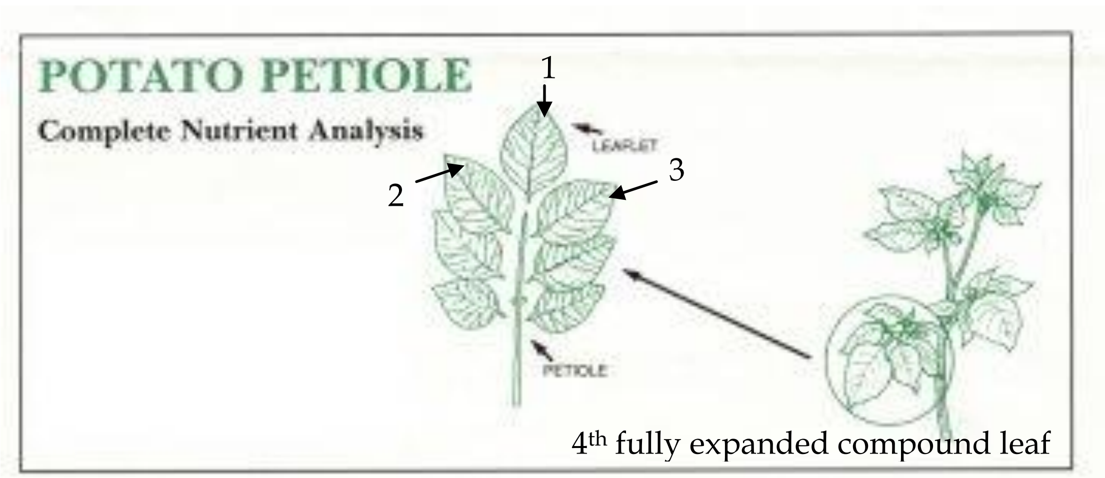

Figure 4: Diagram of petiole and sampling sites.

2.2. Experiment 3.

2.2.1. Study site

The third experiment was conducted in an irrigated commercial potato field. Pre-plant N was applied based upon initial soil tests and with the exception of two areas in the field (Figure 5) in-season N was applied based upon petiole sampling. In the two areas set aside, based upon petiole sampling, 0 and 50% of the in-season required N rate was applied. To achieve these treatments, fertigation was withheld in the 0% treatment and occurred only every second time in the 50% rate.

2.2.2. Greenseeker, SPAD, Dualex and petiole sampling

Three areas were identified and flagged in each of the fertility treatments. At each location, 10 Greenseeker measurements were taken as described above. The measurements were taken in a random pattern around the flags but ensuring that there was a minimum of 10 paces (approx 7.5 meters) between samples. Thus, a total of 30 measurements were made in each fertility treatment.

SPAD and Dualex measurements were taken as described previously. There were 10 plants per sample flag for a total of 30 plants and 180 individual measurements per treatment. The same plants were sampled on each date. Measurements are taken at the same time as the petiole sampling. Typically this occured between 7:30 and 9:30 AM. Petiole samples and hand held instrument measurements were taken weekly over the growing season (June 28, July 5, 12, 18 and 25, and August 2, 9, 16 and 23).

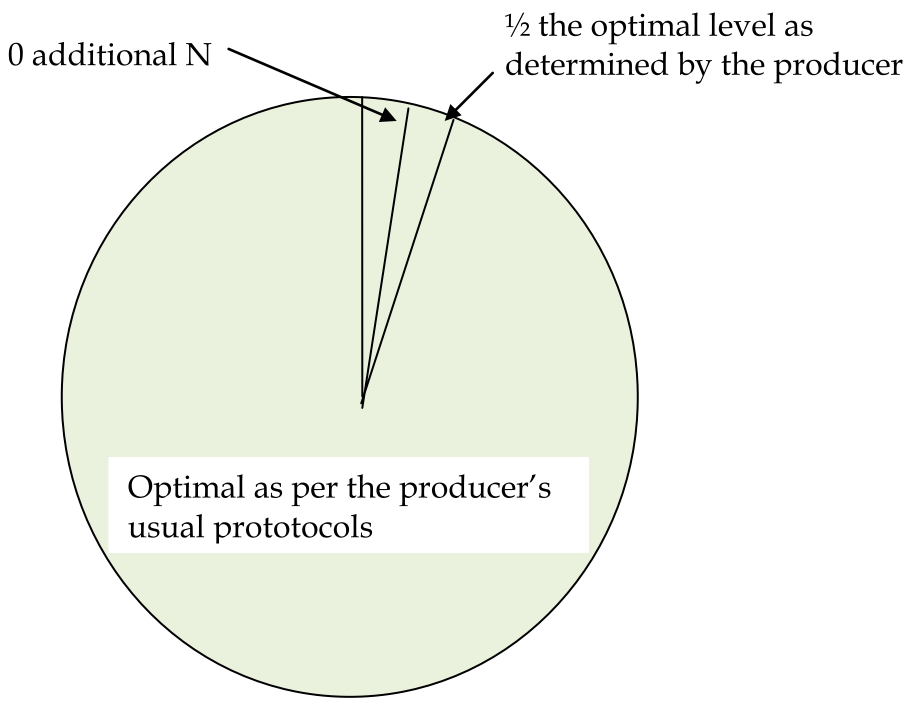

Figure 5: Experimental set-up in the commerical potato field.

3.0 Results

3.1. Experiment 1 and 2

3.1.1. Yield

At Brooks there was no significant difference in marketable yield amongst the various N treatments. However, total potato yield, when compared to the standard 245 kg/ha N split application, was significantly greater in the 170 kg/ha treatment which could be attributed to the greater yield of large potatoes. The yield of small and medium potatoes, compared to the standard 245 kg/ha split N application was unaffected by the various N treatments (Figure 6).

A hailstorm at Vauxhall on 64 DAP resulted in damage to the aboveground plant material and likely contributed to the lower yields at Vauxhall compared to Brooks. Total, marketable and medium sized potato yields were unaffected by N treatment at Vauxhall. However, compared to the standard 278 kg/ha split application of N, large tuber yield was significantly lower and small tuber yield significantly greater in the 123 and 170 kg/ha N treatments (Figure 7).

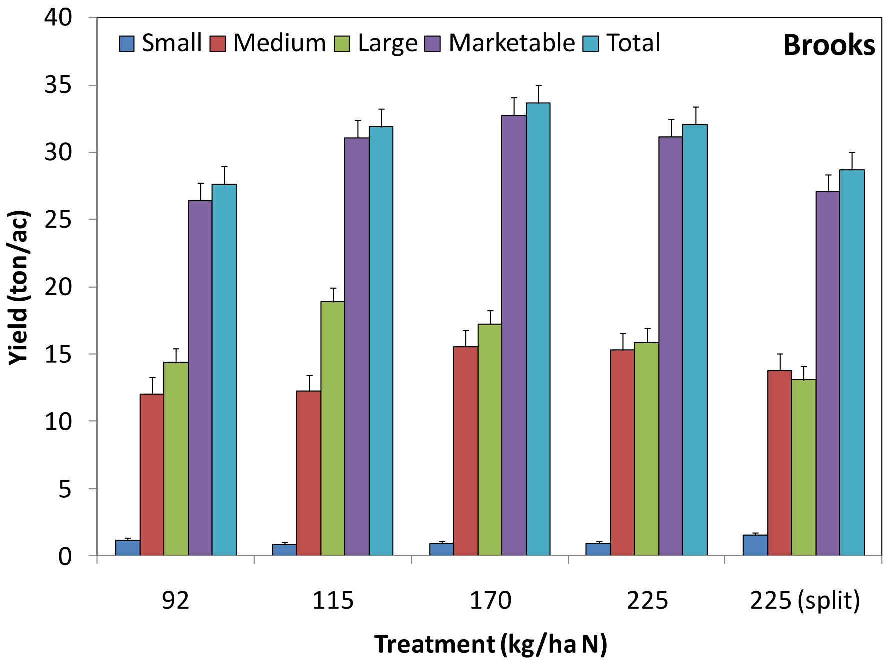

Figure 6: The effect of varying N application rates on potato yield at Brooks, AB**.**

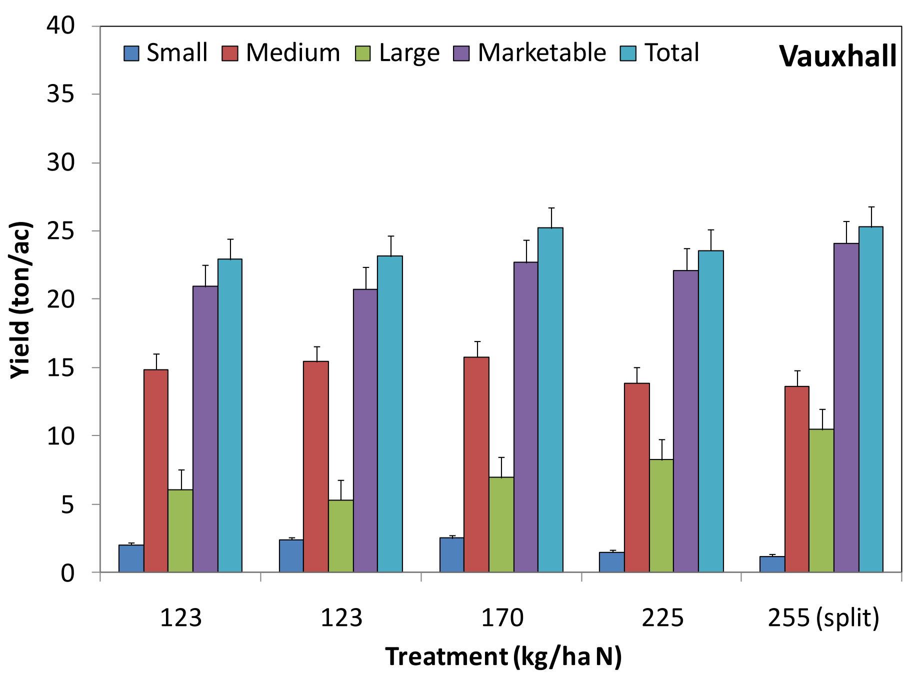

Figure 7: The effect of varying N application rates on potato yield at Vauxhall.

3.1.2. *Petiole NO_3-N*

Petiole NO_3-N levels decreased over the season at Brooks. With the exception of the single pre-plant 225 kg/ha N application 44 DAP, the 225 kg/ha split N treatment showed significantly higher petiole NO_3-N levels compared to the other treatments. 44 and 64 DAP, the reduction in petiole NO_3-N level increased with decreasing N application rate but 86 DAP there was no significant difference in the petiole NO_3-N levels amongst the single N application treatments. With the exception of the 225 kg/ha split application of N 44 DAP, the petiole NO_3-N was below the lower recommended level (Woods et al. 2008).

Petiole NO_3-N levels at Vauxhall were highest 44 DAP but lowest 71 DAP rather than 87 DAP (Figure X). This latter observation may be attributed to the effects of the hailstorm on July 15th which set back potato growth. With the exception of 44 DAP, the petiole NO_3-N levels in the 225 kg/ha split and single pre-plant applications were not significantly different from each other. The 123 and 170 kg/ha N applications rates resulted in a significant reduction in petiole NO_3-N levels, the level of reduction tending to increase with decreasing N application rate. It was noted that the petiole NO_3-N levels were below the lower limit of the optimal levels suggested by Woods et al. 2008.

3.1.3. *Greenseeker*

In all treatments at Brooks, the Greenseeker NDVI values increased from 44 to 64 DAP when full canopy closure was achieved. Thereafter the Greenseeker values remained constant. With respect to the various N treatments, the results were variable amongst dates. The Greenseeker value for the 92 kg/ha treatment was significantly lower than for any other treatment 44 DAP. With time, this difference was reduced and 86 DAP there was no significant difference in the Greenseeker values amongst the various treatments (Figure 10A).

At Vauxhall, in all treatments the Greenseeker NDVI values increased from 44 to 64 DAP when full canopy closure was achieved. With respect to the various N treatments, the results were variable amongst dates. 44 and 85 DAP there was no significant difference amongst treatments while 64 DAP compared to the standard 278 kg/ha split application the Greenseeker values were significantly lower for the other N treatments (Figure 11A). The NDVI values tended to be lower with the lower N rates.

3.1.4. *SPAD*

At Brooks, in all treatments, the SPAD remained fairly constant through the experimental period. On all measurement days the SPAD readings for the 92 and 115 kg/ha N treatments were significantly lower than for the standard 245 kg/ha split application of N. The 170 kg/ha N application also showed a reduction in SPAD readings 44 and 86 DAP but not 64 DAP (Figure 10B). Generally the level of reduction in SPAD readings increased with decreasing N application rate.

At Vauxhall, in all treatments, the SPAD values decreased with DAP. Early in the season, 44 DAP, compared to the 278 kg/ha split N application, the 123 and 170 kg/ha N treatments showed a significant decrease in the SPAD value, the SPAD value decreased with decreasing N application rate (Figure 11B). However, there was no significant difference in the SPAD values amongst all N treatments 71 and 85 DAP.

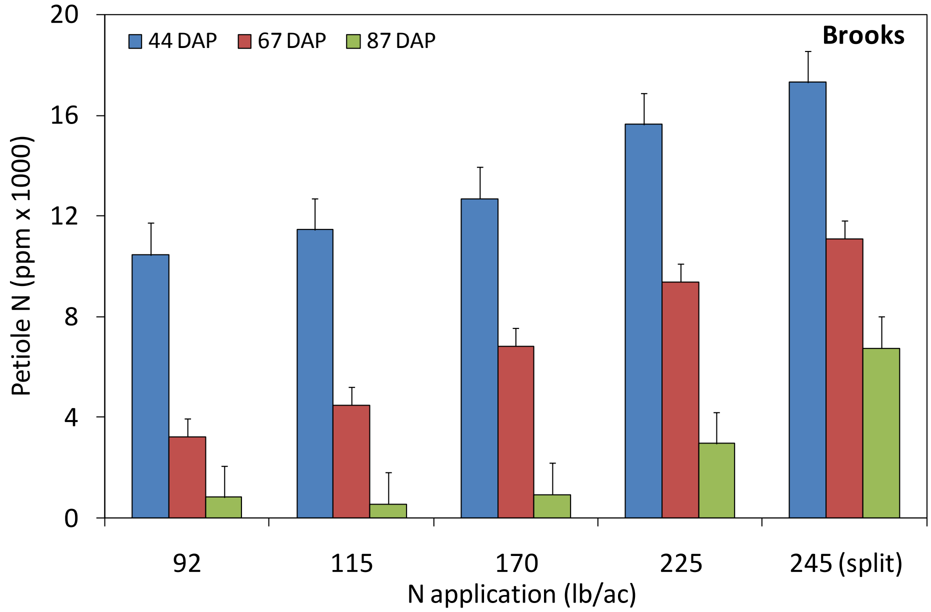

Figure 8: The effect of N application rate on potato petiole NO_3-N levels at Brooks.

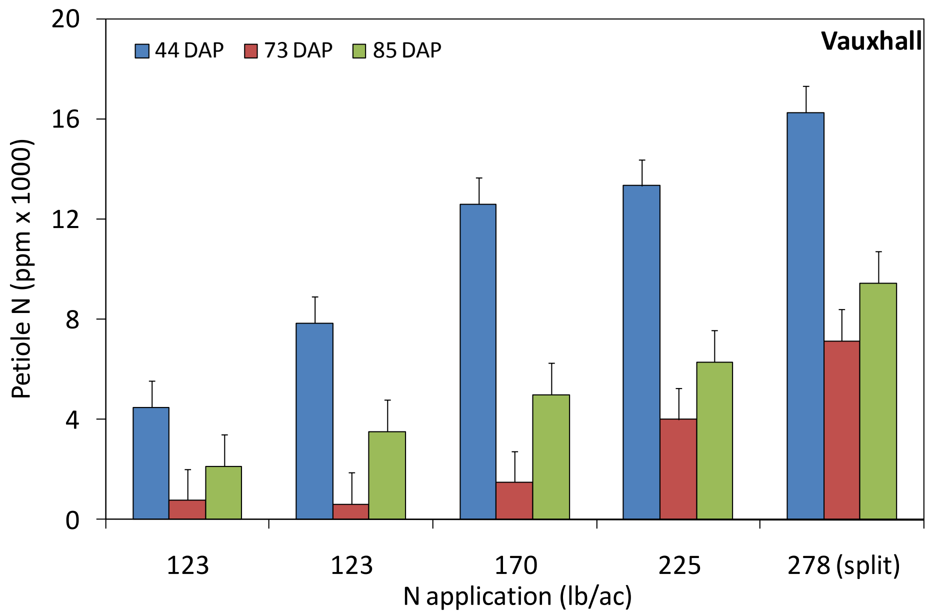

Figure 9: The effect of N application rate on potato petiole NO_3-N levels at Vauxhall.

3.1.5. Dualex

Consistently on each sampling date at Brooks, the two lowest application rates of 92 and 115 kg/ha N showed a significant increase in the potato leaf Dualex values compared to all other N treatments. There was no significant difference in the Dualex values amongst the 170 kg/ha, 225 kg/ha single N treatments and the 245 kg/ha split N application.

Within treatments at Vauxhall, the greatest change in Dualex readings occurred from 44 to 73 DAP when the values increased. From 71 DAP to 85 DAP only a slight increase was observed in the Dualex readings. With the exception of 85 DAP and the 225 kg/ha single N application, relative to the 278 kg/ha split N application, the Dualex readings significantly increased with a decrease in N application rate (Figure 11C). There was no significant difference in the Dualex readings amongst the 123 and 170 kg/ha N treatments.

3.1.6. SPAD/Dualex ratio

At Brooks, the results were similar to those with the Dualex instrument alone with the 92 and 115 kg/ha treatments showing a significant decrease in the SPAD/Dualex ratio compared to all other treatments. There was no significant difference between the SPAD/Dualex ratios in the 92 and 115 kg/ha N treatments. Unlike the Dualex alone, the SPAD/Dualex ratio showed a significant effect for the 170 kg/ha, the value being significantly lower than for the 245 kg/ha N split application treatment (Figure 10D).

In all treatments, the SPAD/Dualex ratio at Vauxhall decreased with DAP. The results were similar to those with the Dualex instrument alone. With the exception of 85 DAP and the 225 kg/ha single N application, relative to the 278 kg/ha split N application, the SPAD/Dualex ratio significantly decreased with a decrease in N application rate (Figure 11D). There was no significant difference in the SPAD/Dualex ratios amongst the 123 and 170 kg/ha N treatments.

3.1.7. Relationship hand held instruments and petiole sampling.

At Brooks there was no relationship between petiole NO_3-N and Greenseeker measurements on any date (Figure 12). The SPAD and SPAD/Dualex showed a strong relationship with petiole NO_3-N both 44 and 64 DAP while the Dualex alone only showed a significant relationship with the petiole NO_3-N 64 DAP. On the last date of measurement 86 DAP there were no significant relationships between petiole NO_3-N and any of the instrument readings. At Vauxhall, on each date a strong relationship was found between the petiole NO_3-N and the Dualex, SPAD/Dualex and Greenseeker measurements but only 44 DAP was a significant relationship observed between petiole NO_3-N and the SPAD measurements (Figure 13).

Overall at Brooks there was a significant relationship between the petiole NO_3-N and all instrument measurements except the SPAD while at Vauxhall a significant relationship was evident between the petiole NO_3-N and all instrument readings (Table 3).

Table 3: The relationship between the hand-held instrument measurements (independent variable) and potato petiole NO_3-N (dependent variable).

Location	Independent variable	Intercept	Slope	R^2	RMSE
Brooks	Dualex	44132	-39067	0.47	3958
	SPAD	-	-	-	-
	SPAD/Dualex	-13416	448	0.37	4324
	Greenseeker	45714	-46370	0.41	4183
Vauxhall	Dualex	-28352	-22733	0.68	2742
	SPAD	-27375	877	0.72	2542
	SPAD/Dualex	-5819	265	0.70	2650
	Greenseeker	37953	-39563	0.33	3941
Vauxhall + Brooks	Dualex	32487	-26805	0.55	2742
	SPAD	-24360	780	0.38	2542
	SPAD/Dualex	-7146	304	0.50	2650
	Greenseeker	40181	-40973	0.36	3941

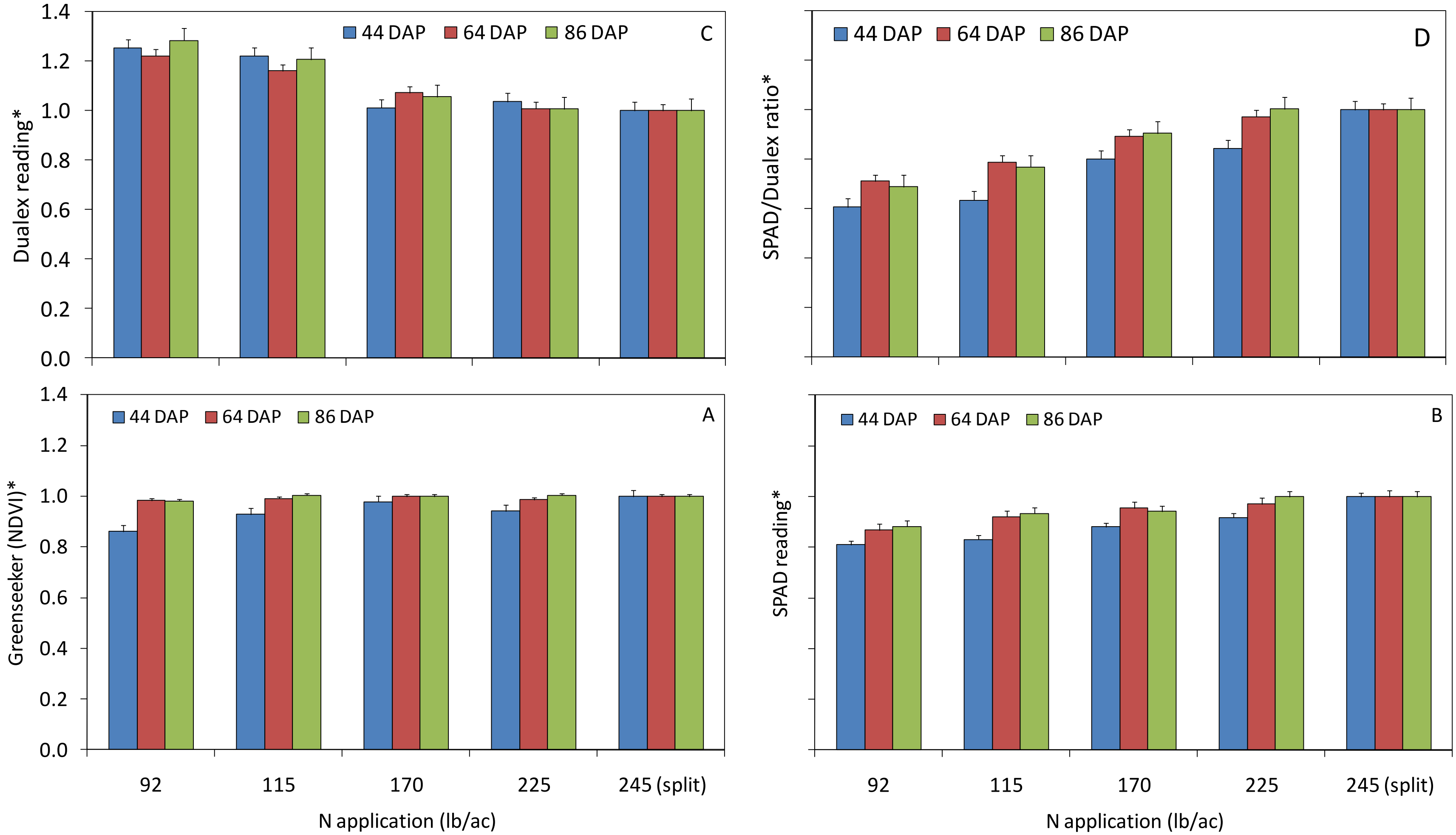

Figure 10: The effect of N application rate on potato canopy Greenseeker (A), potato leaf SPAD (B) and Dualex (C) and SPAD/Dualex ratio (D) values at Brooks.

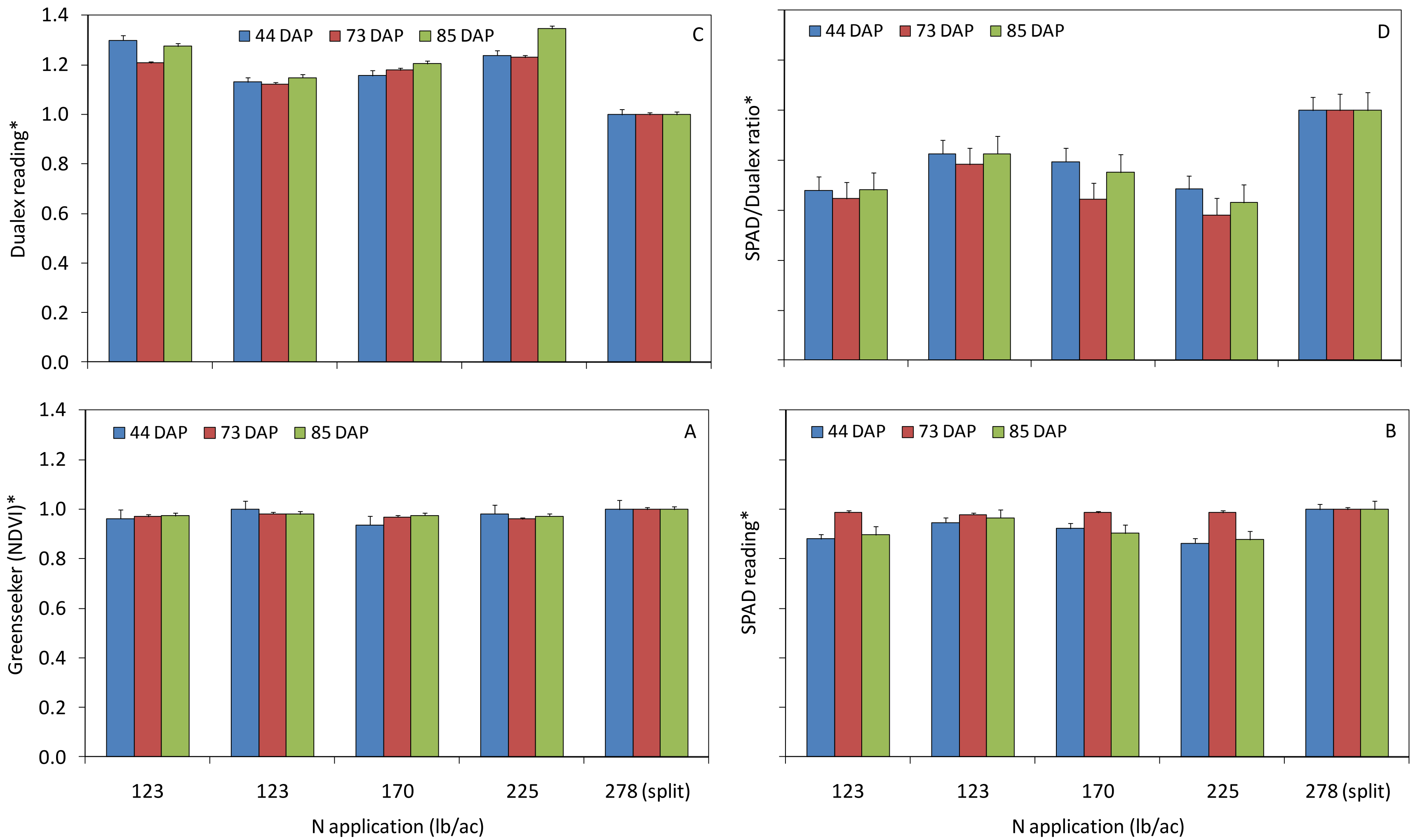

Figure 11: The effect of N application rate on potato canopy Greenseeker (A), potato leaf SPAD (B) and Dualex (C) and SPAD/Dualex ratio (D) values at Vauxhall.

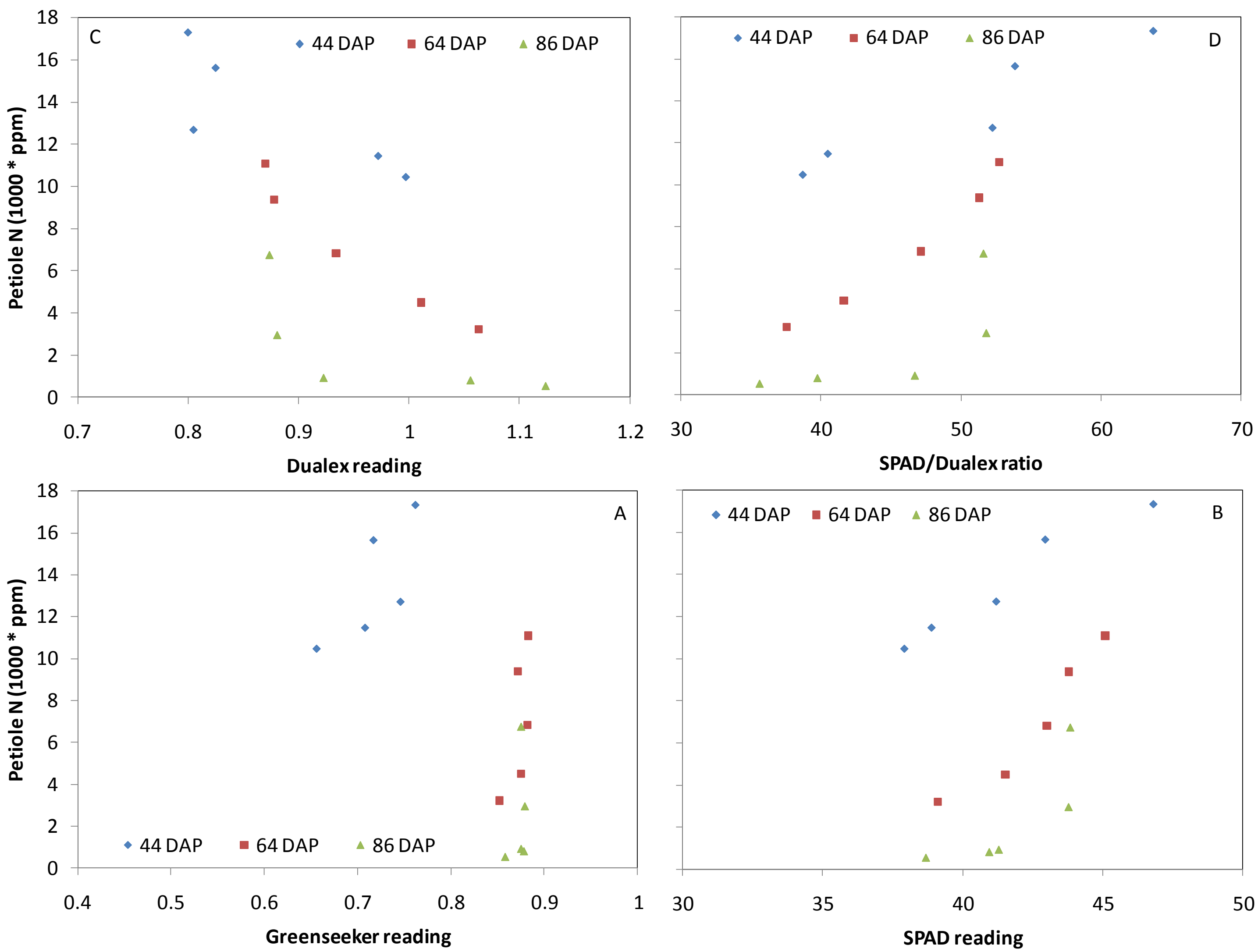

Figure 12: The relationship between the Greenseeker (A), SPAD (B), Dualex (C) and SPAD/Dualex ratio (D) and potato petiole NO_3-N at Brooks in 2008.

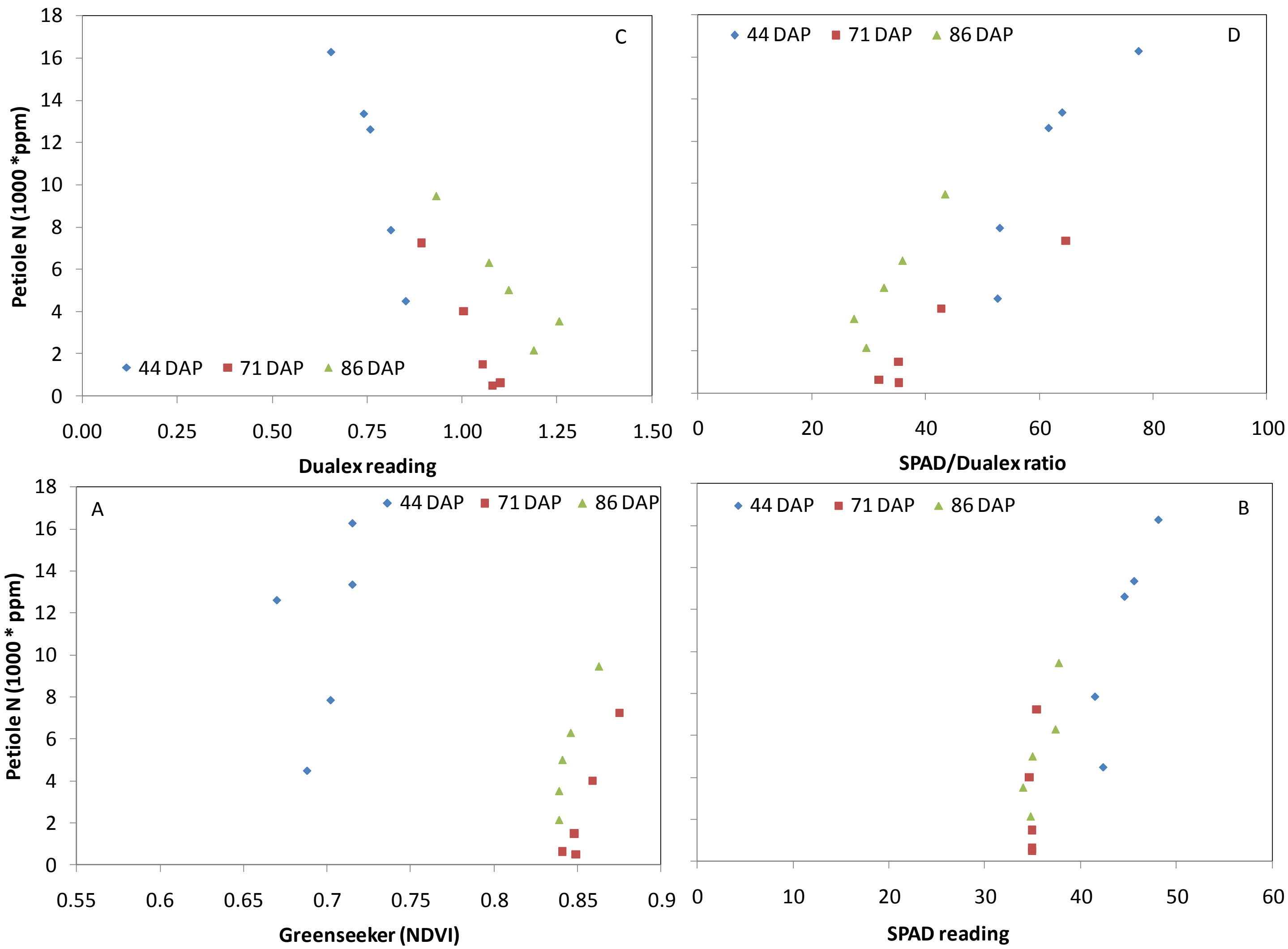

Figure 13: The relationship between the Greenseeker (A), SPAD (B), Dualex (C) and SPAD/Dualex ratio (D) and potato petiole NO_3-N at Vauxhall in 2008.

3.2. Experiment 3.

3.2.1. Yield

The total yield of potatoes in each of the three N treatment levels was similar. Unfortunately, the harvested potatoes were not separated into small, medium, and large tubers so marketable yield could not be determined.

3.2.2. Petiole NO_3-N

The potato petiole NO_3-N levels fluctuated throughout the season for all three treatments, but with few exceptions, the levels were within the optimal target for petiole NO_3-N (Figure 14).

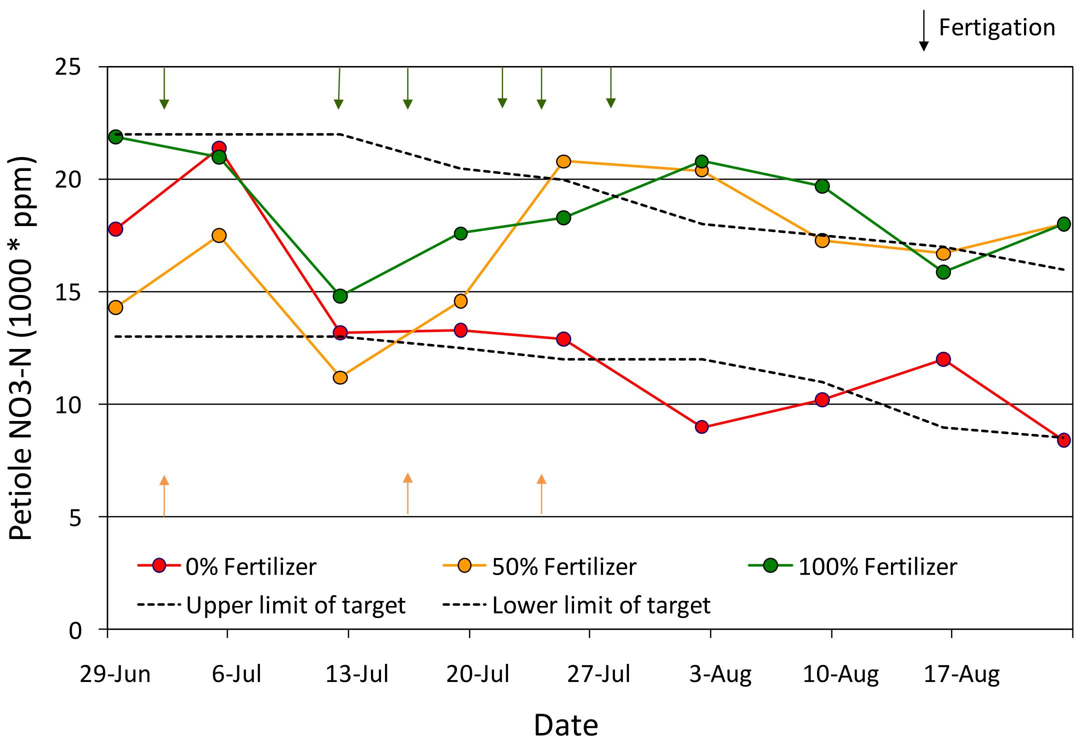

Figure 14: Petiole NO_3-N levels in the 0, 50 and 100% fertility treatments in the commercial field.

3.2.3. Greenseeker, SPAD, Dualex and SPAD/Dualex

With few exceptions the Greeenseeker, SPAD, and Dualex readings and, the SPAD/Dualex ratio values were similar amongst the three fertigation levels (Figure 15).

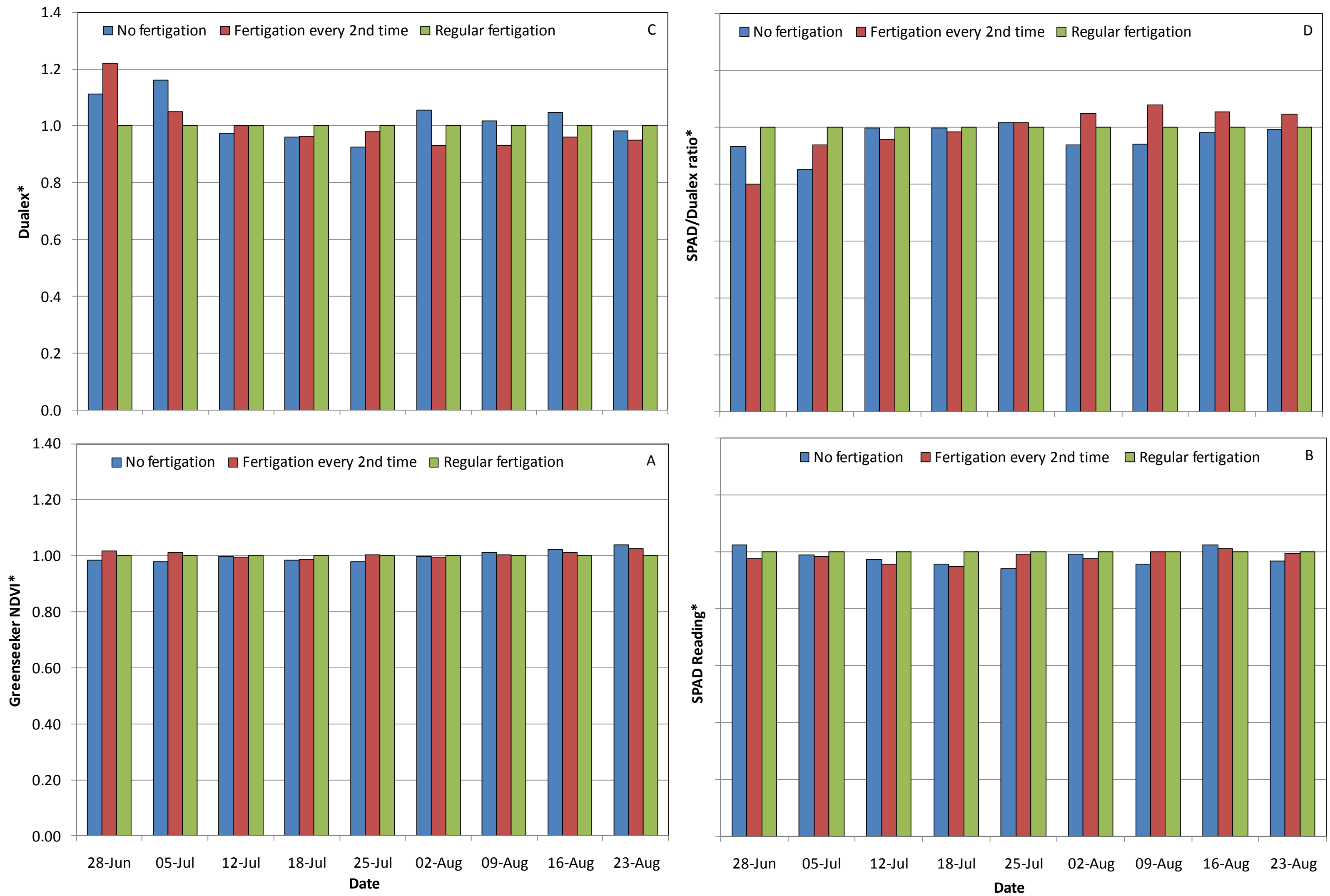

Figure 15: The effect of fertigation treatment on Greenseeker (A), SPAD (B), Dualex (C) and SPAD/Dualex (D) ratio values.

4.0 Discussion

Interestingly, at both Brooks and Vauxhall, although the petiole NO_3-N values were, with few exceptions, well below the acceptable minimum level for target yield (Table 4), the yields were acceptable. In Vauxhall, although the marketable yield of potatoes was unaffected by N treatment, there was the suggestion that the 123 and 170 kg/ha N rates altered yield with the weight of small and large sized tubers increasing and decreasing respectively. This effect on yield was mirrored in a decrease in petiole NO_3-N and SPAD/Dualex ratio values and an increase in Dualex values in plants subjected to 123 and 170 lb/ac N.

At Brooks, yield was unaffected by the various N treatments, yet the petiole NO_3-N results showed differences with respect to the differential N rates. The trends in the results for the Dualex and SPAD/Dualex combination were similar to those for petiole sampling and suggest the potential of these instruments to replace destructive sampling. This is further exemplified by the reasonable relationship observed between the petiole NO_3-N levels and both the Dualex readings and the SPAD/Dualex ratio at Vauxhall and Brooks. With respect to the SPAD and the Greenseeker, the trend in the results with respect to yields and petiole NO_3-N were not consistent over time and site. The Greenseeker readings are a measure of greenness which is a function not only of the colour of the canopy but also the amount of vegetation present. The presence of bare soil in the field of view of the instrument influences the Greenseeker readings which is not the case for the SPAD and the Dualex leaf level instruments.

Table 4: Optimal petiole NO3-N levels for Russet Burbank potatoes in southern Alberta (from Woods et al. 2008).

Days after planting	Optimal NO3-N levels (ppm)	
	Upper limit	Lower limit
44	26040	17640
46	25460	17060
67	19370	10970
71	18210	9810
86	20172	12772
87	19928	12528

Calibration of the hand-held instruments is an issue. In previous studies involving other crops an over fertilised reference strip is used to develop a sufficiency index approach to N requirement. The reference strip eliminates the influence of environment and cultivar differences in the results. In the case of potatoes, petiole NO_3-N curves have been developed for a number of cultivars which are regularly used by producers to manage in-season applications of N. It may be possible to calibrate the hand held instrument readings based upon the petiole NO_3-N levels to derive sufficiency indices.

5.0 Recommendations and potential impact of the study

The results of the two years of this study require to be integrated. However, as in 2007, the Dualex and SPAD/Dualex readings appeared to mirror trends in yield and in petiole NO_3-N levels. The Dualex and SPAD/Dualex ratio show a good correlation with petiole NO_3-N levels despite the fact that the handheld instruments provide a measure of cumulative N levels while the petiole NO_3-N provides a measure of N available at the time of measurement. The Dualex and SPAD/Dualex may be less susceptible to time of day, hydration of the plant etc.
The results suggest that research into the use of the Dualex instrument should be continued and data gathered to relate Dualex readings to N deficiency and N requirements in potatoes.

6.0 Acknowledgements

The author wishes to thank the Potato Growers of Alberta for funding to conduct this study, Alberta Agriculture and Food (M. Konschuh) for establishing and maintaining the field plots, Gary Larson, Logan Pryor and Nicole Pilgrim for field data collection and Sandberg Labs for the petiole analyses. The authors also is grateful to Harold Perry for his interest in the project and for his collaboration in the commercial field scale study.

Bibliography

There are no sources in the current document.

Government of Alberta

Agriculture and Rural Development
Agriculture Research Division
Food and Bio-Industrial Crops Branch

ESN (polymer-coated urea) on Potatoes

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Purpose

- The purpose of this research project was to determine whether polymer-coated urea (ESN – environmentally smart nitrogen) can be used in southern Alberta potato production to improve nitrogen use efficiency while maintaining yield and quality.

Some potential benefits include:

- Maintaining or reducing costs of production by increasing N-use efficiency and reducing one or more in-season N applications
- Reducing N losses due to de-nitrification and leaching
- Reducing potential for nitrate contamination of surface and ground water supplies
- Providing a fertility-based approach to capping specific gravity in the optimal range for processing

- For ESN to be a useful tool for potato N management in Alberta, local information for producers is essential. We needed to determine the best approach to optimize potato yield and quality without significantly increasing costs of production.

CDCS - Brooks

Petiole sampling

Vauxhall

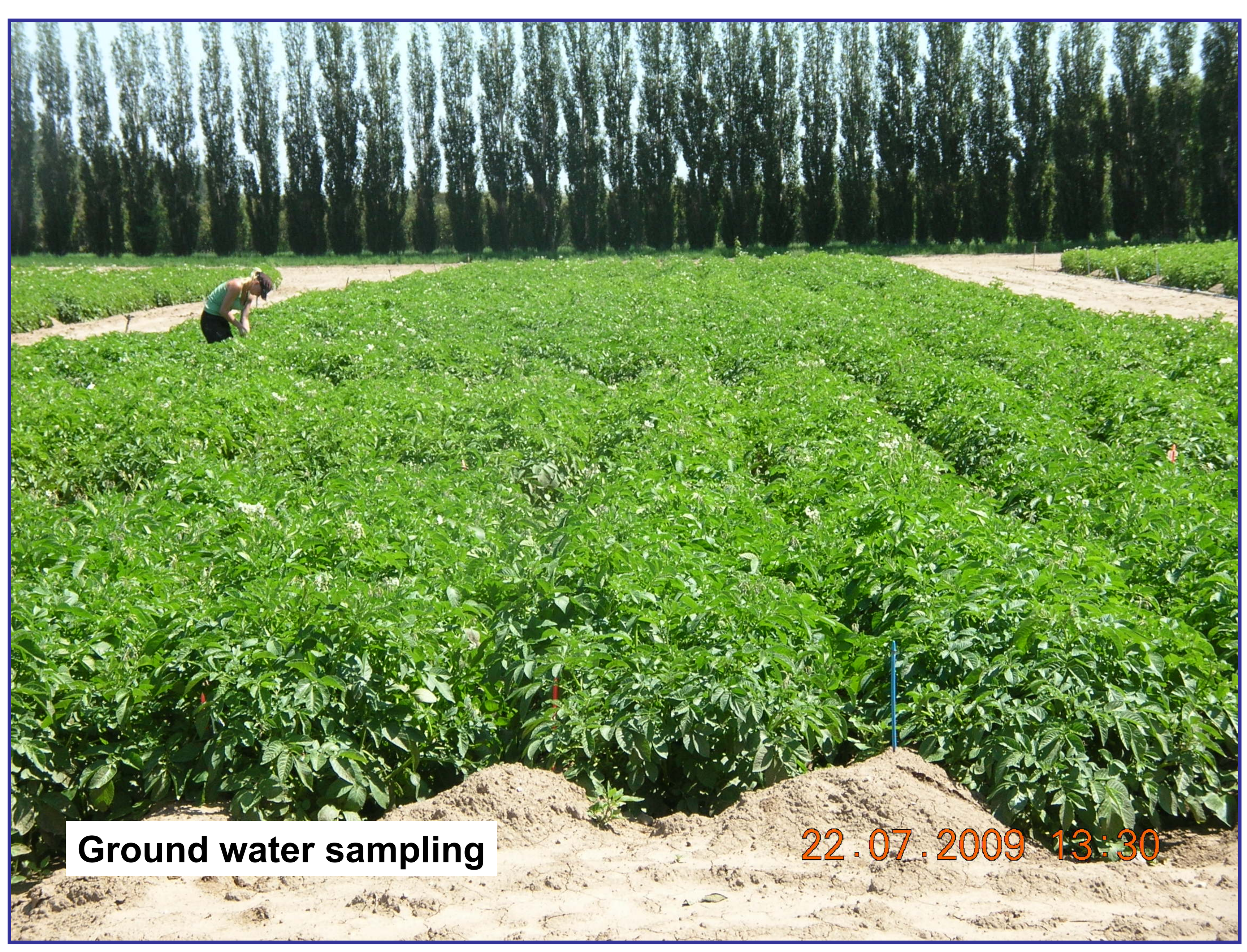
Treatments

2009 Example

Trt #	Soil N	Urea (Pre-plant)	ESN (Pre-plant)	Urea (Top-dressed)	ESN (Top-dressed)	Total N	% of STD
1	75	0	0	0	0	75	37%
2	75	125	0	0	0	200	100%
3	75	75	0	0	0	150	75%
4	75	25	0	0	0	100	50%
5	75	0	125	0	0	200	100%
6	75	0	75	0	0	150	75%
7	75	0	25	0	0	100	50%
8	75	0	0	0	75	150	75%
9	75	38	0	0	37	150	75%
10	75	63	0	62	0	200	100%

Progress

- 2009 was the final year of this three-year trial. The trial was conducted in plots at CDCS (Brooks) and at the AAFC Vauxhall Sub-Station. A total of 6 site years of data were generated and should provide sufficient information to develop recommendations for incorporating ESN as part of a nitrogen management strategy for Russet Burbank potato.
- In 2007, the best economic return at CDCS was observed in the split urea treatment (GSP), while in Vauxhall, the best economic return was observed with a split application (urea pre-plant and ESN at emergence) at the 75% rate.
- In 2008, the best economic return at CDCS was observed with 75% urea pre-plant, while in Vauxhall, the best economic return was observed with an application of ESN (75%) at emergence.
- Differences between sites were related to environmental conditions and irrigation management, while differences between years were related to environmental conditions and the price of fertilizer products.
- ESN can provide a similar or better economic return to a split urea application.
- Statistical and economic analyses of the 2009 results are planned. A final report will be available by March.



Ground water sampling

Acknowledgements

This project is supported financially by Ag & Food Council, Agrium, Alberta Agriculture and Rural Development, and the Potato Growers of Alberta and through in-kind contributions by McCain Foods Canada, Agrium and Sandberg Laboratories. Dr. Ted Harms and Len Hingley provided technical assistance with lysimeter installation and soil moisture monitoring. Technical assistance was provided by Simone Dalpé, Allan Middleton, Pat Pfiffner, and seasonal staff.

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ESN SmartNitrogen · PGA POTATO GROWERS OF ALBERTA · Canada · Agriculture & Food Council The Catalyst

ACAAF Project
Final Report - 2010

Project #: 2007F065R **Date**: June 28, 2010

Submitted by: Dr. Michele Konschuh, Dr. Ross H. McKenzie, and Dr. Francis Zvomuya

Application of polymer-coated urea (ESN) in potato production in southern Alberta (Project #2007F065R; ACAAF Project AB0279)

1. Performance Story

Recent work in other potato production areas with polymer-coated-urea products demonstrated improved nitrogen-use efficiency and decreased nitrate leaching. This project involved growing Russet Burbank potatoes at two southern Alberta research stations to evaluate the use of a polymer coated urea product locally. The purpose of the trial was to determine whether environmentally smart nitrogen (ESN, Agrium) could be used in potato production to reduce the total amount of nitrogen (N) or the number of N applications without sacrificing yield or processing quality. Various quantities of urea and ESN were applied pre-plant and compared with urea applied at planting followed by top-dressing at emergence.

Results indicate that ESN can be used in place of or in concert with urea as an N source for Russet Burbank production in southern Alberta. Six site years of data were generated during the trial. Marketable yields from treatments involving ESN were greater or not significantly different from the split urea (STD) treatment each year of the trial, even when 25% less N was applied. Average tuber size and tuber count in a 10 kg sample were affected more by environmental conditions each year than by N treatments. Applying N as ESN at emergence tended to reduce average tuber size relative to other comparable treatments applied pre-plant or as split applications. In general, the more N applied, the lower the specific gravity and the fewer tubers over 10 oz. ESN has less of an effect on tuber specific gravity than the same quantity of urea.

When economic return was taken into account, marketable yield had a greater impact on crop value than fertilizer price, average tuber size or specific gravity bonuses. That is, the treatments resulting in the greatest marketable yield, also resulted in the greatest economic returns. Most treatments with a better economic return than the STD used a reduced rate of N. Based on the results of this trial, it is feasible to reduce overall N applications by 25%. It is also feasible to use ESN to eliminate the need for in-season N applications. Reducing the quantity of N applied and splitting N applications between pre-plant urea and ESN at emergence gave good marketable yields and good economic returns 4 out of 6 site years.

In my opinion, the project was successful. This information allows us to make recommendations to growers about the effective use of ESN in the nitrogen management of Russet Burbank potatoes. The reduction in applied N and the potential for fewer in-season applications should compensate for the price premium on ESN.

2. Acknowledgements

Funding for the project was provided by Ag & Food Council, Agrium, Alberta Agriculture and Rural Development, and Potato Growers of Alberta.

Special thanks to Ross May and McCain Foods Canada for grading and assessing crop quality each year of the trial, Sandberg Laboratories for petiole nitrate analyses and Dr. Ted Harms for statistical analyses. Technical support from Simone Dalpé, Allan Middleton, Pat Pfiffner, and Len Hingley (ARD), Jim Sukeroff and Ron Gregus (AAFC) was essential for the success of the project.

3. Introduction

Potatoes managed for maximum productivity exert a heavy demand on soil fertility (Hopkins et al. 2008, Westermann 2005, Waterer and Heard 2001). Nitrogen (N) management affects vine and tuber biomass production as well as tuber size, grade, specific gravity and internal and external quality (Hopkins et al. 2008, Stark and Westermann 2003). Insufficient available N leads to insufficient canopy establishment, decreased yield, increased disease susceptibility and early crop senescence. Excessive N before tuber formation can delay tuber bulking and reduce yield, while excessive late-season N usually reduces specific gravity and delays skin set (Stark and Westermann 2003).

Potato producers use a number of tools to manage nitrogen such as soil sampling, fertilizer formulations, timing and placement of fertilizer, and in-season crop monitoring through tissue testing (Hopkins et al. 2009, Zebarth and Rosen 2007). The potential for leaching of nitrogen is closely related to the efficiency of the N management program (Shock et al. 2007, Stark and Westermann 2003). Strategies that match crop N needs with applications during the first 60 days of emergence, improve N-use efficiency (Hopkins et al 2009, Munoz et al. 2005,Westermann 2005, Vos 1999). In recent years, split or periodic N application procedures have become common in many potato-producing regions (Wilson et al. 2009, Hopkins et al. 2008, Love et al. 2005). Splitting the N application is an effective strategy to increase fertilizer use efficiency while limiting nitrate leaching (Zebarth and Rosen 2007, Waterer and Heard 2001) and nitrous oxide emissions (Hyatt et al. 2010, Shoji et al. 2001).

Another tool that is available for N management is polymer-coated urea fertilizers. Urea is an economical source of nitrogen that is converted by soil microbes to ammonium nitrogen. Ammonium forms of nitrogen become available to plants as microbes convert it to nitrate forms. Coated urea products are part of a larger group of controlled-release fertilizers (CRF's), but the release rate is mostly influenced by soil temperature and is less affected by soil moisture than other CRFs. Earlier versions of controlled release fertilizers did not closely match N release with plant demand and resulted in less than satisfactory results. This coupled with higher costs of CRFs has limited their use to high value greenhouse and nursery crops (Munoz et al. 2005, Simonne and Hutchinson 2005).

ESN, environmentally smart nitrogen (44-0-0), is a made in Alberta polymer-coated urea fertilizer. ESN provides a steady N supply for the growing plants while reducing losses due to leaching and denitrification. Both Munoz et al. (2005) and Zvomuya and Rosen (2001) reported that a synchronous association between availability and demand of N could be achieved with just one fertilizer application of a polymer-coated urea at potato planting. Such products can reduce fertilizer application costs because a single application can replace multiple fertilizer applications (Wilson et al. 2009, Zebarth and Rosen 2007). Spring applied ESN could potentially be used to replace broadcast fertilizer at the time of hilling and replace the need for in-season fertigation applications. Recent work in other potato production areas with polymer-coated urea products, have demonstrated improved N-use efficiency and decreased nitrate leaching (Hopkins et al. 2009, Hutchinson 2005, Shoji et al. 2001, Zvomuya and Rosen 2001). Coated urea products range in their peak release dates, and the maximum N release for ESN is approximately 45 days after application. Results from Alberta petiole-N research indicate that N uptake by the potato crop increases dramatically as the plant switches from flowering and tuber initiation to tuber bulking around 75 to 80 days after planting (Woods et al., 2008). Local evaluation is needed to identify products or blends that match the uptake patterns for potato plants.

Project Description:
The trial was conducted on Russet Burbank potatoes at two southern Alberta research stations to ensure that background N was moderate and that N applications could be controlled. One set of replicated plots was established at the Crop Diversification Centre South (CDCS), Brooks and the other was established at the AAFC Substation, Vauxhall, AB. The trial was planned for a total of 3 years to determine the impact of the treatments under a variety of environmental conditions. A total of 6 site years of data was generated and provided sufficient information to develop recommendations for incorporating ESN as part of an N management strategy for Russet Burbank potato producers.

The purpose of the current research was to determine whether ESN could be used in potato production to improve nitrogen use efficiency while maintaining yield and processing quality. The use of polymer coated urea in potato production could potentially reduce the total amount of nitrogen required to grow a high quality processing potato crop.

4. Objectives

- To determine the effect of combinations of urea and polymer-coated urea on yield, specific gravity and quality of Russet Burbank potatoes; and
- To determine whether polymer-coated urea could replace the need for in-season N applications (top-dressing, side-dressing or fertigation), and
- To determine whether polymer-coated urea reduced the risk of nitrate leaching in irrigated potato production; and

- To determine whether polymer-coated urea could be used as a tool for better nitrogen management in Alberta potato production.

5. Methods

This study was conducted for three years (2007 – 2009) at two research facilities in southern Alberta; the Crop Diversification Centre South (CDCS) in Brooks, AB and the Vauxhall substation of the Lethbridge Research Station in Vauxhall, AB. The soils at the CDCS station are Orthic Brown Chernozem with soil textures ranging from loam to silt loam. The soils at the Vauxhall site are also Brown Chernozemic with a sandy loam texture. Composite soil samples were taken at three depths (0 to 15 cm, 15 – 30 cm and 30 – 60 cm) in the spring before planting to test for available nitrate N. Results for each site are presented in Table 10.

Table 10: Selected chemical properties of soils at the **Brooks, AB** and **Vauxhall, AB** sites each year. Composite samples were collected before establishing treatments (April / May) from three depths (0 to 15 cm, 15 – 30 cm and 30 – 60 cm).

	Brooks, AB			**Vauxhall, AB**		
0 – 15 cm	**2007**	**2008**	**2009**	**2007**	**2008**	**2009**
pH	7.7	8.2	7.6	7.7	6.9	7.5
Electrical conductivity mS/cm	0.66	0.41	0.52	0.99	0.66	1.18
Organic Matter %	1.2	1.5	<1.2	2.4	1.9	3.0
Nitrate Nitrogen (NO3-N) lb/ac	40	22	20	24	51	53
Phosphorus (P) lb/ac	102	196	78	73	110	55
Potassium (K) lb/ac	690	760	520	860	1000	980
Sulfate-sulfur (SO4-S) lb/ac	<10	<10	<10	70	24	39
15 – 30 cm						
pH	7.9	8.2	7.6	7.9	7.5	734
Electrical conductivity mS/cm	0.74	0.45	0.50	0.91	0.76	1.75
Nitrate Nitrogen (NO3-N) lb/ac	20	20	27	25	27	38
Sulfate-sulfur (SO4-S) lb/ac	76	<10	<10	69	25	>200
30 – 60 cm						
pH	8.1	8.3	8.2	8.1	8.0	7.3
Electrical conductivity mS/cm	1.01	1.11	0.50	1.36	0.72	6.21
Nitrate Nitrogen (NO3-N) lb/ac	30	40	28	26	32	36
Sulfate-sulfur (SO4-S) lb/ac	>400	348	20	>400	120	>400

Ten N treatments were replicated 5 times in a randomized complete block design. Two sources of N, a 45-day release polymer coated urea (ESN, 44-0-0) manufactured by Agrium Inc. and granular urea (45-0-0) were compared across several rates and application strategies to determine if ESN could be used to reduce nitrogen application costs in-season. Nitrogen treatments were applied using banding equipment in 2007. The nitrogen treatments were banded using a direct seeder at both locations May 9, 2008 and May 15, 2009. Treatments included:

1. No additional nitrogen – check
2. Urea applied pre-plant to bring available N to 225 kg/ha – urea 100% pp
3. Urea applied pre-plant to bring available N to 170 kg/ha – urea 75% pp
4. Urea applied pre-plant to bring available N to 115 kg/ha – urea 50% pp
5. ESN applied pre-plant to bring available N to 225 kg/ha – ESN 100% pp
6. ESN applied pre-plant to bring available N to 170 kg/ha – ESN 75% pp
7. ESN applied pre-plant to bring available N to 115 kg/ha – ESN 50% pp
8. No additional N at planting; **plus** ESN applied and cultivated in at emergence (Idaho) – ESN 75% td
9. Urea applied pre-plant to bring available N to 115 kg/ha plus ESN applied to bring available N to 170 kg/ha and cultivated in at emergence - Urea/ESN split
10. Urea applied pre-plant to bring available N to 170 kg/ha plus urea applied to bring available N to 225 kg/ha and cultivated in at emergence - Urea split – STD 100%

Potatoes were planted approximately 13 – 15 cm deep using a two-row wheel planter in **Brooks** on May 10, 2007, May 14, 2008, and May 19, 2009 and in **Vauxhall** on May 11, 2007, May 13, 2008 and May 22, 2009. Russet Burbank seed (E3) of the same seed lot was used for both locations each year. Seed was cut (70 – 85g seed pieces), suberized, treated with Maxim™ seed piece treatment (500g/100kg seed) in 2007, and Maxim MZ PSP seed piece treatment (500g/100kg seed) in 2008 and 2009. Potatoes were planted 30 cm apart in 6 m rows spaced 0.90 m apart. Each treatment was 4 rows wide. Only one of the centre rows was harvested for yield estimates and tuber evaluations. Each treatment was replicated 5 times to reduce some of the variability inherent in small plot research (see plot plan in Appendix).

Wireless temperature loggers (Model 150 Watchdog, Spectrum Technologies, Plainfield, IL) were attached to the first seed piece in one row of each rep at both locations. Soil temperature data was recorded every two hours for the entire growing season. The data loggers were recovered just prior to harvest and daily maximum, minimum and mean temperature data from each device were retrieved.

Lysimeters (61 cm Soil Water Sampler, Soilmoisture Equipment Corp., Santa Barbara, CA) were installed in four replicates of six treatments (Trt #1, 2, 5, 8, 9, and 10) at the CDCS site each year to compare the potential for nitrate leaching between treatments. Lysimeters were positioned between adjacent potato plants within a potato row in each treatment. A vacuum was established is each tube using a Vacuum Test Hand Pump and Extraction Kit (Soilmoisture Equipment Corp.). Ground water samples were collected from each lysimeter starting June 14 (2007), July 4 (2008) and July 22 (2009) and approximately every two weeks throughout the growing season. Samples were analyzed for nitrate concentration at Lakeside Research Labs, Brooks, AB.

In **Brooks**, the plots were managed following the guidelines for the Western Canadian Potato Breeding Program. Eptam (2.0 L/ac) and Sencor (150 g/ac) were applied (April 30, 2007; May 7, 2008 and April 29, 2009) to control weeds prior to planting. Additional ESN and urea were applied (top-dressed) to treatments 8, 9, and 10 prior to power hilling June 5, 2007 (Tables 1), May 29, 2008 (Table 2) and June 15, 2009 (Table 4). The plots were irrigated with solid set sprinklers to maintain adequate soil moisture.

Foliar fungicides were applied at the **Brooks** location during the growing season to prevent early blight and late blight from developing (Tables 1 – 3). In **Brooks**, Decis 5 EC (60 ml/ac) was applied July 13, 2007, Thionex (0.60 L/ac) was applied July 7, 2008 and Thionex (0.60 L/ac) was applied July 7, 2009 to control Colorado Potato Beetles.

Table 1: Foliar fungicides applied to the 2007 ESN potato trial to prevent early blight and late blight development in **Brooks, AB.**

Date of Application	***Fungicide***	***Rate***
July 13	Dithane DG Rainshield	0.70 kg/ac
July 26	Bravo 500	0.80 L/ac
Aug 24	Ridomil Gold/Bravo	883 mls/ac

Table 2: Foliar fungicides applied to the 2008 ESN potato trial to prevent early blight and late blight development in **Brooks, AB.**

Date of Application	***Fungicide***	***Rate***
July 7	Quadris	324 mL/ac
July 25	Dithance DG Rainshield	0.70 kg/ac
Aug 20	Ridomil Gold with Bravo	883 mL/ac

Table 3: Foliar fungicides applied to the 2009 ESN potato trial to prevent early blight and late blight development in **Brooks, AB.**

Date of Application	***Fungicide***	***Rate***
July 8	Quadris	324 mL/ac
July 30	Ridomil Gold with Bravo	883 mL/ac
Aug 24	Bravo 500	0.65 L/ac

In **Vauxhall**, the plots were managed by sub-station staff. Eptam (3.0 L/ac) was applied (May 7, 2007, April 28, 2008 and May 21, 2009) to control weeds prior to planting. Additional ESN and urea were applied (top-dressed) to treatments 8, 9, and 10 prior to hilling June 8, 2007, June 3, 2008 and June 16, 2009. The plots were irrigated with a combination of solid set sprinklers in 2007 and 2008 and with wheel move and solid set sprinklers in 2009. Soil moisture monitoring equipment was installed in 2008 and 2009 to track soil moisture and recommend irrigation events to maintain soil moisture near 70%.

Foliar fungicides were applied at the **Vauxhall** location during each growing season to prevent early blight and late blight from developing (Tables 4 – 6).

Table 4: Foliar fungicides applied to the **2007** ESN potato trial in **Vauxhall**, AB to prevent early blight and late blight development.

Date of Application	*Fungicide*	*Rate*
June 19, 2007	Bravo 500	0.8 L/ac
July 3	Ridomil Gold/Bravo	883 mL/ac
July 11	Bravo 500	0.8 L/ac
July 20	Tattoo	1.1 L/ac
Aug 1	Bravo 500	0.80 L/ac
Aug 13	Bravo 500	0.8 L/ac
Aug 22	Bravo 500	0.8 L/ac

Table 5: Foliar fungicides applied to the **2008** ESN potato trial in **Vauxhall, AB** to prevent early blight and late blight development.

Date of Application	*Fungicide*	*Rate*
June 23	Bravo	0.8 L/ac
July 3	Bravo	0.8 L/ac
July 18	Bravo	0.8 L/ac
Aug 5	Ridomil Gold with Bravo	883 mL/ac
Aug 18	Bravo	0.8 L/ac

Table 6: Foliar fungicides applied to the **2009** ESN potato trial in **Vauxhall, AB** to prevent early blight and late blight development.

Date of Application	*Fungicide*	*Rate*
July 16	Bravo	0.8 L/ac
July 30	Bravo Ridomil Gold	883 mL/ac
Aug 12	Bravo	0.8 L/ac
Aug 20	Bravo	0.8 L/ac

Foliar insecticides were applied at the **Vauxhall** location during each growing season to control aphids and Colorado Potato Beetles (Tables 7 – 9).

Table 7: Foliar insecticides applied to the **2007** ESN potato trial in **Vauxhall, AB** to control aphids and Colorado Potato Beetles.

Date of Application	*Fungicide*	*Rate*
June 19, 2007	Monitor	0.8 L/ac
June 26	Admire	80 mL/ac
July 11	Monitor	0.8 L/ac
July 20	Monitor	0.8 L/ac
Aug 1	Admire	80 mL/ac
Aug 13	Monitor	0.8 L/ac
Aug 22	Monitor	0.8 L/ac

Table 8: Foliar insecticides applied to the **2008** ESN potato trial in **Vauxhall, AB** to control aphids and Colorado Potato Beetles.

Date of Application	***Insecticide***	***Rate***
June 23	Admire	80 mL/ac
July 3	Monitor	0.8 L/ac
July 18	Success	40 mL/ac
Aug 5	Admire	80 mL/ac
Aug 18	Monitor	0.8 L/ac

Table 9: Foliar insecticides applied to the **2009** ESN potato trial in **Vauxhall, AB** to control aphids and Colorado Potato Beetles.

Date of Application	***Insecticide***	***Rate***
July 16	Monitor	0.8 L/ac
July 30	Admire	80 mL/ac
Aug 12	Admire	80 mL/ac
Aug 20	Monitor	0.8 L/ac

Petiole samples were taken at three dates during each season (**Brooks**: July 4, July 25 and August 8, 2007; June 26, July 18 and August 8, 2008; July 7, July 21 and August 11, 2009 and **Vauxhall**: July 5, July 26, and August 10, 2007; June 27, July 22, and August 6, 2008 and July 9, July 23, and August 13, 2009) to ascertain the N status of the crop and determine any effects of treatments on N levels in petioles.

Reglone (1.4 L/ac) was applied Sept 5, 2007, Sept 12, 2008 and Sept 11, 2009 in **Brooks** to desiccate potato vines. All treatments were harvested mechanically with a one-row Grimme harvester September 21, 2007, Sept 18, 2008, and Sept 23, 2009 at the Brooks location. Reglone (1.0 L/ac) was applied Sept 11, 2007, Sept 11, 2008 and Sept 9, 2009 in **Vauxhall** to desiccate potato vines. Treatments were dug mechanically and hand collected September 18, 2007 at the Vauxhall location. Treatments were harvested with a one-row Grimme harvester Sept 18, 2008. Treatments were dug with a one-row chain digger and hand collected September 24, 2009. At both locations a greater number of small tubers were harvested than with commercial harvesting equipment. This tended to inflate the percentage of small tubers, but did not affect marketable yield figures.

Yield, grade, specific gravity and defects for both sites were determined by McCain Foods Canada after harvest. Yield estimates are presented in tons/acre. An economic analysis of the crop was conducted by McCain using a base price per ton based on delivery from storage prior to Nov 15. It does not include bonus for color or payment for smalls. For the analysis, urea was estimated to cost $400/ton in 2007, $800/ton in 2008 and $600/ton in 2009 and a 15% premium was added for ESN pricing. Each field application was estimated to cost $5 per acre in 2007 and 2008 and $7 per acre in 2009.

Statistical analysis of the petiole nitrate data included analysis of variance (ANOVA) and separation of means by Tukey's multiple means comparison test using Sigma Stat statistical software (SPSS, Chicago, IL). Nitrate concentrations from lysimeter samples were analyzed using a Kruskal-Wallis one-way analysis of variance on ranked data ($p \leq 0.05$).

The yield data presented here were statistically analyzed in SAS using generalized linear model (GLM) and means separation was done using the Duncan's Multiple Range Test ($p \leq 0.05$).

6. Results

Weather Data

Mean temperature and rainfall for the 2007, 2008 and 2009 growing season (May through September) are shown for both sites in Table 10. There were some differences in the weather conditions between growing seasons each year of the trial (Table 10). Mean temperatures in July in 2007 were warmer than normal at both locations. Accumulated precipitation was lower in 2007 than 2008 or 2009 at both sites, but irrigation was used to maintain adequate soil moisture.

Table 10: Mean monthly temperature, rainfall and physiological days (P-days*) for 2007 – 2009 at the **Brooks, AB** and **Vauxhall, AB** sites.

	Brooks, AB			**Vauxhall, AB**		
Temperature (mean, °C)	**2007**	**2008**	**2009**	**2007**	**2008**	**2009**
May	12.0	11.9	11.1	12.2	11.7	11.5
June	16.4	14.9	15.1	16.4	15.1	14.9
July	22.8	18.1	17.8	22.7	18.0	17.8
August	17.1	17.8	16.8	17.3	17.8	17.0
September	10.9	11.3	15.3	11.3	11.6	15.8
Rainfall (mm)						
May	59.4	65.9	14.1	57.3	66.5	30.0
June	43.1	68.3	57.7	35.0	85.2	44.8
July	5.2	61.6	135.6	11.0	56.7	47.5
August	41.7	15.8	41.8	28.4	36.3	85.1
September	31.7	32.1	2.0	14.8	48.3	3.7
Total	181.1	243.7	251.2	146.5	293.0	211.1
P-Days*						
May	137.2	136.0	122.3	143.3	135.9	123.3
June	207.4	181.9	173.2	210.2	185.3	172.4
July	211.9	235.0	235.2	216.3	238.4	241.4
August	213.8	207.1	218.3	212.0	209.9	220.3
September	123.2	137.9	171.5	125.5	140.4	173.4
Total	893.5	897.9	920.2	907.3	909.9	930.8

* P-days: an indexing system, widely used in potatoes for determining stage of development and initiation of disease. With the P-Day approach, the minimum temperature for potato growth and development is 7°C, while the most rapid growth and development takes place at 21°C. The growth rate decreases with the increase in temperature and finally stops at 30°C.

Physiological-days (P-days, Sands et al. 1979) were calculated from the weather data as a method of comparing the growing seasons for potato production (Table 10). An initial comparison of total P-days in each growing season did not indicate much difference between the seasons. However, an evaluation of P-days accumulated within each month of the growing season emphasized differences during specific parts of the season (Table 10). Differences experienced during key stages of growth and development of the tubers are expected to have a greater impact on yield and size profiles than differences very early or very late in the season. Comparing the month of July, there were 21 days over 30°C in 2007, 3 days in 2008, and 4 days in 2009 (data not shown). The difference in temperatures is reflected in the P-days accumulated in June and July of each year. In 2007, approximately 25 to 30 more P-days were accumulated in June of 2007 than 2008 or 2009 and 20 fewer P-days were accumulated in July than in 2008 and 2009. September was also much cooler in 2007 and may have affected tuber bulking.

Maximum, minimum and mean soil temperatures were collected within the hills each year (data not shown). In 2007, soil temperatures at the **Brooks** location ranged from approximately 5°C at planting to almost 35°C before row close. Throughout most of the growing season, soil temperatures fluctuated between 10°C and 25°C with cooler soil temperatures evident at harvest. Soil temperatures in **Vauxhall** were slightly warmer than in Brooks. Soil temperatures in Vauxhall ranged from 7°C to over 30°C until row close. As in Brooks, soil temperatures fluctuated less after row closure and cooled off toward harvest.

In 2008, soil temperatures at the **Brooks** location ranged from approximately 10°C at planting to over 30°C before row close. Throughout most of the growing season, soil temperatures fluctuated between 10°C and 20°C with cooler soil temperatures evident in September. Soil temperatures in **Vauxhall** fluctuated in a narrower range than in Brooks. Soil temperatures in Vauxhall ranged from 10°C to 25°C until row close and between 12°C and 22°C through most of July and August. Somewhat cooler soil temperatures were evident in September.

In 2009, soil temperatures at the **Brooks** location ranged from less than 5°C at planting to over 30°C before row close. Once plants were up and row-close had occurred, soil temperatures fluctuated between 10°C and 26°C. August was cooler than July and September was warmer than normal. Soil temperatures in **Vauxhall** plots fluctuated in a narrower range than in Brooks. Soil temperatures in Vauxhall ranged from 5°C to 28°C until row close and between 12°C and 22°C through most of July and August. Differences between locations may have been due, in part, to the use of different hilling equipment as well as to differences in the growing season.

Nitrate Leaching

There were no rainfall events in 2007 or 2008 that would have lead to nitrate leaching during the time frame that lysimeters were monitored in the plots. In 2009, there was one potential leaching event in mid-July (Table 10). Lysimeters were installed in early June in 2007 and June 5, 2008 just prior to emergence of the potato plants and June 26, 2009 just after emergence of the potato plants. Lysimeters were removed in September prior to harvest each year. In 2007, rainfall while monitoring for nitrate leaching totaled 70.8 mm, well below the 30-year average, especially for July. In 2008, rainfall during this period totaled 163.8 mm and in 2009 rainfall during this period totaled 180.3 mm. Irrigation was necessary and was scheduled to produce optimal yield of potatoes based on estimated soil moisture. Irrigation sufficient to incur leaching would have been counter-productive to the primary objectives of the trial.

In 2007, the median background levels of nitrate in ground water collected from a 60 cm depth ranged from 11 ppm to 360 ppm depending on the location of the replicate in the field and the time of sampling (Fig 7). In 2008, the median background levels of nitrate in leachate ranged from 32 ppm to 170 ppm depending on the location of the replicate in the field (Fig 8). In 2009, the median background levels of nitrate in leachate ranged from 30 ppm to 80 ppm depending on the location of the replicate in the field (Fig 9).

2007: Treatment 1 (check), 2 (100% urea pre-plant), 5 (100% ESN pre-plant) and 8 (75% ESN at emergence) showed fluctuations between sampling dates of up to 20 ppm but the net change was small (Fig. 7). Treatments 9 (75% urea/ESN split) and 10 (100 %split urea) both resulted in greater fluctuation. Only the split urea treatment (Trt #10) showed a consistent increase in nitrate concentration relative to the background level by the end of the season. Data presented are the mean of four replicate samples. None of the nitrate values were significantly different from one another in 2007.

2008: For all of the treatments, median nitrate levels decreased between the June 20 and the July 7 sampling dates in all of the treatments (Fig. 8). The pattern of nitrate concentrations under each treatment was similar. Sampling was discontinued after the August 15 sampling date because ground water samples were not recovered from over 50% of the lysimeters on Aug 15. As of August 15, there was no indication that any of the treatments resulted in a consistent increase in ground water nitrate concentrations. Data presented are the means of four replicate samples. None of the nitrate values were significantly different from one another in 2008.

2009: The median nitrate concentration decreased in the check treatment and in the ESN treatments for dates that samples were analyzed (Fig 9). Unfortunately, data was not available for samples collected July 27 and Aug 20 as there was turn-over in the ownership of the analytical laboratory. Sampling was discontinued after the August 20 sampling date because ground water samples were not recovered from over 50% of the lysimeters on Aug 12. As of August 12, there was no indication that any of the treatments resulted in a consistent increase in ground water nitrate concentrations. Data presented are the means of up to four replicate samples. None of the nitrate values were significantly different from one another in 2009.

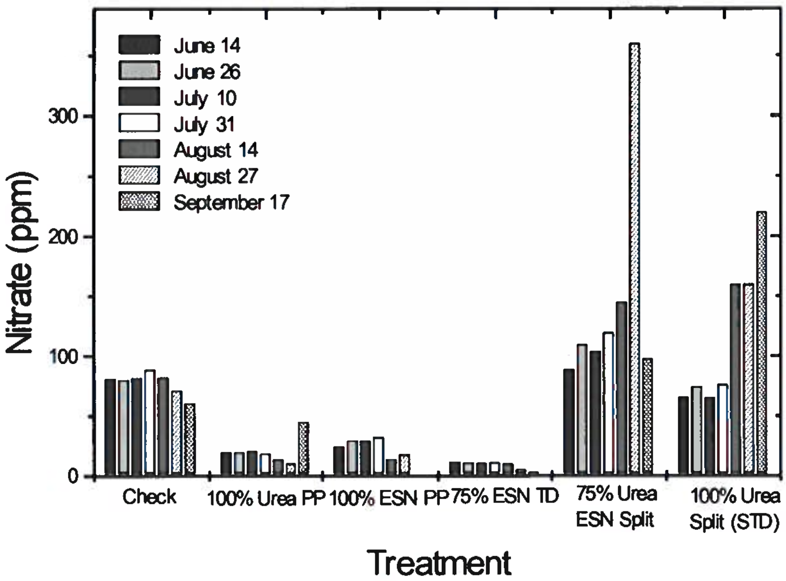

Figure 7: Nitrate concentration in samples of ground water recovered from lysimeters installed within treated areas of the field in **2007**.

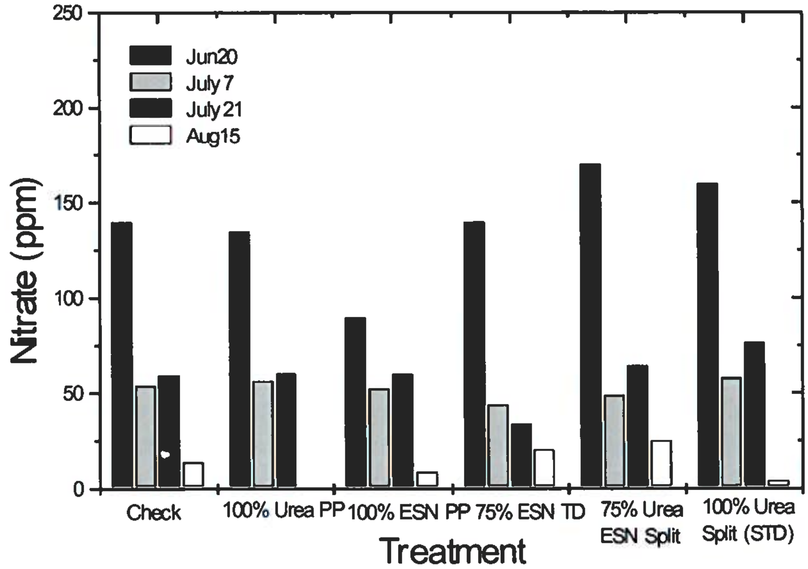

Figure 8: Nitrate concentration in samples of ground water recovered from lysimeters installed in **2008** within treated areas of the field.

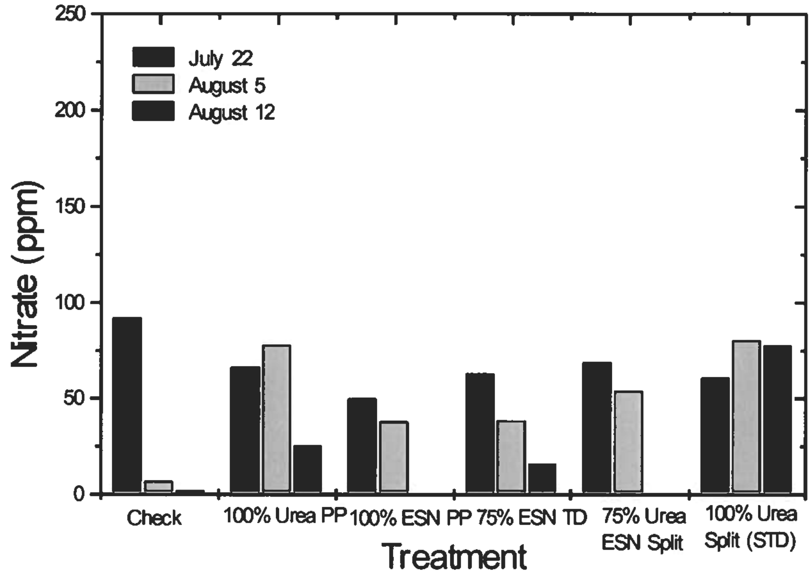

Figure 9: Nitrate concentration in samples of ground water recovered from lysimeters installed in **2009** within treated areas of the field.

Petiole Nitrates

Petiole nitrate concentrations in all treatments decreased throughout the growing season each year in **Brooks.** The first petiole sampling date was selected to coincide with the maximum release date of pre-plant ESN, approximately 45 to 50 days after incorporation. At the first sampling date in 2007, nitrate levels in the petioles ranged from about 16,000 ppm for the check to over 20,000 ppm for treatments with optimal nitrogen applied (Table 11). By the first sampling date in 2008, nitrate levels in the petioles ranged from just over 10,000 ppm for the check to over 17,000 ppm for the split urea (STD) treatment. In 2009, petiole nitrate concentrations at the first sampling date ranged from around 17,000 ppm for the check to over 20,000 ppm for treatment with adequate N. With the exception of the check treatments, the petiole nitrate concentrations at the beginning of each season fell within recommended levels for Russet Burbank production in southern Alberta (Woods et al., 2008).

In 2007, petiole nitrates collected at the Brooks location dropped off gradually throughout the growing season. In 2008 and 2009, petiole nitrates fell rapidly between the first and the second sampling dates even though no leaching events occurred during the season. This may reflect rapid vegetative growth of the plants rather than any deficiencies in N availability. By the second sampling date in 2009 and the third sampling date in 2008 and 2009, petiole nitrates for most treatments fell below recommendations by Woods et al. (2008) for southern Alberta. As expected, treatments with less N applied pre-plant started out with lower petiole nitrate levels and treatments with the greatest applied N levels, whether ESN or urea, maintained the highest petiole nitrate concentrations throughout the season. Split N applications typically maintained petiole nitrates at higher levels through the season than pre-plant applications, although some exceptions were observed. Wilson et al. (2009) also noted higher petiole nitrate concentrations as N rate increased and higher petiole nitrate concentrations with split N applications.

Table 11: Petiole nitrate levels for each treatment at the Brooks, AB and **Vauxhall, AB** locations. Samples were taken from the fourth petiole from up to eighty stems at three times during each growing season:

Treatment	Brooks, AB			Vauxhall, AB		
2007	July 4	July 25	Aug 8	July 5	July 26	Aug 10
Check	15600 b	10600 a	6760 a	11160 e	12100 b	5200 a
100% urea PP	20640 a	12800 a	8260 a	19120 ab	16880 ab	7800 a
75% urea PP	19440 ab	12220 a	6300 a	18960 b	17400 ab	7880 a
50% urea PP	17600 ab	9500 a	5760 a	13360 de	14040 ab	4480 a
100% ESN PP	19040 ab	13200 a	8360a	17840 abc	18960 a	8400 a
75% ESN PP	18840 ab	12560 a	6600 a	17260 abc	16520 ab	8240 a
50% ESN PP	18240 ab	10380 a	6460 a	14560 de	15360 ab	6160 a
75% ESN TD	17720 ab	14340 a	9000 a	15360 cd	16460 ab	7440 a
75% urea/ESN split	19360 ab	12800 a	9980 a	17660 abc	16080 ab	6720 a
100% urea split (STD)	20440 a	13800 a	9920 a	20320 a	20440 a	10800 a
2008	Jun 26	July 18	Aug 8	June 27	July 22	Aug 6
Check	10460 b	3215 d	383 a	4500 d	394 a	1564 b
100% urea PP	15640 ab	9386 ab	2297 a	13360 ab	2758 a	5084 ab
75% urea PP	12700 ab	6821 bcd	383 a	12620 abc	394 a	5476 ab
50% urea PP	11460 b	4489 cd	383 a	7860 cd	591 a	1956 ab
100% ESN PP	15820 ab	8261 abc	1531a	14880 a	2364 a	4302 ab
75% ESN PP	14480 ab	5403 bcd	766 a	11420 abc	591 a	3129 ab
50% ESN PP	12680 ab	4680 cd	766 a	8740 bcd	591 a	1760 ab
75% ESN TD	13980 ab	8969 ab	1531 a	12460 abc	6697 a	7822 ab
75% urea/ESN split	13240 ab	8582 abc	766 a	13680 ab	1576 a	3716 ab
100% urea split (STD)	17320 a	11093 a	8040 a	16280 a	6697 a	7822 a
2009	July 7	July 21	Aug 11	July 9	July 23	Aug 13
Check	18560 b	1160 c	1620 a	7980 a	4540 b	1400 a
100% urea PP	22720 ab	6760 abc	6000 a	14260 a	8520 ab	6600 a
75% urea PP	22880 ab	4020 abc	3140 a	12000 a	6440 ab	3100 a
50% urea PP	19280 b	1280 c	2140 a	5750 a	4160 b	8000 a
100% ESN PP	23840 ab	9260 ab	6480 a	12725 a	8080 ab	2900 a
75% ESN PP	26360 a	3000 cb	2600 a	9775 a	6925 ab	2350 a
50% ESN PP	21920 ab	2440 c	2300 a	10580 a	4025 b	1000 a
75% ESN TD	22700 ab	3250 bc	1700 a	11500 a	6650 ab	3100 a
75% urea/ESN split	23360 ab	5620 abc	4200 a	13420 a	5080 ab	1400 a
100% urea split (STD)	22760 ab	9780 a	6800 a	16740 a	15800 a	11600 a

Petiole nitrate levels in Vauxhall followed a different pattern in each year of the trial. In 2007, petiole N levels from the Vauxhall plots ranged from 11,000 to 20,000 on the first sampling date in early July (Table 11). As we observed in Brooks, treatments with the highest pre-plant applications of nitrogen had the highest petiole nitrate levels. Petiole nitrates remained high for the second sampling date and decreased by the third sampling date. Petiole nitrates appeared to be somewhat independent of the amount of N applied in 2007. Additional nitrogen may have become available during the growing season as a result of mineralization of organic matter.

In 2008, petiole nitrate levels ranged from around 4500 ppm for the check to around 16,000 ppm for the split urea (STD) treatment (Table 11). As with samples from the Brooks location, petiole nitrate concentrations were higher for treatments with 100% N than 75% or 50% N. In Vauxhall, the 100% treatments, 75% urea treatment and the split applications had petiole nitrate concentrations in the recommended range at the first sampling date. The crop in Vauxhall was damaged by hail July 16, 2008 and the up to 40% of the foliage was damaged. Petiole nitrate levels at the second sampling date were much lower for all treatments, and lower than the nitrate levels observed from the third sampling event. The replacement of vegetative tissue likely resulted in a re-allocation of N within the potato plants. By the third sampling date, petiole nitrates were higher than similar treatments in Brooks. The interruption of growth and development caused by the hail storm affected the nitrate concentration in the fourth petiole. Petiole nitrate concentrations for most of the treatments were below the recommended range in early August (Woods et al., 2008).

In 2009, petiole nitrate levels from the Vauxhall plots decreased throughout the season (Table 11). Nitrate levels ranged from around 8,000 ppm for the check to around 16,000 ppm for the split urea (STD) application treatment in early July. As with the samples from the Brooks location, petiole nitrate concentrations were generally higher for treatments with 100% N than 75% or 50% N. In Vauxhall, the 100% treatments, 75% urea treatment and the split applications had sufficient petiole-N at the first sampling date. Petiole nitrate levels at the second sampling date were lower for all treatments than the first sampling date and only petioles from the split urea (STD) treatment had sufficient nitrate based on southern Alberta recommendations (Woods et al., 2008). By the third sampling date, only petioles from the 100% urea pre-plant, 100% ESN pre-plant and the STD had nitrate levels within recommended levels. The check and treatments supplied with 50 to 75% N had inadequate N based on the 2008 recommendations.

Potato Yield and Grade

Potato yield, grade and estimated crop value relative to the STD are presented in Table 12 for each treatment harvested in **Brooks** during the three year trial. There were no significant differences in marketable yield or average tuber size between treatments in 2007 or 2009 and a few significant differences in 2008. Polymer-coated urea products have been shown by others (Wilson et al. 2009, Hopkins et al. 2008, Shoji et al. 2001) to produce similar or greater yields than soluble N at equivalent rates. Average tuber size in 2007 was quite small and a high percentage of tubers were undersized. In 2008, however, some statistical differences were observed in marketable tuber yields and yields of specific size categories. Pre-plant application of urea at 75% of the STD rate yielded the most marketable tubers, while the check and the 50% ESN pre-plant treatments yielded the least. Wilson et al. (2009) reported that an increase in the N rate applied resulted in a greater percentage of tubers over 6 oz., an economically important size class. Average tuber size was lower with pre-plant or top-dressed ESN applications in 2008 than with pre-plant urea or the urea/ESN split. The split urea application resulted in average tuber sizes that were not significantly different from the ESN treatments, while the urea/ESN split application resulted in an average tuber size similar to the check and the urea pre-plant treatments. In general, urea treatments resulted in a higher percentage of tubers over 10 oz compared to ESN treatments in 2008. In 2009, around 10% of the tubers were small (under 3 oz.) and fewer than 20% of the tubers were over 10 oz. The weather may have played a role in the size distribution of the crop. There were delays in the spring as a result of cool weather, August was more moderate and September was warmer than usual. Our trial was desiccated September 11 and we likely lost 2 weeks of potential bulking that might have helped differentiate between treatments.

All of the treatments in 2007 resulted in a lower net crop value than the STD treatment. In 2008, all of the treatments yielded a higher net crop value than the STD treatment, and in 2009, all treatments in Brooks, except the check treatment, gave similar or better gross economic return on a sample contract than the STD (Table 12). The greatest net crop value in 2008 was achieved with 75% urea applied pre-plant. For economic return in 2009, the best treatment in Brooks was 50% ESN applied pre-plant. Applying ESN (75%) at emergence and the urea/ESN split application gave better economic returns than the STD. Wilson et al. (2009) provided a simple economic analysis for their work with various rates of polymer-coated urea and split applied N treatments. Their analysis suggests that the use of polymer-coated urea could reduce or eliminate the need for fertigation on coarse-textured soils. In this study, each of the treatments with a better economic return than the STD used a reduced rate of N. The best economic return may shift with urea price changes.

Specific gravity of tubers was affected by N source and timing each year as well as by environmental factors (Table 12). Wilson et al. (2009) reported that N treatments did not significantly affect specific gravity, but that other factors, such as temperature or irrigation, may have contributed to differences between years. In this study, and in work reported by Belanger et al. (2002), the greater the quantity of N applied, the lower the specific gravity. The highest specific gravity tubers were usually observed in the check treatment and the 50% rate of urea and ESN. The lowest specific gravity was observed from treatments with 100% N applied whether pre-plant or split application (STD). Pre-plant N had a greater impact on specific gravity than top-dressed N. The trend was that urea reduced specific gravity more than ESN, although differences between treatments were not always statistically significant.

In 2009, only the 100% urea pre-plant treatment resulted in an economic return greater than the STD split urea application. The check resulted in the lowest economic return. Although efforts were made to improve the irrigation practices at Vauxhall throughout the trial, irrigation efficiency was still quite variable. In the event that irrigation is not optimized, it is unlikely that the timing and quantity of N applied will make significant improvements in the yield or quality the potato crop.

Table 13: Yield and grade of potatoes harvested from plots in **Vauxhall, AB** grown with different nitrogen sources in **2007, 2008 and 2009.** Data in each column followed by the same letter in a given year are not significantly different from one another.

Treatment	% under-sized	Mkt Yld (ton/ac)	>10 oz. (%)	Avg Tuber size (oz)	Tuber count (10 kg)	SG	Crop Value (% of STD)
2007							
Check	14.2 b	16.7 b	3.0 ab	4.1 ab	86.8 ab	1.095 ab	83.1
100% urea PP	14.6 ab	17.6 b	2.9 ab	4.0 ab	89.4 ab	1.094 ab	87.4
75% urea PP	12.9 b	18.1 ab	3.1 ab	4.3 ab	83.6 ab	1.094 ab	96.3
50% urea PP	12.7 b	19.7 ab	4.0 ab	4.5 ab	80.6 ab	1.098 ab	86.0
100% ESN PP	14.0 b	16.9 b	3.2 ab	4.4 ab	84.6 ab	1.096 ab	97.7
75% ESN PP	15.5 ab	16.8 b	2.8 ab	3.9 ab	92.0 ab	1.100 a	86.8
50% ESN PP	12.3 b	20.2 ab	4.1 ab	4.5 ab	78.4 b	1.098 ab	89.2
75% ESN TD	11.4 b	18.8 ab	3.0 ab	4.4 ab	81.4 ab	1.092 b	75.9
75% urea/ESN split	11.2 b	22.3 a	4.8 a	4.8 a	74.4 b	1.096 ab	87.5
100% urea split (STD)	19.3 a	16.4 b	2.1 b	3.7 b	98.6 a	1.094 ab	100.0
2008							
Check	9.0 ab	21.6 c	25.6 bc	6.2 ab	57.8 abc	1.088 abc	90.1
100% urea PP	6.3 ab	22.8 bc	34.5 abc	6.4 ab	55.6 abc	1.086 abc	93.2
75% urea PP	10.6 a	23.4 bc	26.0 bc	5.8 b	62.4 a	1.087 abc	96.0
50% urea PP	10.5 a	21.4 c	23.0 c	5.8 b	61.6 ab	1.090 ab	87.4
100% ESN PP	6.6 ab	25.7 abc	27.9 abc	6.5 ab	54.6 abc	1.086 bc	103.4
75% ESN PP	8.7 ab	22.7 bc	27.2 bc	7.1 a	61.0 ab	1.088 ab	93.7
50% ESN PP	10.3 a	21.2 c	26.6 bc	5.8 b	61.4 ab	1.090 a	88.8
75% ESN TD	5.4 b	29.3 a	42.1 a	7.1 a	49.8 bc	1.083 c	115.4
75% urea/ESN split	7.0 ab	27.5 ab	39.2 ab	6.9 ab	52.0 abc	1.086 bc	111.8
100% urea split (STD)	4.6 b	24.8 abc	41.6 a	7.3 a	48.6 c	1.083 c	100.0
2009							
Check	15.7 a	13.5 b	13.8 ab	4.2 b	84.9 a	1.088 abcd	76.5
100% urea PP	10.5 a	20.4 a	18.1 ab	4.9 ab	72.9 ab	1.084 d	107.3
75% urea PP	8.4 a	17.7 ab	20.2 ab	4.9 ab	71.6 ab	1.086 abcd	99.1
50% urea PP	13.8 a	17.4 ab	11.1 b	4.7 ab	76.1 ab	1.090 abc	98.4
100% ESN PP	13.7 a	17.9 ab	20.6 ab	4.8 ab	76.5 ab	1.084 cd	92.9
75% ESN PP	14.7 a	16.7 ab	15.7 ab	4.8 ab	74.5 ab	1.091 a	93.1
50% ESN PP	11.7 a	15.8 ab	20.3 ab	4.7 ab	74.9 ab	1.090 abc	89.3
75% ESN TD	7.9 a	16.7 ab	17.5 ab	5.0 ab	70.7 b	1.090 ab	93.1
75% urea/ESN split	10.2 a	16.1 ab	19.9 ab	5.0 ab	71.5 ab	1.087 abcd	89.6
100% urea split (STD)	8.0 a	19.1 a	22.6 a	5.10 a	69.9 b	1.085 bcd	100.0

yield and quality while refining costs of production. The data generated over the past three years of the trial will:
- be useful in BMP development for potato production in Alberta;
- determine whether polymer coated urea can reduce total nitrogen applied or reduce the number of in-season nitrogen applications required for optimal potato yield and quality
- provide economic evaluations of the use of polymer coated urea
- potentially reduce nitrogen losses to leaching and denitrification processes
- will address using the ESN technology under soil type and environmental conditions specific to southern Alberta.

The short and long-term outcomes depend heavily on the information generated from the trials. Adoption by growers can be monitored through ESN sales. Growers must be able to realize benefits to using ESN that exceed the price premium on ESN over urea fertilizer prices. Potato growers are asking questions about how to incorporate ESN in their nitrogen management strategy for potatoes and some early adopters have already experimented with polymer coated urea.

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11. Summary

Recent work in other potato production areas with polymer-coated-urea products have demonstrated improved nitrogen-use efficiency and decreased nitrate leaching (Hopkins et al 2009, Hutchinson 2005, Shoji et al. 2001, Zvomuya and Rosen 2001). This project involved growing Russet Burbank potatoes at two southern Alberta research stations to evaluate the use of a polymer-coated urea product locally. The purpose of the trial was to determine whether environmentally smart nitrogen (ESN, Agrium) could be used in potato production to reduce the total amount of N or the number of N applications without sacrificing yield or processing quality. Various quantities of urea and ESN were applied pre-plant and compared with urea at planting followed by top-dressing at emergence. Marketable yields from treatments involving ESN were greater or not significantly different from the split urea (STD) treatment each year of the trial, even when 25% less N was applied. In general, the more N applied, the lower the specific gravity and the fewer tubers over 10 oz. When economic return was taken into account, marketable yield had a greater impact on crop value than fertilizer price, average tuber size or specific gravity bonuses. Each treatment with a better economic return than the STD used a reduced rate of N. Based on the results of the trial, it is feasible to reduce overall N applications by 25%. Employing a split application with urea pre-plant and ESN at emergence gave good results in 2008 and 2009 provided that irrigation was timely and sufficient.

Resources used in the project:

This project is supported financially by Ag & Food Council, Agrium, Alberta Agriculture and Rural Development, and the Potato Growers of Alberta and through in-kind contributions by Agriculture and Agri-Food Canada, McCain Foods Canada, Agrium and Sandberg Laboratories.

Year	Applicant / Industry Cash	Applicant / Industry In-kind	Provincial Government Cash	Provincial Government In-kind	Federal Government Cash	Federal Government In-kind
2007-08	18,000	2,500	0	14,500	15,800	9,500
2008-09	12,000	2,500	0	14,500	13,000	9,500
2009-10	12,000	2,500	0	14,500	13,700	9,500

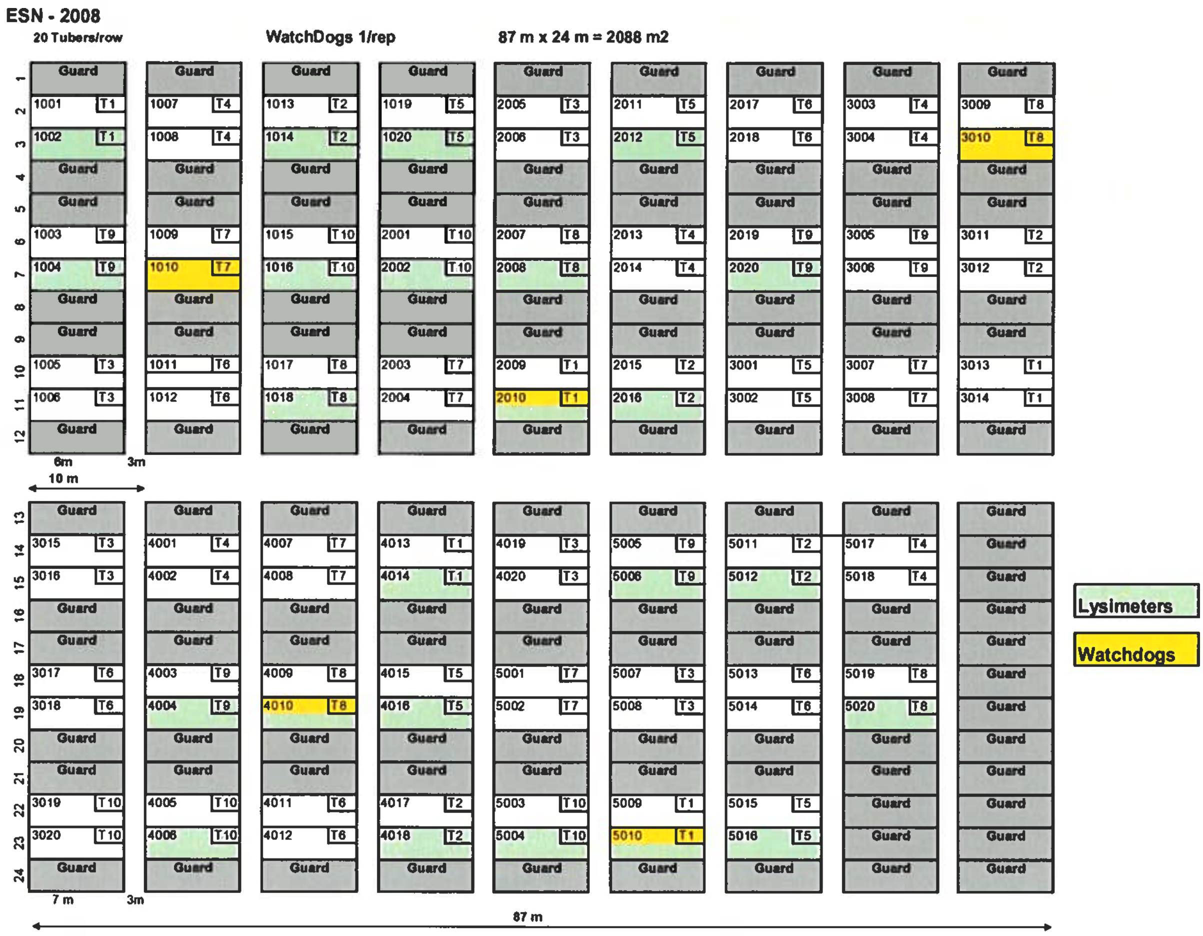

Figure A1: Sample plot plan of ESN Trial. Plot plans were similar for both locations each year of the trial.

ACAAF Project
Final Report - 2010

Project #: 2007F065R **Date**: June 28, 2010

Submitted by: Dr. Michele Konschuh, Dr. Ross H. McKenzie, and Dr. Francis Zvomuya

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Application of polymer-coated urea (ESN) in potato production in southern Alberta (Project #2007F065R; ACAAF Project AB0279)

1. Performance Story

Recent work in other potato production areas with polymer-coated-urea products demonstrated improved nitrogen-use efficiency and decreased nitrate leaching. This project involved growing Russet Burbank potatoes at two southern Alberta research stations to evaluate the use of a polymer coated urea product locally. The purpose of the trial was to determine whether environmentally smart nitrogen (ESN, Agrium) could be used in potato production to reduce the total amount of nitrogen (N) or the number of N applications without sacrificing yield or processing quality. Various quantities of urea and ESN were applied pre-plant and compared with urea applied at planting followed by top-dressing at emergence.

Results indicate that ESN can be used in place of or in concert with urea as an N source for Russet Burbank production in southern Alberta. Six site years of data were generated during the trial. Marketable yields from treatments involving ESN were greater or not significantly different from the split urea (STD) treatment each year of the trial, even when 25% less N was applied. Average tuber size and tuber count in a 10 kg sample were affected more by environmental conditions each year than by N treatments. Applying N as ESN at emergence tended to reduce average tuber size relative to other comparable treatments applied pre-plant or as split applications. In general, the more N applied, the lower the specific gravity and the fewer tubers over 10 oz. ESN has less of an effect on tuber specific gravity than the same quantity of urea.

When economic return was taken into account, marketable yield had a greater impact on crop value than fertilizer price, average tuber size or specific gravity bonuses. That is, the treatments resulting in the greatest marketable yield, also resulted in the greatest economic returns. Most treatments with a better economic return than the STD used a reduced rate of N. Based on the results of this trial, it is feasible to reduce overall N applications by 25%. It is also feasible to use ESN to eliminate the need for in-season N applications. Reducing the quantity of N applied and splitting N applications between pre-plant urea and ESN at emergence gave good marketable yields and good economic returns 4 out of 6 site years.

In my opinion, the project was successful. This information allows us to make recommendations to growers about the effective use of ESN in the nitrogen management of Russet Burbank potatoes. The reduction in applied N and the potential for fewer in-season applications should compensate for the price premium on ESN.

2. Acknowledgements

Funding for the project was provided by Ag & Food Council, Agrium, Alberta Agriculture and Rural Development, and Potato Growers of Alberta.

Special thanks to Ross May and McCain Foods Canada for grading and assessing crop quality each year of the trial, Sandberg Laboratories for petiole nitrate analyses and Dr. Ted Harms for statistical analyses. Technical support from Simone Dalpé, Allan Middleton, Pat Pfiffner, and Len Hingley (ARD), Jim Sukeroff and Ron Gregus (AAFC) was essential for the success of the project.

3. Introduction

Potatoes managed for maximum productivity exert a heavy demand on soil fertility (Hopkins et al. 2008, Westermann 2005, Waterer and Heard 2001). Nitrogen (N) management affects vine and tuber biomass production as well as tuber size, grade, specific gravity and internal and external quality (Hopkins et al. 2008, Stark and Westermann 2003). Insufficient available N leads to insufficient canopy establishment, decreased yield, increased disease susceptibility and early crop senescence. Excessive N before tuber formation can delay tuber bulking and reduce yield, while excessive late-season N usually reduces specific gravity and delays skin set (Stark and Westermann 2003).

Potato producers use a number of tools to manage nitrogen such as soil sampling, fertilizer formulations, timing and placement of fertilizer, and in-season crop monitoring through tissue testing (Hopkins et al. 2009, Zebarth and Rosen 2007). The potential for leaching of nitrogen is closely related to the efficiency of the N management program (Shock et al. 2007, Stark and Westermann 2003). Strategies that match crop N needs with applications during the first 60 days of emergence, improve N-use efficiency (Hopkins et al 2009, Munoz et al. 2005,Westermann 2005, Vos 1999). In recent years, split or periodic N application procedures have become common in many potato-producing regions (Wilson et al. 2009, Hopkins et al. 2008, Love et al. 2005). Splitting the N application is an effective strategy to increase fertilizer use efficiency while limiting nitrate leaching (Zebarth and Rosen 2007, Waterer and Heard 2001) and nitrous oxide emissions (Hyatt et al. 2010, Shoji et al. 2001).

Another tool that is available for N management is polymer-coated urea fertilizers. Urea is an economical source of nitrogen that is converted by soil microbes to ammonium nitrogen. Ammonium forms of nitrogen become available to plants as microbes convert it to nitrate forms. Coated urea products are part of a larger group of controlled-release fertilizers (CRF's), but the release rate is mostly influenced by soil temperature and is less affected by soil moisture than other CRFs. Earlier versions of controlled release fertilizers did not closely match N release with plant demand and resulted in less than satisfactory results. This coupled with higher costs of CRFs has limited their use to high value greenhouse and nursery crops (Munoz et al. 2005, Simonne and Hutchinson 2005).

ESN, environmentally smart nitrogen (44-0-0), is a made in Alberta polymer-coated urea fertilizer. ESN provides a steady N supply for the growing plants while reducing losses due to leaching and denitrification. Both Munoz et al. (2005) and Zvomuya and Rosen (2001) reported that a synchronous association between availability and demand of N could be achieved with just one fertilizer application of a polymer-coated urea at potato planting. Such products can reduce fertilizer application costs because a single application can replace multiple fertilizer applications (Wilson et al. 2009, Zebarth and Rosen 2007). Spring applied ESN could potentially be used to replace broadcast fertilizer at the time of hilling and replace the need for in-season fertigation applications. Recent work in other potato production areas with polymer-coated urea products, have demonstrated improved N-use efficiency and decreased nitrate leaching (Hopkins et al. 2009, Hutchinson 2005, Shoji et al. 2001, Zvomuya and Rosen 2001). Coated urea products range in their peak release dates, and the maximum N release for ESN is approximately 45 days after application. Results from Alberta petiole-N research indicate that N uptake by the potato crop increases dramatically as the plant switches from flowering and tuber initiation to tuber bulking around 75 to 80 days after planting (Woods et al., 2008). Local evaluation is needed to identify products or blends that match the uptake patterns for potato plants.

Project Description:
The trial was conducted on Russet Burbank potatoes at two southern Alberta research stations to ensure that background N was moderate and that N applications could be controlled. One set of replicated plots was established at the Crop Diversification Centre South (CDCS), Brooks and the other was established at the AAFC Substation, Vauxhall, AB. The trial was planned for a total of 3 years to determine the impact of the treatments under a variety of environmental conditions. A total of 6 site years of data was generated and provided sufficient information to develop recommendations for incorporating ESN as part of an N management strategy for Russet Burbank potato producers.

The purpose of the current research was to determine whether ESN could be used in potato production to improve nitrogen use efficiency while maintaining yield and processing quality. The use of polymer coated urea in potato production could potentially reduce the total amount of nitrogen required to grow a high quality processing potato crop.

4. Objectives

- To determine the effect of combinations of urea and polymer-coated urea on yield, specific gravity and quality of Russet Burbank potatoes; and
- To determine whether polymer-coated urea could replace the need for in-season N applications (top-dressing, side-dressing or fertigation), and
- To determine whether polymer-coated urea reduced the risk of nitrate leaching in irrigated potato production; and

- To determine whether polymer-coated urea could be used as a tool for better nitrogen management in Alberta potato production.

5. Methods

This study was conducted for three years (2007 – 2009) at two research facilities in southern Alberta; the Crop Diversification Centre South (CDCS) in Brooks, AB and the Vauxhall substation of the Lethbridge Research Station in Vauxhall, AB. The soils at the CDCS station are Orthic Brown Chernozem with soil textures ranging from loam to silt loam. The soils at the Vauxhall site are also Brown Chernozemic with a sandy loam texture. Composite soil samples were taken at three depths (0 to 15 cm, 15 – 30 cm and 30 – 60 cm) in the spring before planting to test for available nitrate N. Results for each site are presented in Table 10.

Table 10: Selected chemical properties of soils at the **Brooks, AB** and **Vauxhall, AB** sites each year. Composite samples were collected before establishing treatments (April / May) from three depths (0 to 15 cm, 15 – 30 cm and 30 – 60 cm).

	Brooks, AB			**Vauxhall, AB**		
0 – 15 cm	**2007**	**2008**	**2009**	**2007**	**2008**	**2009**
pH	7.7	8.2	7.6	7.7	6.9	7.5
Electrical conductivity mS/cm	0.66	0.41	0.52	0.99	0.66	1.18
Organic Matter %	1.2	1.5	<1.2	2.4	1.9	3.0
Nitrate Nitrogen (NO3-N) lb/ac	40	22	20	24	51	53
Phosphorus (P) lb/ac	102	196	78	73	110	55
Potassium (K) lb/ac	690	760	520	860	1000	980
Sulfate-sulfur (SO4-S) lb/ac	<10	<10	<10	70	24	39
15 – 30 cm						
pH	7.9	8.2	7.6	7.9	7.5	734
Electrical conductivity mS/cm	0.74	0.45	0.50	0.91	0.76	1.75
Nitrate Nitrogen (NO3-N) lb/ac	20	20	27	25	27	38
Sulfate-sulfur (SO4-S) lb/ac	76	<10	<10	69	25	>200
30 – 60 cm						
pH	8.1	8.3	8.2	8.1	8.0	7.3
Electrical conductivity mS/cm	1.01	1.11	0.50	1.36	0.72	6.21
Nitrate Nitrogen (NO3-N) lb/ac	30	40	28	26	32	36
Sulfate-sulfur (SO4-S) lb/ac	>400	348	20	>400	120	>400

Ten N treatments were replicated 5 times in a randomized complete block design. Two sources of N, a 45-day release polymer coated urea (ESN, 44-0-0) manufactured by Agrium Inc. and granular urea (45-0-0) were compared across several rates and application strategies to determine if ESN could be used to reduce nitrogen application costs in-season. Nitrogen treatments were applied using banding equipment in 2007. The nitrogen treatments were banded using a direct seeder at both locations May 9, 2008 and May 15, 2009. Treatments included:

1. No additional nitrogen – check
2. Urea applied pre-plant to bring available N to 225 kg/ha – urea 100% pp
3. Urea applied pre-plant to bring available N to 170 kg/ha – urea 75% pp
4. Urea applied pre-plant to bring available N to 115 kg/ha – urea 50% pp
5. ESN applied pre-plant to bring available N to 225 kg/ha – ESN 100% pp
6. ESN applied pre-plant to bring available N to 170 kg/ha – ESN 75% pp
7. ESN applied pre-plant to bring available N to 115 kg/ha – ESN 50% pp
8. No additional N at planting; **plus** ESN applied and cultivated in at emergence (Idaho) – ESN 75% td
9. Urea applied pre-plant to bring available N to 115 kg/ha plus ESN applied to bring available N to 170 kg/ha and cultivated in at emergence - Urea/ESN split
10. Urea applied pre-plant to bring available N to 170 kg/ha plus urea applied to bring available N to 225 kg/ha and cultivated in at emergence - Urea split – STD 100%

Potatoes were planted approximately 13 – 15 cm deep using a two-row wheel planter in **Brooks** on May 10, 2007, May 14, 2008, and May 19, 2009 and in **Vauxhall** on May 11, 2007, May 13, 2008 and May 22, 2009. Russet Burbank seed (E3) of the same seed lot was used for both locations each year. Seed was cut (70 – 85g seed pieces), suberized, treated with Maxim^{TM} seed piece treatment (500g/100kg seed) in 2007, and Maxim MZ PSP seed piece treatment (500g/100kg seed) in 2008 and 2009. Potatoes were planted 30 cm apart in 6 m rows spaced 0.90 m apart. Each treatment was 4 rows wide. Only one of the centre rows was harvested for yield estimates and tuber evaluations. Each treatment was replicated 5 times to reduce some of the variability inherent in small plot research (see plot plan in Appendix).

Wireless temperature loggers (Model 150 Watchdog, Spectrum Technologies, Plainfield, IL) were attached to the first seed piece in one row of each rep at both locations. Soil temperature data was recorded every two hours for the entire growing season. The data loggers were recovered just prior to harvest and daily maximum, minimum and mean temperature data from each device were retrieved.

Lysimeters (61 cm Soil Water Sampler, Soilmoisture Equipment Corp., Santa Barbara, CA) were installed in four replicates of six treatments (Trt #1, 2, 5, 8, 9, and 10) at the CDCS site each year to compare the potential for nitrate leaching between treatments. Lysimeters were positioned between adjacent potato plants within a potato row in each treatment. A vacuum was established is each tube using a Vacuum Test Hand Pump and Extraction Kit (Soilmoisture Equipment Corp.). Ground water samples were collected from each lysimeter starting June 14 (2007), July 4 (2008) and July 22 (2009) and approximately every two weeks throughout the growing season. Samples were analyzed for nitrate concentration at Lakeside Research Labs, Brooks, AB.

In **Brooks**, the plots were managed following the guidelines for the Western Canadian Potato Breeding Program. Eptam (2.0 L/ac) and Sencor (150 g/ac) were applied (April 30, 2007; May 7, 2008 and April 29, 2009) to control weeds prior to planting. Additional ESN and urea were applied (top-dressed) to treatments 8, 9, and 10 prior to power hilling June 5, 2007 (Tables 1), May 29, 2008 (Table 2) and June 15, 2009 (Table 4). The plots were irrigated with solid set sprinklers to maintain adequate soil moisture.

Foliar fungicides were applied at the **Brooks** location during the growing season to prevent early blight and late blight from developing (Tables 1 – 3). In **Brooks**, Decis 5 EC (60 ml/ac) was applied July 13, 2007, Thionex (0.60 L/ac) was applied July 7, 2008 and Thionex (0.60 L/ac) was applied July 7, 2009 to control Colorado Potato Beetles.

Table 1: Foliar fungicides applied to the 2007 ESN potato trial to prevent early blight and late blight development in **Brooks**, **AB**.

Date of Application	***Fungicide***	***Rate***
July 13	Dithane DG Rainshield	0.70 kg/ac
July 26	Bravo 500	0.80 L/ac
Aug 24	Ridomil Gold/Bravo	883 mls/ac

Table 2: Foliar fungicides applied to the 2008 ESN potato trial to prevent early blight and late blight development in **Brooks, AB.**

Date of Application	***Fungicide***	***Rate***
July 7	Quadris	324 mL/ac
July 25	Dithance DG Rainshield	0.70 kg/ac
Aug 20	Ridomil Gold with Bravo	883 mL/ac

Table 3: Foliar fungicides applied to the 2009 ESN potato trial to prevent early blight and late blight development in **Brooks, AB.**

Date of Application	***Fungicide***	***Rate***
July 8	Quadris	324 mL/ac
July 30	Ridomil Gold with Bravo	883 mL/ac
Aug 24	Bravo 500	0.65 L/ac

In **Vauxhall**, the plots were managed by sub-station staff. Eptam (3.0 L/ac) was applied (May 7, 2007, April 28, 2008 and May 21, 2009) to control weeds prior to planting. Additional ESN and urea were applied (top-dressed) to treatments 8, 9, and 10 prior to hilling June 8, 2007, June 3, 2008 and June 16, 2009. The plots were irrigated with a combination of solid set sprinklers in 2007 and 2008 and with wheel move and solid set sprinklers in 2009. Soil moisture monitoring equipment was installed in 2008 and 2009 to track soil moisture and recommend irrigation events to maintain soil moisture near 70%.

Foliar fungicides were applied at the **Vauxhall** location during each growing season to prevent early blight and late blight from developing (Tables 4 – 6).

Table 4: Foliar fungicides applied to the **2007** ESN potato trial in **Vauxhall**, AB to prevent early blight and late blight development.

Date of Application	*Fungicide*	*Rate*
June 19, 2007	Bravo 500	0.8 L/ac
July 3	Ridomil Gold/Bravo	883 mL/ac
July 11	Bravo 500	0.8 L/ac
July 20	Tattoo	1.1 L/ac
Aug 1	Bravo 500	0.80 L/ac
Aug 13	Bravo 500	0.8 L/ac
Aug 22	Bravo 500	0.8 L/ac

Table 5: Foliar fungicides applied to the **2008** ESN potato trial in **Vauxhall, AB** to prevent early blight and late blight development.

Date of Application	*Fungicide*	*Rate*
June 23	Bravo	0.8 L/ac
July 3	Bravo	0.8 L/ac
July 18	Bravo	0.8 L/ac
Aug 5	Ridomil Gold with Bravo	883 mL/ac
Aug 18	Bravo	0.8 L/ac

Table 6: Foliar fungicides applied to the **2009** ESN potato trial in **Vauxhall, AB** to prevent early blight and late blight development.

Date of Application	*Fungicide*	*Rate*
July 16	Bravo	0.8 L/ac
July 30	Bravo Ridomil Gold	883 mL/ac
Aug 12	Bravo	0.8 L/ac
Aug 20	Bravo	0.8 L/ac

Foliar insecticides were applied at the **Vauxhall** location during each growing season to control aphids and Colorado Potato Beetles (Tables 7 – 9).

Table 7: Foliar insecticides applied to the **2007** ESN potato trial in **Vauxhall, AB** to control aphids and Colorado Potato Beetles.

Date of Application	*Fungicide*	*Rate*
June 19, 2007	Monitor	0.8 L/ac
June 26	Admire	80 mL/ac
July 11	Monitor	0.8 L/ac
July 20	Monitor	0.8 L/ac
Aug 1	Admire	80 mL/ac
Aug 13	Monitor	0.8 L/ac
Aug 22	Monitor	0.8 L/ac

Table 8: Foliar insecticides applied to the **2008** ESN potato trial in **Vauxhall, AB** to control aphids and Colorado Potato Beetles.

Date of Application	*Insecticide*	*Rate*
June 23	Admire	80 mL/ac
July 3	Monitor	0.8 L/ac
July 18	Success	40 mL/ac
Aug 5	Admire	80 mL/ac
Aug 18	Monitor	0.8 L/ac

Table 9: Foliar insecticides applied to the **2009** ESN potato trial in **Vauxhall, AB** to control aphids and Colorado Potato Beetles.

Date of Application	*Insecticide*	*Rate*
July 16	Monitor	0.8 L/ac
July 30	Admire	80 mL/ac
Aug 12	Admire	80 mL/ac
Aug 20	Monitor	0.8 L/ac

Petiole samples were taken at three dates during each season (**Brooks**: July 4, July 25 and August 8, 2007; June 26, July 18 and August 8, 2008; July 7, July 21 and August 11, 2009 and **Vauxhall**: July 5, July 26, and August 10, 2007; June 27, July 22, and August 6, 2008 and July 9, July 23, and August 13, 2009) to ascertain the N status of the crop and determine any effects of treatments on N levels in petioles.

Reglone (1.4 L/ac) was applied Sept 5, 2007, Sept 12, 2008 and Sept 11, 2009 in **Brooks** to desiccate potato vines. All treatments were harvested mechanically with a one-row Grimme harvester September 21, 2007, Sept 18, 2008, and Sept 23, 2009 at the Brooks location. Reglone (1.0 L/ac) was applied Sept 11, 2007, Sept 11, 2008 and Sept 9, 2009 in **Vauxhall** to desiccate potato vines. Treatments were dug mechanically and hand collected September 18, 2007 at the Vauxhall location. Treatments were harvested with a one-row Grimme harvester Sept 18, 2008. Treatments were dug with a one-row chain digger and hand collected September 24, 2009. At both locations a greater number of small tubers were harvested than with commercial harvesting equipment. This tended to inflate the percentage of small tubers, but did not affect marketable yield figures.

Yield, grade, specific gravity and defects for both sites were determined by McCain Foods Canada after harvest. Yield estimates are presented in tons/acre. An economic analysis of the crop was conducted by McCain using a base price per ton based on delivery from storage prior to Nov 15. It does not include bonus for color or payment for smalls. For the analysis, urea was estimated to cost $400/ton in 2007, $800/ton in 2008 and $600/ton in 2009 and a 15% premium was added for ESN pricing. Each field application was estimated to cost $5 per acre in 2007 and 2008 and $7 per acre in 2009.

Statistical analysis of the petiole nitrate data included analysis of variance (ANOVA) and separation of means by Tukey's multiple means comparison test using Sigma Stat statistical software (SPSS, Chicago, IL). Nitrate concentrations from lysimeter samples were analyzed using a Kruskal-Wallis one-way analysis of variance on ranked data ($p \leq 0.05$).

The yield data presented here were statistically analyzed in SAS using generalized linear model (GLM) and means separation was done using the Duncan's Multiple Range Test ($p \leq 0.05$).

6. Results

Weather Data

Mean temperature and rainfall for the 2007, 2008 and 2009 growing season (May through September) are shown for both sites in Table 10. There were some differences in the weather conditions between growing seasons each year of the trial (Table 10). Mean temperatures in July in 2007 were warmer than normal at both locations. Accumulated precipitation was lower in 2007 than 2008 or 2009 at both sites, but irrigation was used to maintain adequate soil moisture.

Table 10: Mean monthly temperature, rainfall and physiological days (P-days*) for 2007 – 2009 at the **Brooks, AB** and **Vauxhall, AB** sites.

	Brooks, AB			**Vauxhall, AB**		
Temperature (mean, ˚C)	**2007**	**2008**	**2009**	**2007**	**2008**	**2009**
May	12.0	11.9	11.1	12.2	11.7	11.5
June	16.4	14.9	15.1	16.4	15.1	14.9
July	22.8	18.1	17.8	22.7	18.0	17.8
August	17.1	17.8	16.8	17.3	17.8	17.0
September	10.9	11.3	15.3	11.3	11.6	15.8
Rainfall (mm)						
May	59.4	65.9	14.1	57.3	66.5	30.0
June	43.1	68.3	57.7	35.0	85.2	44.8
July	5.2	61.6	135.6	11.0	56.7	47.5
August	41.7	15.8	41.8	28.4	36.3	85.1
September	31.7	32.1	2.0	14.8	48.3	3.7
Total	181.1	243.7	251.2	146.5	293.0	211.1
P-Days*						
May	137.2	136.0	122.3	143.3	135.9	123.3
June	207.4	181.9	173.2	210.2	185.3	172.4
July	211.9	235.0	235.2	216.3	238.4	241.4
August	213.8	207.1	218.3	212.0	209.9	220.3
September	123.2	137.9	171.5	125.5	140.4	173.4
Total	893.5	897.9	920.2	907.3	909.9	930.8

* P-days: an indexing system, widely used in potatoes for determining stage of development and initiation of disease. With the P-Day approach, the minimum temperature for potato growth and development is 7°C, while the most rapid growth and development takes place at 21°C. The growth rate decreases with the increase in temperature and finally stops at 30°C.

Physiological-days (P-days, Sands et al. 1979) were calculated from the weather data as a method of comparing the growing seasons for potato production (Table 10). An initial comparison of total P-days in each growing season did not indicate much difference between the seasons. However, an evaluation of P-days accumulated within each month of the growing season emphasized differences during specific parts of the season (Table 10). Differences experienced during key stages of growth and development of the tubers are expected to have a greater impact on yield and size profiles than differences very early or very late in the season. Comparing the month of July, there were 21 days over 30˚C in 2007, 3 days in 2008, and 4 days in 2009 (data not shown). The difference in temperatures is reflected in the P-days accumulated in June and July of each year. In 2007, approximately 25 to 30 more P-days were accumulated in June of 2007 than 2008 or 2009 and 20 fewer P-days were accumulated in July than in 2008 and 2009. September was also much cooler in 2007 and may have affected tuber bulking.

Maximum, minimum and mean soil temperatures were collected within the hills each year (data not shown). In 2007, soil temperatures at the **Brooks** location ranged from approximately 5°C at planting to almost 35˚C before row close. Throughout most of the growing season, soil temperatures fluctuated between 10˚C and 25˚C with cooler soil temperatures evident at harvest. Soil temperatures in **Vauxhall** were slightly warmer than in Brooks. Soil temperatures in Vauxhall ranged from 7˚C to over 30˚C until row close. As in Brooks, soil temperatures fluctuated less after row closure and cooled off toward harvest.

In 2008, soil temperatures at the **Brooks** location ranged from approximately 10˚C at planting to over 30˚C before row close. Throughout most of the growing season, soil temperatures fluctuated between 10˚C and 20˚C with cooler soil temperatures evident in September. Soil temperatures in **Vauxhall** fluctuated in a narrower range than in Brooks. Soil temperatures in Vauxhall ranged from 10˚C to 25˚C until row close and between 12˚C and 22˚C through most of July and August. Somewhat cooler soil temperatures were evident in September.

In 2009, soil temperatures at the **Brooks** location ranged from less than 5˚C at planting to over 30˚C before row close. Once plants were up and row-close had occurred, soil temperatures fluctuated between 10˚C and 26˚C. August was cooler than July and September was warmer than normal. Soil temperatures in **Vauxhall** plots fluctuated in a narrower range than in Brooks. Soil temperatures in Vauxhall ranged from 5˚C to 28˚C until row close and between 12˚C and 22˚C through most of July and August. Differences between locations may have been due, in part, to the use of different hilling equipment as well as to differences in the growing season.

Nitrate Leaching

There were no rainfall events in 2007 or 2008 that would have lead to nitrate leaching during the time frame that lysimeters were monitored in the plots. In 2009, there was one potential leaching event in mid-July (Table 10). Lysimeters were installed in early June in 2007 and June 5, 2008 just prior to emergence of the potato plants and June 26, 2009 just after emergence of the potato plants. Lysimeters were removed in September prior to harvest each year. In 2007, rainfall while monitoring for nitrate leaching totaled 70.8 mm, well below the 30-year average, especially for July. In 2008, rainfall during this period totaled 163.8 mm and in 2009 rainfall during this period totaled 180.3 mm. Irrigation was necessary and was scheduled to produce optimal yield of potatoes based on estimated soil moisture. Irrigation sufficient to incur leaching would have been counter-productive to the primary objectives of the trial.

In 2007, the median background levels of nitrate in ground water collected from a 60 cm depth ranged from 11 ppm to 360 ppm depending on the location of the replicate in the field and the time of sampling (Fig 7). In 2008, the median background levels of nitrate in leachate ranged from 32 ppm to 170 ppm depending on the location of the replicate in the field (Fig 8). In 2009, the median background levels of nitrate in leachate ranged from 30 ppm to 80 ppm depending on the location of the replicate in the field (Fig 9).

2007: Treatment 1 (check), 2 (100% urea pre-plant), 5 (100% ESN pre-plant) and 8 (75% ESN at emergence) showed fluctuations between sampling dates of up to 20 ppm but the net change was small (Fig. 7). Treatments 9 (75% urea/ESN split) and 10 (100 %split urea) both resulted in greater fluctuation. Only the split urea treatment (Trt #10) showed a consistent increase in nitrate concentration relative to the background level by the end of the season. Data presented are the mean of four replicate samples. None of the nitrate values were significantly different from one another in 2007.

2008: For all of the treatments, median nitrate levels decreased between the June 20 and the July 7 sampling dates in all of the treatments (Fig. 8). The pattern of nitrate concentrations under each treatment was similar. Sampling was discontinued after the August 15 sampling date because ground water samples were not recovered from over 50% of the lysimeters on Aug 15. As of August 15, there was no indication that any of the treatments resulted in a consistent increase in ground water nitrate concentrations. Data presented are the means of four replicate samples. None of the nitrate values were significantly different from one another in 2008.

2009: The median nitrate concentration decreased in the check treatment and in the ESN treatments for dates that samples were analyzed (Fig 9). Unfortunately, data was not available for samples collected July 27 and Aug 20 as there was turn-over in the ownership of the analytical laboratory. Sampling was discontinued after the August 20 sampling date because ground water samples were not recovered from over 50% of the lysimeters on Aug 12. As of August 12, there was no indication that any of the treatments resulted in a consistent increase in ground water nitrate concentrations. Data presented are the means of up to four replicate samples. None of the nitrate values were significantly different from one another in 2009.

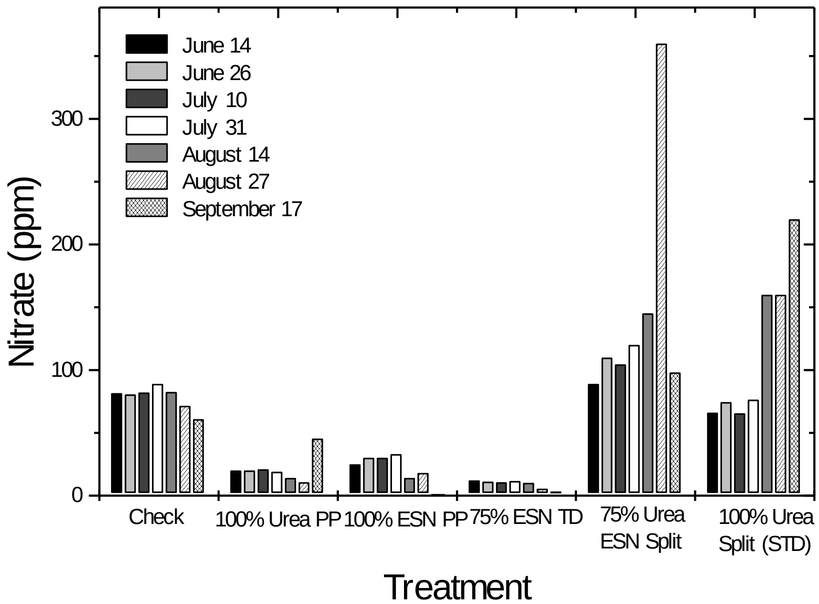

Figure 7: Nitrate concentration in samples of ground water recovered from lysimeters installed within treated areas of the field in **2007**.

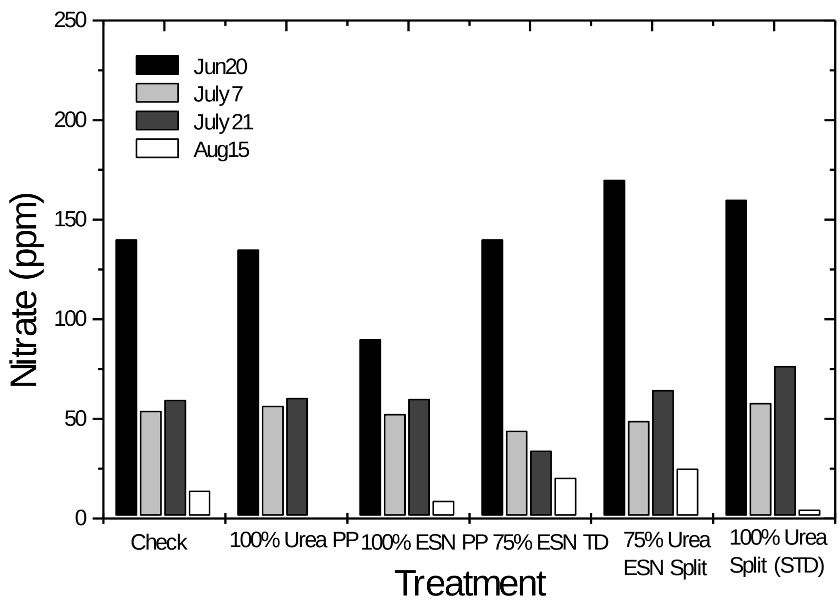

Figure 8: Nitrate concentration in samples of ground water recovered from lysimeters installed in **2008** within treated areas of the field.

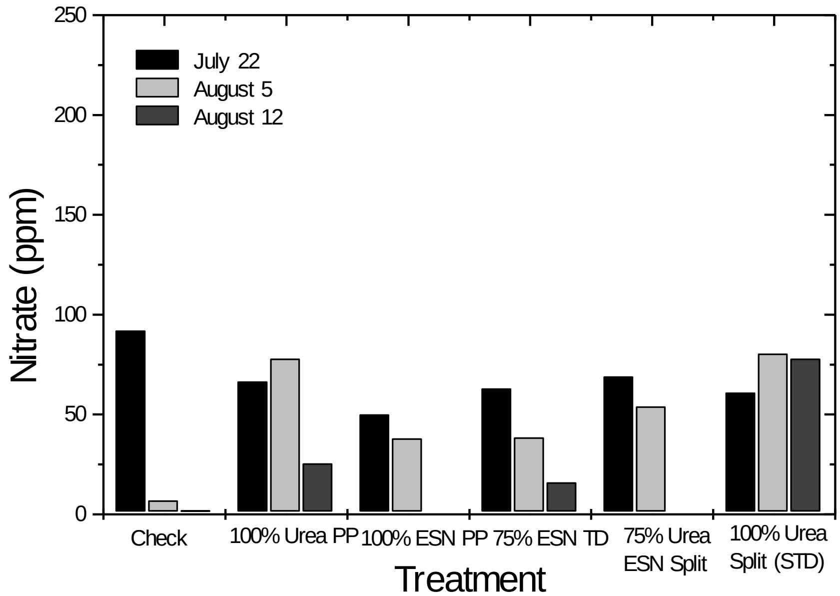

Figure 9: Nitrate concentration in samples of ground water recovered from lysimeters installed in **2009** within treated areas of the field.

Petiole Nitrates

Petiole nitrate concentrations in all treatments decreased throughout the growing season each year in **Brooks.** The first petiole sampling date was selected to coincide with the maximum release date of pre-plant ESN, approximately 45 to 50 days after incorporation. At the first sampling date in 2007, nitrate levels in the petioles ranged from about 16,000 ppm for the check to over 20,000 ppm for treatments with optimal nitrogen applied (Table 11). By the first sampling date in 2008, nitrate levels in the petioles ranged from just over 10,000 ppm for the check to over 17,000 ppm for the split urea (STD) treatment. In 2009, petiole nitrate concentrations at the first sampling date ranged from around 17,000 ppm for the check to over 20,000 ppm for treatment with adequate N. With the exception of the check treatments, the petiole nitrate concentrations at the beginning of each season fell within recommended levels for Russet Burbank production in southern Alberta (Woods et al., 2008).

In 2007, petiole nitrates collected at the Brooks location dropped off gradually throughout the growing season. In 2008 and 2009, petiole nitrates fell rapidly between the first and the second sampling dates even though no leaching events occurred during the season. This may reflect rapid vegetative growth of the plants rather than any deficiencies in N availability. By the second sampling date in 2009 and the third sampling date in 2008 and 2009, petiole nitrates for most treatments fell below recommendations by Woods et al. (2008) for southern Alberta. As expected, treatments with less N applied pre-plant started out with lower petiole nitrate levels and treatments with the greatest applied N levels, whether ESN or urea, maintained the highest petiole nitrate concentrations throughout the season. Split N applications typically maintained petiole nitrates at higher levels through the season than pre-plant applications, although some exceptions were observed. Wilson et al. (2009) also noted higher petiole nitrate concentrations as N rate increased and higher petiole nitrate concentrations with split N applications.

Table 11: Petiole nitrate levels for each treatment at the Brooks, AB and **Vauxhall, AB** locations. Samples were taken from the fourth petiole from up to eighty stems at three times during each growing season:

Treatment	Brooks, AB			Vauxhall, AB		
2007	July 4	July 25	Aug 8	July 5	July 26	Aug 10
Check	15600 b	10600 a	6760 a	11160 e	12100 b	5200 a
100% urea PP	20640 a	12800 a	8260 a	19120 ab	16880 ab	7800 a
75% urea PP	19440 ab	12220 a	6300 a	18960 b	17400 ab	7880 a
50% urea PP	17600 ab	9500 a	5760 a	13360 de	14040 ab	4480 a
100% ESN PP	19040 ab	13200 a	8360a	17840 abc	18960 a	8400 a
75% ESN PP	18840 ab	12560 a	6600 a	17260 abc	16520 ab	8240 a
50% ESN PP	18240 ab	10380 a	6460 a	14560 de	15360 ab	6160 a
75% ESN TD	17720 ab	14340 a	9000 a	15360 cd	16460 ab	7440 a
75% urea/ESN split	19360 ab	12800 a	9980 a	17660 abc	16080 ab	6720 a
100% urea split (STD)	20440 a	13800 a	9920 a	20320 a	20440 a	10800 a
2008	Jun 26	July 18	Aug 8	June 27	July 22	Aug 6
Check	10460 b	3215 d	383 a	4500 d	394 a	1564 b
100% urea PP	15640 ab	9386 ab	2297 a	13360 ab	2758 a	5084 ab
75% urea PP	12700 ab	6821 bcd	383 a	12620 abc	394 a	5476 ab
50% urea PP	11460 b	4489 cd	383 a	7860 cd	591 a	1956 ab
100% ESN PP	15820 ab	8261 abc	1531a	14880 a	2364 a	4302 ab
75% ESN PP	14480 ab	5403 bcd	766 a	11420 abc	591 a	3129 ab
50% ESN PP	12680 ab	4680 cd	766 a	8740 bcd	591 a	1760 ab
75% ESN TD	13980 ab	8969 ab	1531 a	12460 abc	6697 a	7822 ab
75% urea/ESN split	13240 ab	8582 abc	766 a	13680 ab	1576 a	3716 ab
100% urea split (STD)	17320 a	11093 a	8040 a	16280 a	6697 a	7822 a
2009	July 7	July 21	Aug 11	July 9	July 23	Aug 13
Check	18560 b	1160 c	1620 a	7980 a	4540 b	1400 a
100% urea PP	22720 ab	6760 abc	6000 a	14260 a	8520 ab	6600 a
75% urea PP	22880 ab	4020 abc	3140 a	12000 a	6440 ab	3100 a
50% urea PP	19280 b	1280 c	2140 a	5750 a	4160 b	8000 a
100% ESN PP	23840 ab	9260 ab	6480 a	12725 a	8080 ab	2900 a
75% ESN PP	26360 a	3000 cb	2600 a	9775 a	6925 ab	2350 a
50% ESN PP	21920 ab	2440 c	2300 a	10580 a	4025 b	1000 a
75% ESN TD	22700 ab	3250 bc	1700 a	11500 a	6650 ab	3100 a
75% urea/ESN split	23360 ab	5620 abc	4200 a	13420 a	5080 ab	1400 a
100% urea split (STD)	22760 ab	9780 a	6800 a	16740 a	15800 a	11600 a

Petiole nitrate levels in Vauxhall followed a different pattern in each year of the trial. In 2007, petiole N levels from the Vauxhall plots ranged from 11,000 to 20,000 on the first sampling date in early July (Table 11). As we observed in Brooks, treatments with the highest pre-plant applications of nitrogen had the highest petiole nitrate levels. Petiole nitrates remained high for the second sampling date and decreased by the third sampling date. Petiole nitrates appeared to be somewhat independent of the amount of N applied in 2007. Additional nitrogen may have become available during the growing season as a result of mineralization of organic matter.

In 2008, petiole nitrate levels ranged from around 4500 ppm for the check to around 16,000 ppm for the split urea (STD) treatment (Table 11). As with samples from the Brooks location, petiole nitrate concentrations were higher for treatments with 100% N than 75% or 50% N. In Vauxhall, the 100% treatments, 75% urea treatment and the split applications had petiole nitrate concentrations in the recommended range at the first sampling date. The crop in Vauxhall was damaged by hail July 16, 2008 and the up to 40% of the foliage was damaged. Petiole nitrate levels at the second sampling date were much lower for all treatments, and lower than the nitrate levels observed from the third sampling event. The replacement of vegetative tissue likely resulted in a re-allocation of N within the potato plants. By the third sampling date, petiole nitrates were higher than similar treatments in Brooks. The interruption of growth and development caused by the hail storm affected the nitrate concentration in the fourth petiole. Petiole nitrate concentrations for most of the treatments were below the recommended range in early August (Woods et al., 2008).

In 2009, petiole nitrate levels from the Vauxhall plots decreased throughout the season (Table 11). Nitrate levels ranged from around 8,000 ppm for the check to around 16,000 ppm for the split urea (STD) application treatment in early July. As with the samples from the Brooks location, petiole nitrate concentrations were generally higher for treatments with 100% N than 75% or 50% N. In Vauxhall, the 100% treatments, 75% urea treatment and the split applications had sufficient petiole-N at the first sampling date. Petiole nitrate levels at the second sampling date were lower for all treatments than the first sampling date and only petioles from the split urea (STD) treatment had sufficient nitrate based on southern Alberta recommendations (Woods et al., 2008). By the third sampling date, only petioles from the 100% urea pre-plant, 100% ESN pre-plant and the STD had nitrate levels within recommended levels. The check and treatments supplied with 50 to 75% N had inadequate N based on the 2008 recommendations.

Potato Yield and Grade

Potato yield, grade and estimated crop value relative to the STD are presented in Table 12 for each treatment harvested in **Brooks** during the three year trial. There were no significant differences in marketable yield or average tuber size between treatments in 2007 or 2009 and a few significant differences in 2008. Polymer-coated urea products have been shown by others (Wilson et al. 2009, Hopkins et al. 2008, Shoji et al. 2001) to produce similar or greater yields than soluble N at equivalent rates. Average tuber size in 2007 was quite small and a high percentage of tubers were undersized. In 2008, however, some statistical differences were observed in marketable tuber yields and yields of specific size categories. Pre-plant application of urea at 75% of the STD rate yielded the most marketable tubers, while the check and the 50% ESN pre-plant treatments yielded the least. Wilson et al. (2009) reported that an increase in the N rate applied resulted in a greater percentage of tubers over 6 oz., an economically important size class. Average tuber size was lower with pre-plant or top-dressed ESN applications in 2008 than with pre-plant urea or the urea/ESN split. The split urea application resulted in average tuber sizes that were not significantly different from the ESN treatments, while the urea/ESN split application resulted in an average tuber size similar to the check and the urea pre-plant treatments. In general, urea treatments resulted in a higher percentage of tubers over 10 oz compared to ESN treatments in 2008. In 2009, around 10% of the tubers were small (under 3 oz.) and fewer than 20% of the tubers were over 10 oz. The weather may have played a role in the size distribution of the crop. There were delays in the spring as a result of cool weather, August was more moderate and September was warmer than usual. Our trial was desiccated September 11 and we likely lost 2 weeks of potential bulking that might have helped differentiate between treatments.

All of the treatments in 2007 resulted in a lower net crop value than the STD treatment. In 2008, all of the treatments yielded a higher net crop value than the STD treatment, and in 2009, all treatments in Brooks, except the check treatment, gave similar or better gross economic return on a sample contract than the STD (Table 12). The greatest net crop value in 2008 was achieved with 75% urea applied pre-plant. For economic return in 2009, the best treatment in Brooks was 50% ESN applied pre-plant. Applying ESN (75%) at emergence and the urea/ESN split application gave better economic returns than the STD. Wilson et al. (2009) provided a simple economic analysis for their work with various rates of polymer-coated urea and split applied N treatments. Their analysis suggests that the use of polymer-coated urea could reduce or eliminate the need for fertigation on coarse-textured soils. In this study, each of the treatments with a better economic return than the STD used a reduced rate of N. The best economic return may shift with urea price changes.

Specific gravity of tubers was affected by N source and timing each year as well as by environmental factors (Table 12). Wilson et al. (2009) reported that N treatments did not significantly affect specific gravity, but that other factors, such as temperature or irrigation, may have contributed to differences between years. In this study, and in work reported by Belanger et al. (2002), the greater the quantity of N applied, the lower the specific gravity. The highest specific gravity tubers were usually observed in the check treatment and the 50% rate of urea and ESN. The lowest specific gravity was observed from treatments with 100% N applied whether pre-plant or split application (STD). Pre-plant N had a greater impact on specific gravity than top-dressed N. The trend was that urea reduced specific gravity more than ESN, although differences between treatments were not always statistically significant.

Table 12: Yield and grade of potatoes harvested from plots in **Brooks, AB** grown with different nitrogen sources in **2007, 2008 and 2009.** Data in each column followed by the same letter in a given year are not significantly different from one another.

Treatment	% under-sized	Mkt Yld (ton/ac)	>10 oz. (%)	Avg Tuber size (oz)	Tuber count (10 kg)	SG	Crop Value (% of STD)
2007							
Check	19.5 ab	21.8 a	3.7 a	3.9 a	86.8 ab	1.085 abc	83.1
100% urea PP	14.5 ab	24.2 a	4.2 a	4.5 a	89.4 ab	1.079 c	87.4
75% urea PP	10.4 b	26.1 a	4.6 a	4.8 a	83.6 ab	1.082 bc	96.3
50% urea PP	16.3 ab	22.4 a	4.2 a	4.3 a	80.6 ab	1.089 a	86.0
100% ESN PP	11.7 ab	26.7 a	4.5 a	4.5 a	84.6 ab	1.082 bc	97.7
75% ESN PP	13.8 ab	22.8 a	3.9 a	4.4 a	92.0 ab	1.086 ab	86.8
50% ESN PP	15.4 ab	24.1 a	4.2 a	4.2 a	78.4 b	1.083 abc	89.2
75% ESN TD	21.6 a	20.7 a	3.6 a	3.9 a	81.4 ab	1.082 bc	75.9
75% urea/ESN split	15.6 ab	23.3 a	3.5 a	4.3 a	74.4 b	1.085 abc	87.5
100% urea split (STD)	10.9 ab	26.7 a	4.9 a	4.8 a	98.6 a	1.084 abc	100.0
2008							
Check	4.3 abc	27.2 b	51.5 ab	8.9 a	40.6 b	1.094 a	100.4
100% urea PP	2.9 c	32.1 ab	49.6 abc	8.9 a	39.8 b	1.088 abc	117.1
75% urea PP	2.6 c	33.8 a	51.5 ab	8.7 a	40.6 b	1.088 bc	124.2
50% urea PP	2.5 c	32.0 ab	59.6 a	9.3 a	38.0 b	1.093 a	117.9
100% ESN PP	6.1 a	32.4 ab	40.1 cd	7.2 c	49.2 a	1.088 abc	117.7
75% ESN PP	5.0 ab	30.4 ab	37.2 d	7.2 c	49.6 a	1.093 ab	111.3
50% ESN PP	4.9 ab	27.3 b	46.3 bcd	7.6 bc	47.2 a	1.093 ab	100.6
75% ESN TD	4.4 ab	30.9 ab	41.5 bcd	7.2 c	48.8 a	1.089 abc	112.3
75% urea/ESN split	3.7 bc	32.3 ab	51.5 ab	8.4 ab	42.0 b	1.088 abc	117.8
100% urea split (STD)	5.4 ab	28.0 b	47.0 bcd	7.6 bc	47.2 a	1.085 c	100.0
2009							
Check	12.3 a	21.4 a	18.6 a	4.53 a	80.0 a	1.096 ab	98.7
100% urea PP	11.1 a	22.7 a	17.3 a	4.79 a	75.7 a	1.091 bcd	102.1
75% urea PP	11.7 a	22.9 a	17.1 a	4.67 a	75.8 a	1.092 bcd	104.6
50% urea PP	10.4 a	23.7 a	18.8 a	4.87 a	73.5 a	1.099 a	104.5
100% ESN PP	13.6 a	22.9 a	12.7 a	4.37 a	81.2 a	1.088 d	101.8
75% ESN PP	9.6 a	23.6 a	17.1 a	5.06 a	71.4 a	1.094 abcd	105.4
50% ESN PP	8.8 a	25.4 a	16.9 a	4.57 a	77.7 a	1.095 abcd	115.8
75% ESN TD	10.4 a	24.4 a	16.1 a	4.49 a	78.9 a	1.095 abc	110.8
75% urea/ESN split	11.5 a	24.1 a	19.1 a	4.76 a	75.5 a	1.095 abcd	107.8
100% urea split (STD)	9.6 a	22.3 a	19.8 a	4.83 a	73.5 a	1.089 cd	100.0

Potato yield, grade and estimated crop value relative to the STD are presented in Table 13 for each treatment harvested in **Vauxhall** during the three year trial. Potato yields from the Vauxhall site were lower than yields at the Brooks site all three years of the trial, possibly a result of the different irrigation strategies between the two locations. In 2007, the greatest marketable yield in Vauxhall was observed with the urea/ESN split application. The split urea application resulted in the greatest yield of undersized tubers, and the smallest yield of marketable tubers. There was good separation between treatments in data from the Vauxhall plots in 2008 in spite of higher background N (Table 13) and a hail event in mid-July. In 2008, the greatest marketable yield was observed when ESN was applied at emergence (ESN 75% TD). The 100% ESN pre-plant and split application treatments also resulted in very good marketable yield in 2008. In 2008 and 2009 marketable yield for the check was not significantly different from the 50% urea and ESN treatments because of high background N levels. The check and 50% N treatments resulted in the fewest tubers over 10 oz in 2008, while split treatments and ESN at emergence resulted in the greatest yield of tubers over 10 oz. The largest average tuber size was observed with the split application treatments, the 75% ESN treatment and when ESN was applied at emergence. This treatment (ESN 75% TD) was similar to the ESN recommendations developed in Idaho for Russet Burbank production. There was some separation between treatments in data from the Vauxhall plots in 2009 in spite of higher background N. In general, the more N applied, the better the yield and size profile (fewer smalls, higher mean tubers size, etc.). In 2009, the greatest marketable yield was observed with 100% urea pre-plant and the split urea application (STD). Relative to the check, the STD resulted in significantly greater yield, greater mean tuber size, and more tubers over 10 oz. Many of the differences observed between other treatments were not statistically significant.

Specific gravities of tubers from the various nitrogen treatments were not significantly different from the check in 2007, although some treatments showed significant differences from one another (Table 13). In 2008, generally the higher the N applied, the lower the specific gravity. The highest specific gravity values were observed from the check and the 50% urea and ESN treatments, while the lowest specific gravity values were observed with the STD treatment and when ESN was applied at emergence. In 2009, the highest specific gravity values were observed from the check, the 50% and 75% treatments, while the lowest specific gravity values were observed with the STD treatment, 100% pre-plant urea and 100% pre-plant ESN. As with samples from the Brooks location, the trend indicates that urea affects specific gravity more than ESN.

In 2007, the best economic return in Vauxhall was observed when 75% ESN was applied at emergence and with a split urea/ESN application was used. Economic return depends in part on the yield and profile of the crop, and in part on the price for urea and ESN fertilizers. In 2008, most of the treatments at Vauxhall resulted in a lower economic return than the STD treatment. Overall, the best economic return in Vauxhall was observed when urea (100%) was applied pre-plant. In this case, other agronomic factors, such as irrigation, likely played a greater role than the source and timing of N in the yield and grade of the crop.

In 2009, only the 100% urea pre-plant treatment resulted in an economic return greater than the STD split urea application. The check resulted in the lowest economic return. Although efforts were made to improve the irrigation practices at Vauxhall throughout the trial, irrigation efficiency was still quite variable. In the event that irrigation is not optimized, it is unlikely that the timing and quantity of N applied will make significant improvements in the yield or quality the potato crop.

Table 13: Yield and grade of potatoes harvested from plots in **Vauxhall, AB** grown with different nitrogen sources in **2007, 2008 and 2009.** Data in each column followed by the same letter in a given year are not significantly different from one another.

Treatment	% under-sized	Mkt Yld (ton/ac)	>10 oz. (%)	Avg Tuber size (oz)	Tuber count (10 kg)	SG	Crop Value (% of STD)
2007							
Check	14.2 b	16.7 b	3.0 ab	4.1 ab	86.8 ab	1.095 ab	83.1
100% urea PP	14.6 ab	17.6 b	2.9 ab	4.0 ab	89.4 ab	1.094 ab	87.4
75% urea PP	12.9 b	18.1 ab	3.1 ab	4.3 ab	83.6 ab	1.094 ab	96.3
50% urea PP	12.7 b	19.7 ab	4.0 ab	4.5 ab	80.6 ab	1.098 ab	86.0
100% ESN PP	14.0 b	16.9 b	3.2 ab	4.4 ab	84.6 ab	1.096 ab	97.7
75% ESN PP	15.5 ab	16.8 b	2.8 ab	3.9 ab	92.0 ab	1.100 a	86.8
50% ESN PP	12.3 b	20.2 ab	4.1 ab	4.5 ab	78.4 b	1.098 ab	89.2
75% ESN TD	11.4 b	18.8 ab	3.0 ab	4.4 ab	81.4 ab	1.092 b	75.9
75% urea/ESN split	11.2 b	22.3 a	4.8 a	4.8 a	74.4 b	1.096 ab	87.5
100% urea split (STD)	19.3 a	16.4 b	2.1 b	3.7 b	98.6 a	1.094 ab	100.0
2008							
Check	9.0 ab	21.6 c	25.6 bc	6.2 ab	57.8 abc	1.088 abc	90.1
100% urea PP	6.3 ab	22.8 bc	34.5 abc	6.4 ab	55.6 abc	1.086 abc	93.2
75% urea PP	10.6 a	23.4 bc	26.0 bc	5.8 b	62.4 a	1.087 abc	96.0
50% urea PP	10.5 a	21.4 c	23.0 c	5.8 b	61.6 ab	1.090 ab	87.4
100% ESN PP	6.6 ab	25.7 abc	27.9 abc	6.5 ab	54.6 abc	1.086 bc	103.4
75% ESN PP	8.7 ab	22.7 bc	27.2 bc	7.1 a	61.0 ab	1.088 ab	93.7
50% ESN PP	10.3 a	21.2 c	26.6 bc	5.8 b	61.4 ab	1.090 a	88.8
75% ESN TD	5.4 b	29.3 a	42.1 a	7.1 a	49.8 bc	1.083 c	115.4
75% urea/ESN split	7.0 ab	27.5 ab	39.2 ab	6.9 ab	52.0 abc	1.086 bc	111.8
100% urea split (STD)	4.6 b	24.8 abc	41.6 a	7.3 a	48.6 c	1.083 c	100.0
2009							
Check	15.7 a	13.5 b	13.8 ab	4.2 b	84.9 a	1.088 abcd	76.5
100% urea PP	10.5 a	20.4 a	18.1 ab	4.9 ab	72.9 ab	1.084 d	107.3
75% urea PP	8.4 a	17.7 ab	20.2 ab	4.9 ab	71.6 ab	1.086 abcd	99.1
50% urea PP	13.8 a	17.4 ab	11.1 b	4.7 ab	76.1 ab	1.090 abc	98.4
100% ESN PP	13.7 a	17.9 ab	20.6 ab	4.8 ab	76.5 ab	1.084 cd	92.9
75% ESN PP	14.7 a	16.7 ab	15.7 ab	4.8 ab	74.5 ab	1.091 a	93.1
50% ESN PP	11.7 a	15.8 ab	20.3 ab	4.7 ab	74.9 ab	1.090 abc	89.3
75% ESN TD	7.9 a	16.7 ab	17.5 ab	5.0 ab	70.7 b	1.090 ab	93.1
75% urea/ESN split	10.2 a	16.1 ab	19.9 ab	5.0 ab	71.5 ab	1.087 abcd	89.6
100% urea split (STD)	8.0 a	19.1 a	22.6 a	5.10 a	69.9 b	1.085 bcd	100.0

Potato yield from the Brooks site was higher each year than yield at the Vauxhall site for all treatments. Very different responses to the nitrogen treatments were observed at the two research locations in 2007. These differences were thought to be related to different agronomic practices, soil types or environmental conditions. In 2008, a severe hail storm in mid-July in Vauxhall likely reduced yield relative to Brooks. Similar responses to the nitrogen treatments were observed at the two research locations in 2008 in spite of hail damage at the Vauxhall site. Soil moisture was monitored at both sites in 2008 and 2009 to try to ensure that irrigation management was more consistent between the two sites. In 2009, a combination of solid set and wheel move sprinklers was set up at the Vauxhall site which increased variability between replicates. The 2009 crop was smaller than expected at both locations. A significant amount of bulking may have taken place in September if the crops had not been desiccated. Differences between treatments would likely have been more apparent if the crop had additional time to bulk.

Yield variation was evident between years at each location as well (Tables 12 & 13). An initial evaluation of cumulative physiological days (P-Days, Sands et al. 1979) for each season did not reveal any clues, but P-day accumulation at key growth stages provided a plausible explanation. A higher percentage of small tubers were harvested from both locations in 2007 compared to 2008 and 2009. As reported earlier, there were 21 days over 30˚C in July of 2007, 3 days in 2008, and 4 days in 2009 (data not shown). The difference in temperatures is reflected in the P-days accumulated in June and July of each year Table 10). In 2007, approximately 25 to 30 more P-days were accumulated in June of 2007 than 2008 or 2009 and 20 fewer P-days were accumulated in July than in 2008 and 2009. Heat in June may have affected tuber initiation. Excessive heat in July likely reduced growth and development of the potato plants. September was also much cooler in 2007 and may have reduced tuber bulking.

7. Conclusions

ESN can be used in place of or in concert with urea as an N source for Russet Burbank production in southern Alberta. Six site years of data were generated during the trial. Lysimeters were installed within treatments at the Brooks location of the trial to monitor nitrate levels below the root zone in each treatment. Plots were irrigated to maximize yield rather than to encourage leaching and there were no significant leaching events during the trial. Few differences were observed between treatments.

Petiole nitrates were monitored each year of the trial. Petioles nitrates from all treatments except the check fell within the recommended range for processing potatoes in southern Alberta at the first sampling date in late June or early July. Depending on the year and the location, petioles often dropped below the recommended range by the second or third sampling date. As expected, treatments with less N applied pre-plant reflected lower petiole nitrate concentrations and treatments with the greatest applied N, whether ESN or urea, maintained the highest petiole nitrate concentrations throughout the season. Split applications typically maintained petiole nitrates at higher levels through the season than pre-plant applications, although some exceptions were observed.

Treatments involving ESN resulted in marketable yields that were greater or not significantly different than yields from the split urea (STD) treatment. Average tuber size and tuber count in a 10 kg sample were affected more by environmental conditions each year than by N treatments. Applying N as ESN at emergence tended to reduce average tuber size relative to other comparable treatments applied pre-plant or as split applications. In general, though, the more N applied, the lower the average tuber size and the fewer tubers over 10 oz. The more N applied, the lower the specific gravity of tubers. ESN had less of an effect on tuber specific gravity than the same quantity of urea. ESN applied at hilling reduced specific gravity more than pre-plant application of ESN.

In this study, tuber size profiles, specific gravity and price of fertilizer were all taken into account for the crop value calculations. Base price assumed November delivery and fry colour bonuses were not taken into account. Marketable yield had the greatest impact on relative crop value in this study. That is, the treatments resulting in the greatest marketable yield, also resulted in the greatest economic return. Treatments where only 75% of the STD N rate was applied gave better economic returns than the STD treatment 4 out of 6 site years. Based on the results of this trial, it is feasible to reduce overall N applications by 25%. It is also feasible to use ESN to eliminate the need for in-season N applications. Reducing the quantity of N applied and splitting N applications between pre-plant urea and ESN at emergence gave good marketable yields and good economic returns 4 out of 6 site years.

8. Project Reach

Processing potato growers in southern Alberta are one target audience for this research. Producers need tools to improve nitrogen use efficiency and reduce cost of production for potatoes to remain competitive. The Potato Growers of Alberta (PGA) comprises more than 106 potato producers, 70 of whom grow processing potatoes. The PGA sponsored a portion of the project. Information was provided annually to the growers via the AGM and producer meetings.

Potato processors may also benefit by keeping contract prices in a range that maintains their competitiveness in a global market. Improvements in crop quality may also be realized with timely nitrogen applications. One Alberta processing company, McCain Foods, is partnering with us in the evaluation of the potato crops. Other processors will be kept apprised of the results of the project via PGA meetings.

Indirectly, members of the public may benefit from the efficient use of resources and the prudent use of nitrogen fertilizers. The impact of the study on this group is difficult to estimate. The results of the trial may be disseminated via popular press articles at the end of the research project depending on the outcome of the trials.

9. Project Impact

For ESN to be a useful tool for potato N management in Alberta, local information for producers is essential. There is a need to determine the best approach to optimize potato

yield and quality while refining costs of production. The data generated over the past three years of the trial will:
- be useful in BMP development for potato production in Alberta;
- determine whether polymer coated urea can reduce total nitrogen applied or reduce the number of in-season nitrogen applications required for optimal potato yield and quality
- provide economic evaluations of the use of polymer coated urea
- potentially reduce nitrogen losses to leaching and denitrification processes
- will address using the ESN technology under soil type and environmental conditions specific to southern Alberta.

The short and long-term outcomes depend heavily on the information generated from the trials. Adoption by growers can be monitored through ESN sales. Growers must be able to realize benefits to using ESN that exceed the price premium on ESN over urea fertilizer prices. Potato growers are asking questions about how to incorporate ESN in their nitrogen management strategy for potatoes and some early adopters have already experimented with polymer coated urea.

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11. Summary

Recent work in other potato production areas with polymer-coated-urea products have demonstrated improved nitrogen-use efficiency and decreased nitrate leaching (Hopkins et al 2009, Hutchinson 2005, Shoji et al. 2001, Zvomuya and Rosen 2001). This project involved growing Russet Burbank potatoes at two southern Alberta research stations to evaluate the use of a polymer-coated urea product locally. The purpose of the trial was to determine whether environmentally smart nitrogen (ESN, Agrium) could be used in potato production to reduce the total amount of N or the number of N applications without sacrificing yield or processing quality. Various quantities of urea and ESN were applied pre-plant and compared with urea at planting followed by top-dressing at emergence. Marketable yields from treatments involving ESN were greater or not significantly different from the split urea (STD) treatment each year of the trial, even when 25% less N was applied. In general, the more N applied, the lower the specific gravity and the fewer tubers over 10 oz. When economic return was taken into account, marketable yield had a greater impact on crop value than fertilizer price, average tuber size or specific gravity bonuses. Each treatment with a better economic return than the STD used a reduced rate of N. Based on the results of the trial, it is feasible to reduce overall N applications by 25%. Employing a split application with urea pre-plant and ESN at emergence gave good results in 2008 and 2009 provided that irrigation was timely and sufficient.

Resources used in the project:

This project is supported financially by Ag & Food Council, Agrium, Alberta Agriculture and Rural Development, and the Potato Growers of Alberta and through in-kind contributions by Agriculture and Agri-Food Canada, McCain Foods Canada, Agrium and Sandberg Laboratories.

Year	Applicant / Industry Cash	Applicant / Industry In-kind	Provincial Government Cash	Provincial Government In-kind	Federal Government Cash	Federal Government In-kind
2007-08	18,000	2,500	0	14,500	15,800	9,500
2008-09	12,000	2,500	0	14,500	13,000	9,500
2009-10	12,000	2,500	0	14,500	13,700	9,500

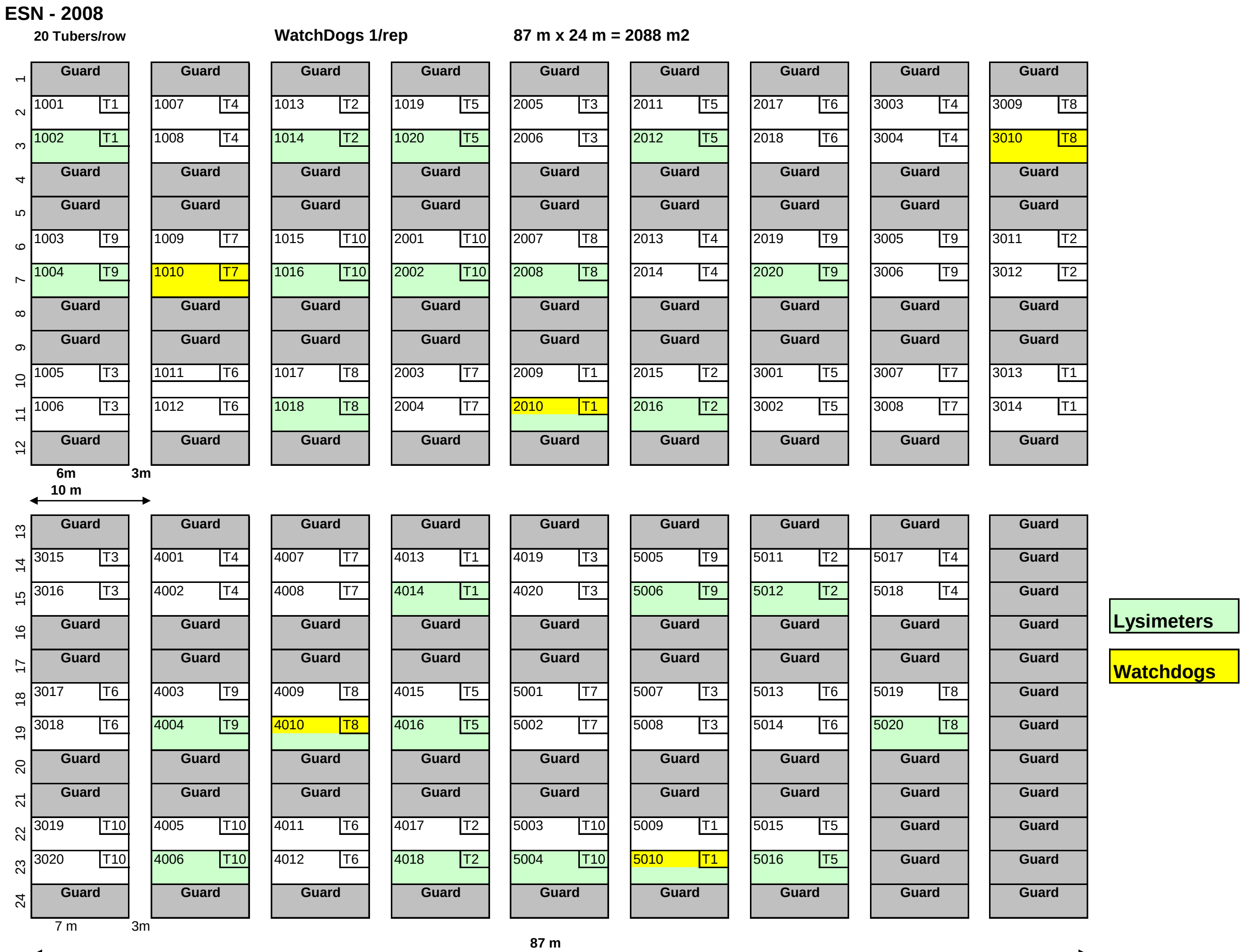

Figure A1: Sample plot plan of ESN Trial. Plot plans were similar for both locations each year of the trial.

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ESN on Russet Burbank

PAA Meeting Corvallis, OR August 17, 2010

Michele Konschuh, Ross McKenzie and Francis Zvomuya

Government of Alberta

Objectives:

- To determine:
  - the effect of combinations of urea and ESN on yield, specific gravity and quality of Russet Burbank potatoes in Alberta; and
  - whether ESN can replace the need for in-season N applications (top-dressing, side-dressing or fertigation); and
  - whether ESN reduces the risk of nitrate leaching in irrigated potato production; and
  - whether ESN can be used as a tool for better nitrogen management in Alberta potato production.

Approach Taken:

- Plot research at CDCS and Vauxhall
- Temperature sensors in hills at both locations
- Lysimeters in Brooks to monitor potential nitrate leaching
- Petiole samples in late June, mid-July and early August
- Crop quality and value assessed by McCain Foods

Treatments:

- Check - no additional nitrogen
- Urea - pre-plant - 100% (225 kg/ha total)
- Urea - pre-plant - 75% kg/ha (170 kg/ha total)
- Urea - pre-plant - 50% (115 kg/ha total)
- ESN - pre-plant - 100% (225 kg/ha total)
- ESN - pre-plant - 75% (170 kg/ha total)
- ESN - pre-plant - 50% (115 kg/ha total)
- Idaho - ESN – at emergence – 75% (170 lbs/ac total)
- Urea/ESN Split - Urea - pre-plant plus ESN at emergence – 75% (50:50)
- STD - Urea - pre-plant - plus urea at emergence – 100% (50:50)

Pre-plant Treatments

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Planting

CDCS Plots

Lysimeter Samples

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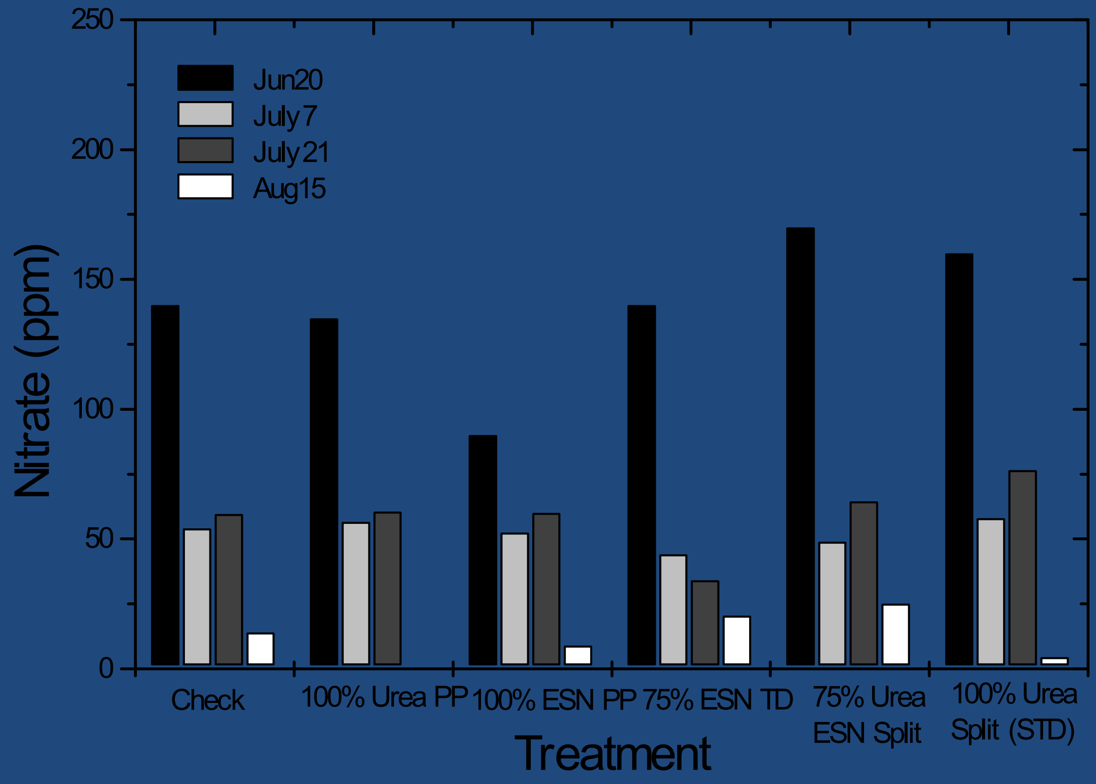
Nitrate Leaching



Nitrate Leaching

- There were no rainfall events in 2007 or 2008 that would have lead to nitrate leaching during the time frame that lysimeters were monitored in the plots.
- In 2009, there was one potential leaching event in mid-July .
- None of the nitrate values were significantly different from one another in any of the trial years.

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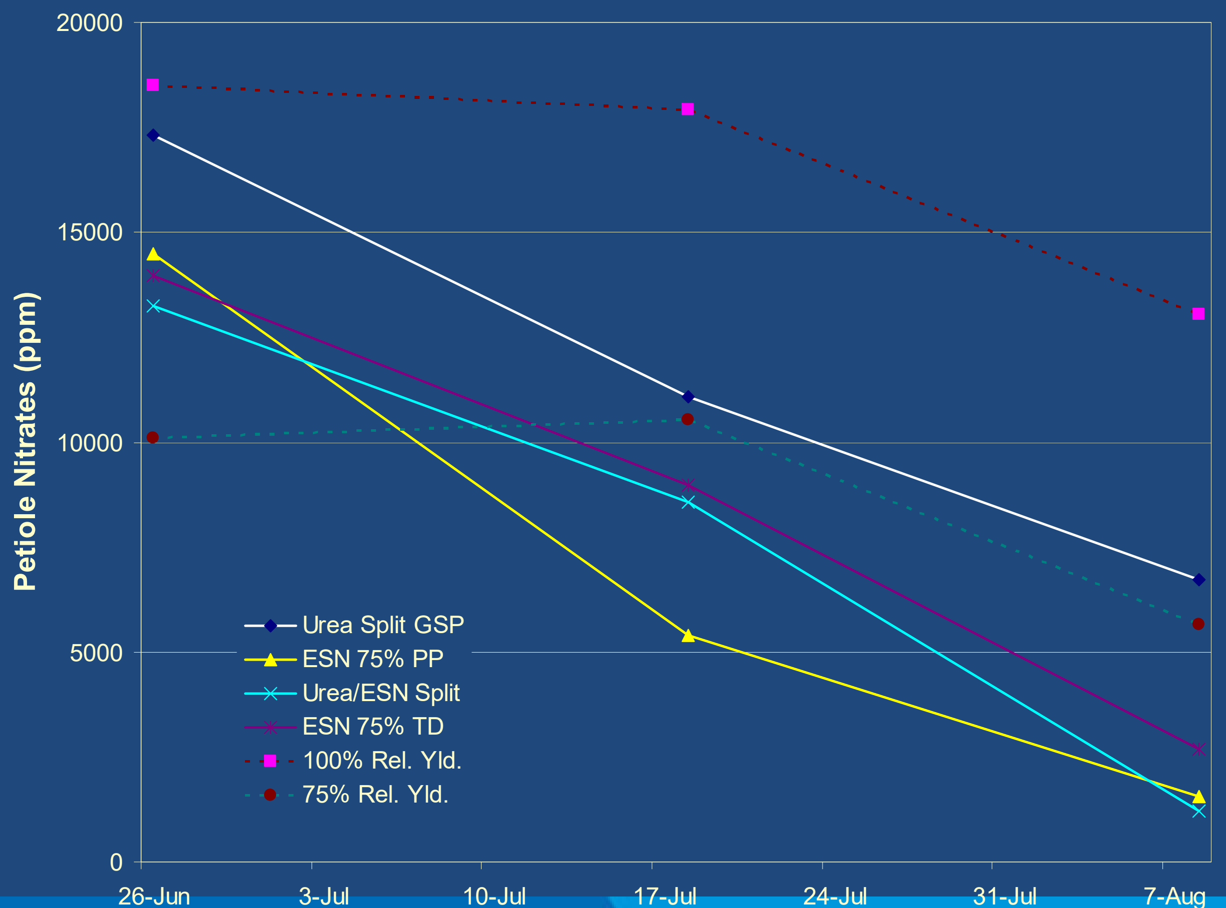
Petiole Sampling

Petiole Nitrates

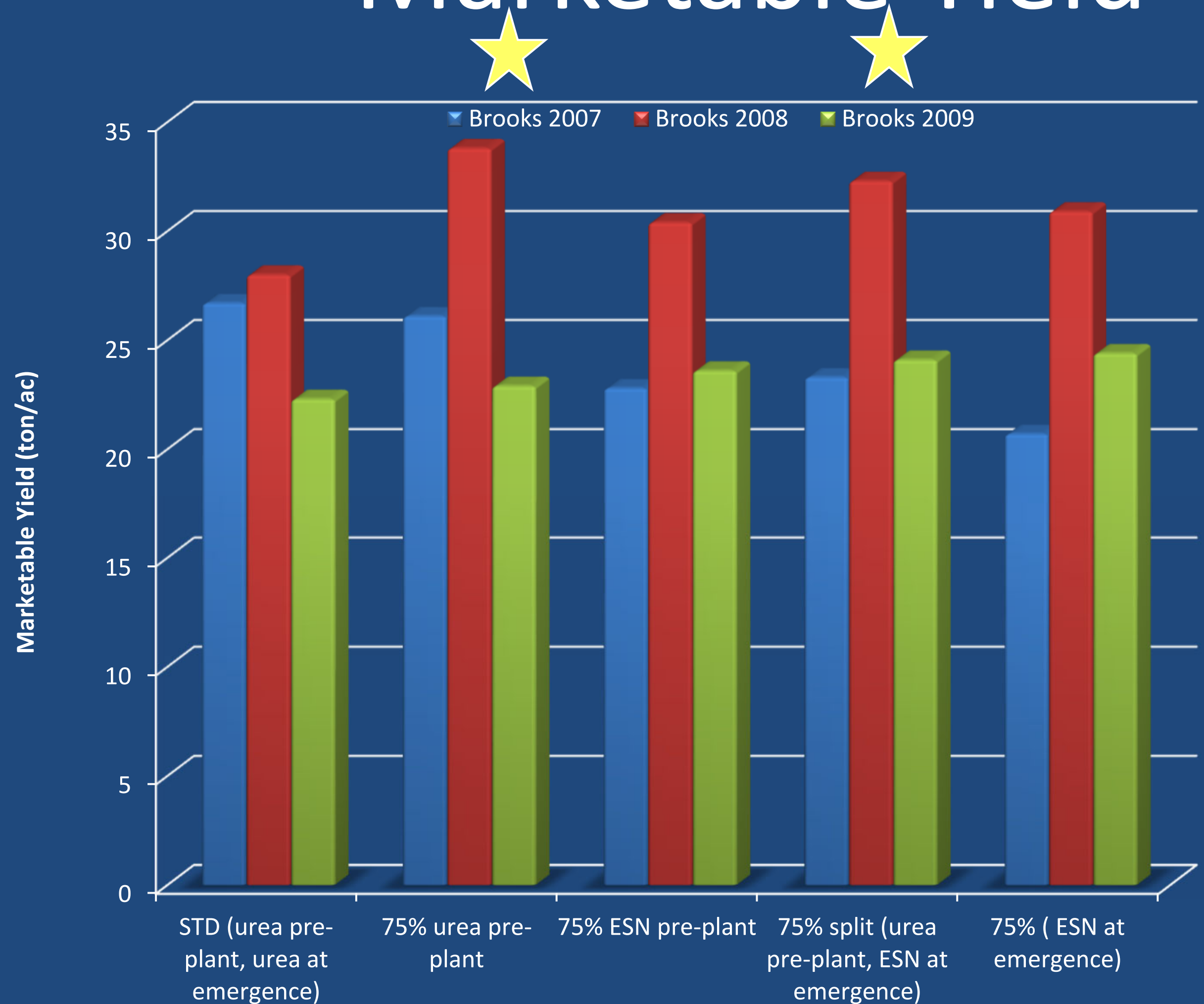
- By the second sampling date in 2009 and the third sampling date in 2007 and 2008, petiole nitrates for most treatments fell below regional recommendations for southern Alberta.
- As expected, treatments with less N applied pre-plant started out with lower petiole nitrate levels and treatments with the greatest applied N levels, whether ESN or urea, maintained the highest petiole nitrate concentrations throughout the season.
- Split N applications typically maintained petiole nitrates at higher levels through the season than pre-plant applications, although some exceptions were observed.

2008 Petioles - Brooks



Harvesting

Marketable Yield



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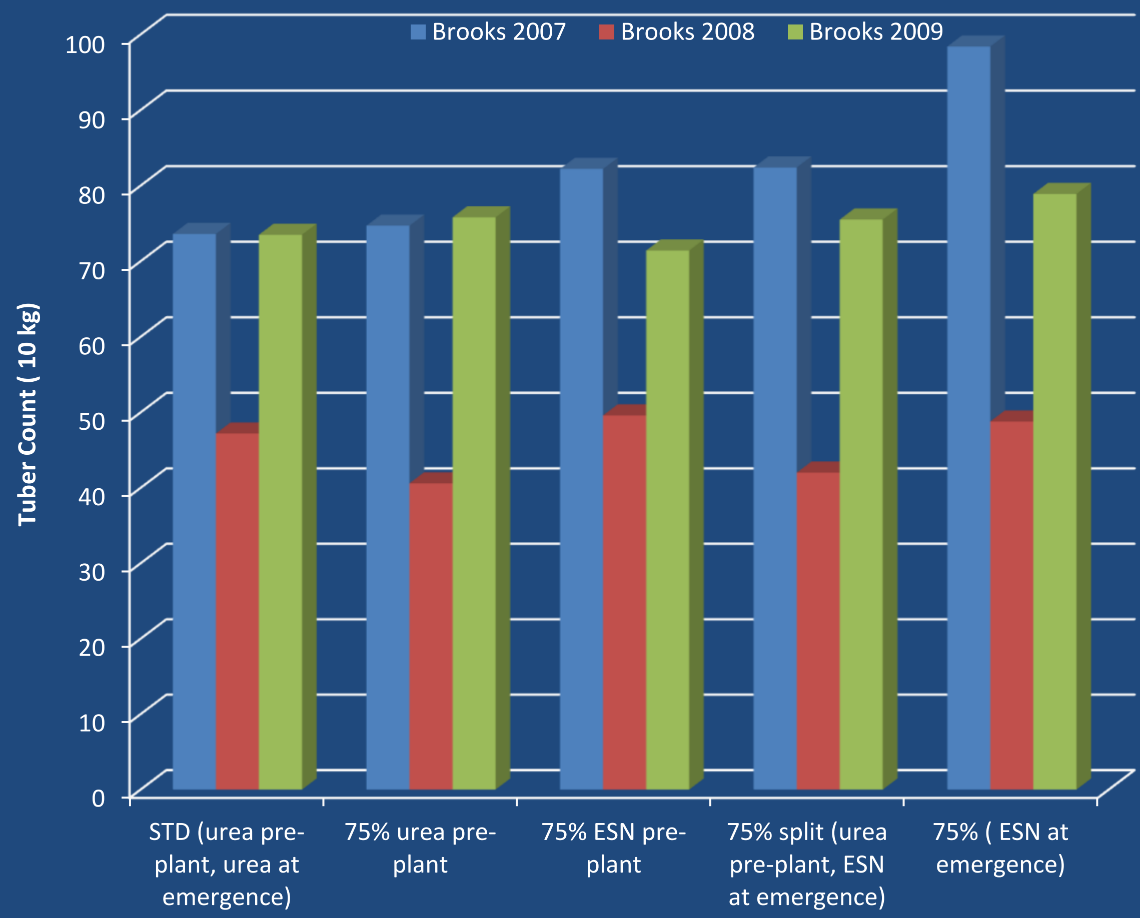
Marketable Yield

- In 2 out of 3 years, ESN treatments resulted in a greater marketable yield than the STD treatment (split urea).
- Pre-plant urea at 75% resulted in equal or greater marketable yield than 100% pre-plant, and near equal or greater marketable yield than the STD treatment.

Tuber Count

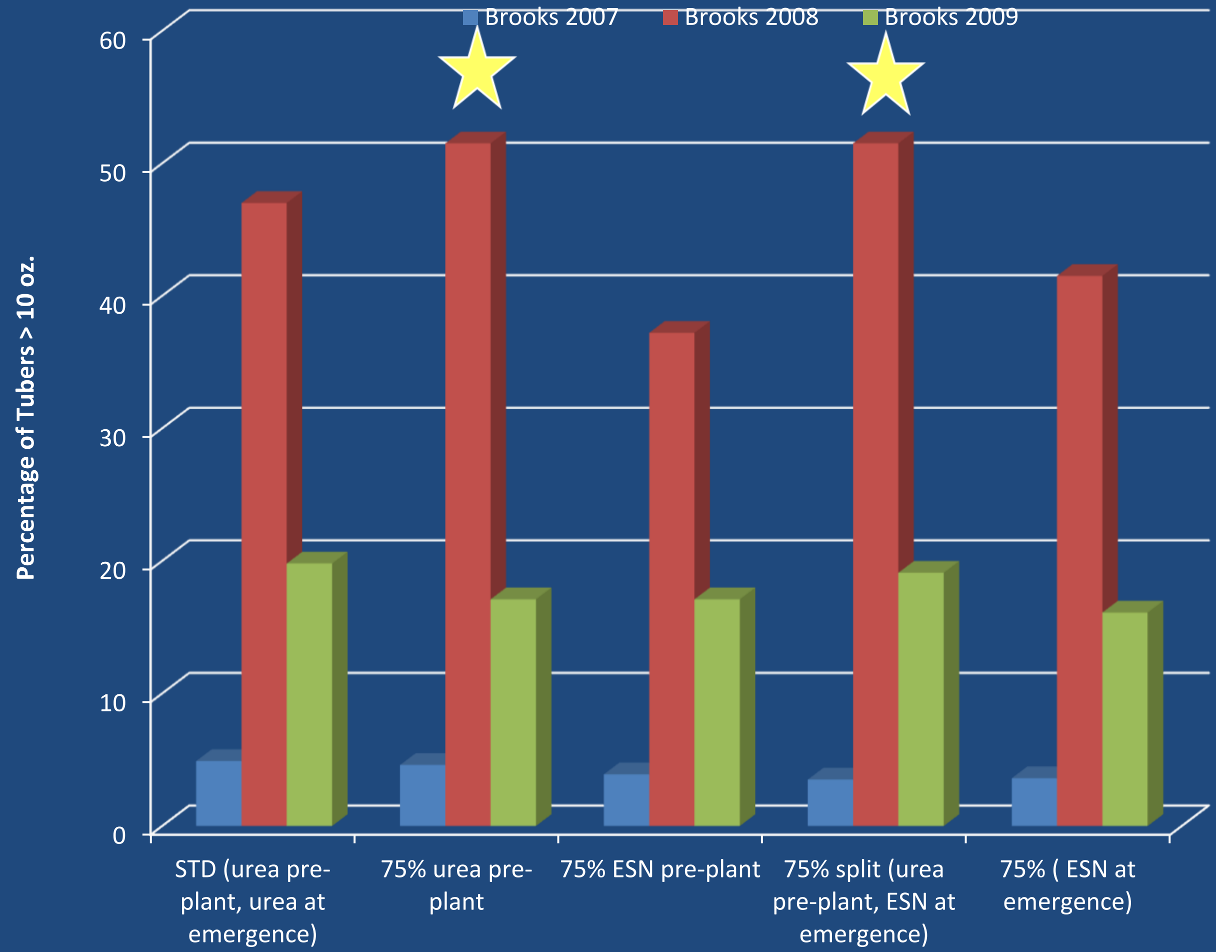


Brooks 2007
Brooks 2008
Brooks 2009
Tuber Count (10 kg)
100
90
80
70
60
50
40
30
20
10
0
STD (urea pre-plant, urea at emergence)
75% urea pre-plant
75% ESN pre-plant
75% split (urea pre-plant, ESN at emergence)
75% (ESN at emergence)

Tuber Size and Count

- Average tuber size and tuber count in a 10 kg sample are affected more by weather conditions in a given year than by N treatments.
- Applying 75% ESN all at emergence tended to reduce average tuber size and increase the tuber count.

% Tubers > 10 oz.



Brooks 2007
Brooks 2008
Brooks 2009
Percentage of Tubers > 10 oz.
60
50
40
30
20
10
0
STD (urea pre-plant, urea at emergence)
75% urea pre-plant
75% ESN pre-plant
75% split (urea pre-plant, ESN at emergence)
75% (ESN at emergence)

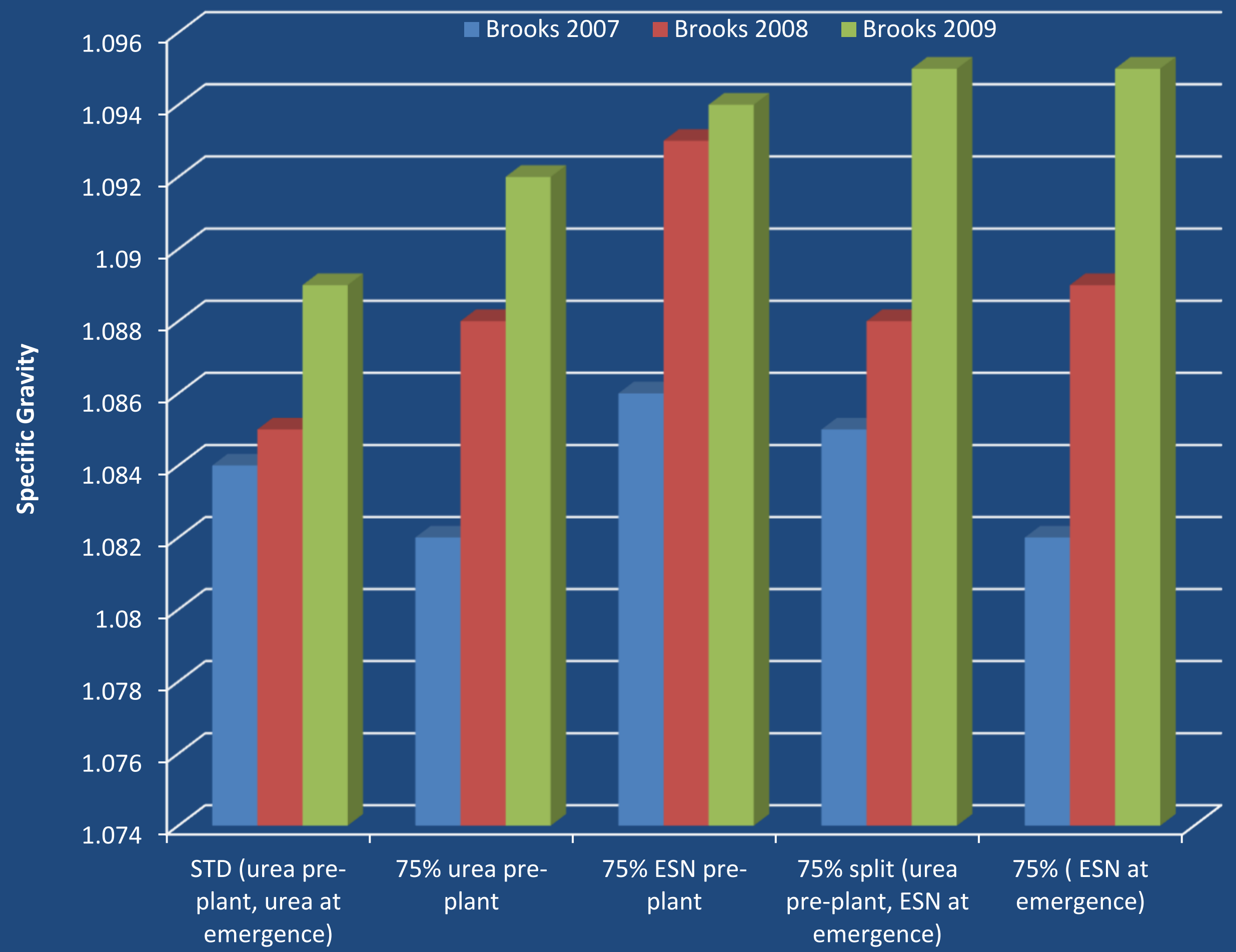
P Days

Month	2007	2008	2009
May	137.2	136.0	122.3
June	207.4	181.9	173.2
July	211.9*	235.0	235.2
August	213.8	207.1	218.0
September	123.2	137.9	171.5
Total	893.5	897.9	920.2

Tubers over 10 oz.

- The type of year we had affected the percentage of tubers over 10 oz. more than the N treatments.
- In general, the more N, the fewer tubers over 10 oz.
- In general, split applications result in more tubers over 10 oz. than equivalent pre-plant applications.

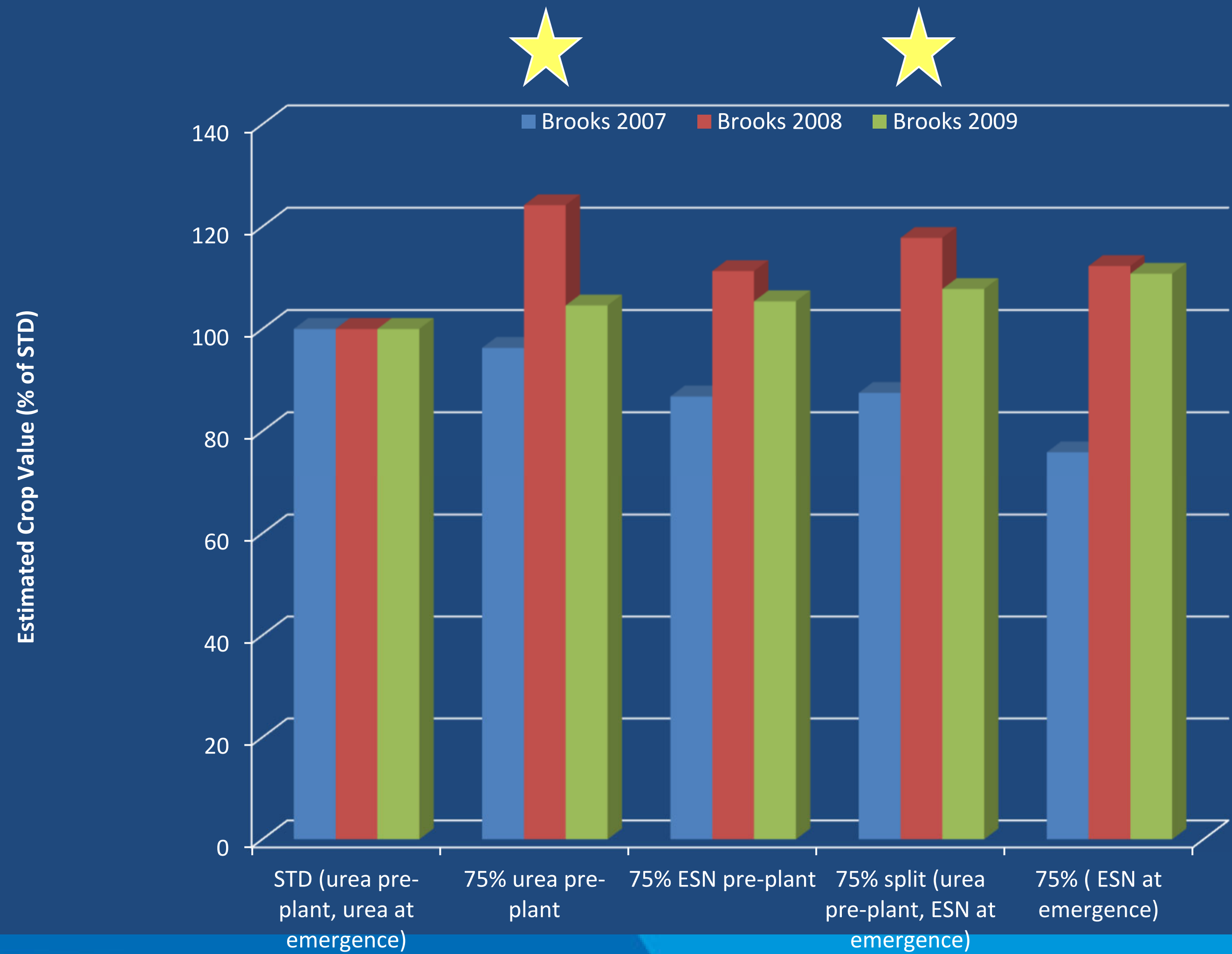
Specific Gravity



Specific Gravity

- The greater the quantity of N applied, the lower the SG:
  - The highest SG tubers were usually observed in the check treatment and the 50% rate of urea and ESN.
  - The lowest SG was observed from treatments with 100% N applied whether pre-plant or split application (STD).
- Pre-plant N had a greater impact on SG than top-dressed N.
- The trend was that urea reduced SG more than ESN, although differences between treatments were not always statistically significant.

Crop Value



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Estimated Crop Value

- In this study, tuber size profiles, SG and price of fertilizer were taken into account for the crop value calculations.
- Marketable yield had the greatest impact on relative crop value in this study.
- That is, the treatments resulting in the greatest marketable yield, also resulted in the greatest economic return.
- Treatments where only 75% of the STD N rate was applied gave better economic returns than the STD treatment 4 out of 6 site years.

Conclusions

- Based on the results of this trial, it is feasible to reduce overall N applications in Alberta by 25%.
- It is also feasible to use ESN to eliminate the need for in-season N applications.
- Reducing the quantity of N applied and splitting N applications between pre-plant urea and ESN at emergence gave good marketable yields and good economic returns 4 out of 6 site years.

Acknowledgements

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ESN
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Government of Alberta

Nitrogen for Improved Yield, Quality, and Profitability of Potato
Alberta Location – Interim Report
March 31, 2015

Project Description:

Introduction

The competitiveness of Canada's potato industry is dependent upon the production of high quality tubers in the most cost-efficient manner possible. Management of nitrogen fertilizer additions is one of the most practical means by which growers have to improve the economics of their production system and limit environmental impacts of potato production (Zebarth and Rosen 2007). Reviews of nitrogen management in potato stress the importance of matching crop demand for N by controlling the timing, placement, source and rate of additions and considering the N supply capacity of soil (Davenport et al. 2005, Monoz et al. 2005, Zebarth and Rosen 2007, Vos 2009).

Matching crop N demand with N availability in soil is the best means of optimizing nitrogen use efficiency and marketable yield of potato (Zebarth and Rosen 2007). Splitting the application of N to applying some at planting and then later as top-dressing at hilling or in irrigation water as fertigation can improve nitrogen use efficiency in soils prone to leaching of nitrate (Errebhi et al. 1998) and similar to conditions in eastern Canada and irrigated potato in the west. How to assess in crop N status to set fertigation amounts however is uncertain. Tools such as nitrate concentration of petioles (Goffart et al. 2008), reflectance of the crop (van Evert et al. 2012), and chlorophyll content (Olivier et al. 2006) relate well to N status of the crop. How to use these in crop measures to best adjust N additions at hilling or with fertigation however remains to be resolved. A different approach to matching N demand and N availability relies upon slowing the release of N from fertilizer added at planting such banding products near the seed so it is less prone to leaching prior to the period of greatest N demand, tuber bulking (Westermann and Sojka (1996). Recently available enhanced efficiency fertilizers that either stabilize N for longer in soil as ammonium with soil enzyme inhibitors or retard release of urea by coating granules with polymer (Trenkel 2010), are new options to growers. If the price premium of these products over regular urea granules is warranted remains to be resolved for our growing conditions.

Matching the availability of added fertilizer to potato N demand should result in maximizing nitrogen use efficiency. It is recommended that potato growers apply fertilizer N partly at planting and later once plants have emerged (Province of Manitoba Soil Fertility Guide). This is usually achieved by split application of fertilizer with some at planting and remainder at hilling or fertigated with irrigation water. Split application of fertilizer N is beneficial in soils prone to leaching of nitrate such as in sand soil and humid conditions (Errebhi et al. 1998). Split application of fertilizer increases production costs such as labour and fuel. Thus, it is important to growers to insure maximal return in investment for these added costs. One example is of increased production costs is the increasing use of fertigation in the Prairie Provinces though hard evidence to the benefit to nitrogen use efficiency and returns is lacking. Further, fertigation during hot summer periods likely will promote volatilization of urea in the urea ammonium nitrate solution applied. Fertigation is actively promoted in the Pacific NorthWest of the U.S.A. (Lang et al. 1999) and the processers familiar with that production system are promoting the practice in the Prairies where they also manage processing facilities.

Recently, enhanced efficiency fertilizers such as SuperU (slow release urea with urease and nitrification inhibitors) and ESN (controlled release with polymer coated urea) have become available to growers. It remains uncertain if the price premium for the products is justified by increased returns. In Minnesota, Hyatt et al. (2010) reported polymer coated urea did not increase yield but did decrease emissions of the greenhouse gas, nitrous oxide. In the same state, Wilson et al. (2009) reported lower N rates with polymer coated urea (ESN) were required to achieve maximum. However, Kelling et al. (2011) reported that for 3 of 6 site years in Wisconsin, the nitrification inhibitor, DCD with ammonium sulfate, increased gross yield but for 4 of 6 sites years marketable yield decreased. The decrease was because of ammonium accumulation in soil deforming tubers resulting increased culls.

A problem with elucidating if controlled released or stabilized products increase yield in the aforementioned studies has been the lack of comparison of the performance of the same N form (ex. urea) with or without being controlled release (ESN) or stabilized (ex. SuperU). Thus, it is difficult to determine the impact of the enhanced efficiency fertilizers when treatment comparisons vary in the form of the N.

The purpose of the current research is to provide data to determine whether ESN, split applications, fertigation or a combination of these strategies can be used in potato production to improve nitrogen use efficiency while maintaining yield and quality.

The objectives include:

1. Determine optimal timing and source of N fertilizers for irrigated potato.
2. Evaluate the effectiveness of monitoring plant N status to adjust fertigation additions.
3. To determine the effect of combinations of urea and polymer coated urea on yield, specific gravity and quality of Russet Burbank potatoes; and
4. To determine whether polymer coated urea can replace the need for in-season N applications (top-dressing, side-dressing or fertigation).

Approach Taken

The trial was conducted on Russet Burbank potatoes at the Alberta Irrigation Technology Centre in Lethbridge, AB to ensure that background N was low, N applications could be controlled, and the crop was irrigated using a pivot system. The trial is planned for 2 - 4 years to determine the impact of the treatments under a variety of environmental conditions. This trial is part of a larger initiative being led by Dr. Mario Tenuta of the University of Manitoba.

Six soil samples were taken at depths of 0 to 15cm and 15 to 120cm to make a composite soil sample in the fall of 2013. Soil N was taken into account when calculating N applications for each treatment.

Various quantities of urea and ESN (polymer-coated urea) were used pre-plant. Some of the treatments also involved N applications at the time of hilling and others included simulated fertigation treatments to reach the same total N applied. The nitrogen treatments were applied using a Conserv-a-Pak machine May 23 at both locations, Top-dressed N was applied by hand prior to power hilling June 27 and fertigation was simulated by applying ammonium nitrate and irrigating on three dates, July 22, August 8 and August 21, 2014 (Table 1). All treatments included an application of mono-ammonium phosphate (MAP) to provide starter P. Approximately 10 kg/ha N was supplied with the MAP and is included in the total N column (soil plus applied). The target N was intended to be approximately 80% of an agronomist recommended rate for Russet Burbank Production in southern Alberta, but was inadvertently applied at 100% as soil test N was not accounted for at the time of application.

Table 1: Nitrogen treatments (kg/ha) used to determine the effects of fertilization strategies on irrigated Russet Burbank in Alberta.

		Pre-plant		Hilling	Simulated Fertigation			
	Treatments	Urea	ESN	Top-Dressed	22 Jul	8 Aug	21 Aug	Applied
1	Untreated Check							0
2	Urea Pre-Plant Broadcast; 100%	190						190
3	Urea Split (60:40)	115		75				190
4	Urea/ESN Split (60:40)	115		75				190
5	ESN + Fertigation D (60:40)		115		25	25	25	190
6	ESN Broadcast; 100%		190					190
7	50% ESN / 50% Urea Broadcast	95	95					190
8	High Broadcast + Fertigation A	115			25	25	25	190
9	Urea/ESN 60:40 Split + Fertigation B	70		45	25	25	25	190
10	ESN:Urea 50:50 Split + Fertigation C	58	58		25	25	25	190

Treatments included:

1. No additional nitrogen (approximately 73 kg/ha soil test plus MAP) – check
2. Urea applied pre-plant (190 kg/ha) – urea 100% pp
3. 60% N applied as urea pre-plant; 40% N applied as urea at hilling – urea split
4. 60 % N applied as urea pre-plant; 40% N applied as ESN at hilling – urea/ESN split
5. 60% N applied pre-plant as ESN; 40% N applied via three fertigation events – ESN + fertigation
6. ESN applied pre-plant (190 kg/ha) – ESN 100% pp

7. Urea:ESN (50:50) applied pre-plant (95 kg/ha urea and 95 kg/ac ESN) – Pre-plant 50:50
8. 60% N applied pre-plant as urea; 40% N applied via three fertigation events – Urea + fertigation A
9. Urea applied pre-plant; ESN applied at hilling; three fertigation events – Split + fertigation B
10. Urea and ESN applied pre-plant; three fertigation events – 50:50 + fertigation C

2014
Russet Burbank seed (E3) was cut (approximately 70 to 85 g seed pieces), suberized, and treated with MaximMZ™ seed piece treatment (500g/100kg seed) prior to planting. Tubers were planted approximately 13 to 14 cm deep and 30 cm apart in rows spaced 0.90 metres apart using a four-row cup planter in Lethbridge on May 27, 2014. Treatments were set up as a split plot, with pre-plant N as a main treatment. Each treatment was 4 rows wide. The centre two rows were used for petiole sampling. Only one of the centre rows was harvested for yield estimates and tuber evaluations. Each treatment was replicated 4 times to reduce some of the variability inherent in small plot research (Appendix A).

The plots were scouted and managed following recommendations of a contract agronomist, ProMax Agronomy Services. The plots were irrigated with a centre pivot and low-pressure nozzles as required to maintain soil moisture close to 70% capacity, typically once or twice per week.

Roundup (1 L/ac) was sprayed prior to planting (May 21) to reduce weed pressure. Seed of standard cultivars was provided by Edmonton Potato Growers and seed of test cultivars was provided by each participant. Potatoes were planted June 5, 2014 approximately 5 to 5½"deep using a two-row tuber unit planter. Seed was planted at 30cm spacing in 6m rows spaced 90cm apart.

The potatoes were hilled June 27 with a power hiller. Sencor 75DF (100 g/ac) and Centurion (76 mL/ac) were applied prior to emergence (June 3) to control weeds. The plots were irrigated to maintain soil moisture close to 70%. Foliar fungicides were applied several times during the growing season to prevent early and late blight from developing (Table 2).

Table 2: Foliar fungicides applied to the potato crop in 2014 to prevent early and late blight development.

Date of Application	***Fungicide***	***Rate***
16 July	Bravo	1 L/ac
26 July	Dithane	900 g/ac
5 Aug	Bravo	1 L/ac
12 Aug	Dithane	900 g/ac

19 Aug	Dithane	900 g/ac
27 Aug	Bravo	1 L/ac
2 Sept	Bravo	1 L/ac
8 Sept	Bravo	1 L/ac

Additional ESN and urea were applied (top-dressed) to treatments 3, 4, and 9 prior to hilling June 27th.

Petiole samples were taken at three times (July 23, August 8 and August 21 during the season to follow the N-status of the crop throughout the season. Simulated fertigation treatments (ammonium nitrate broadcast) were applied immediately after petiole sampling (July 23, August 8, and August 21) and irrigated in.

Soil samples were taken at depths of 0 to 30cm prior to the first (July 21) and second (Aug. 8) petiole sampling and fertigation events. Twelve cores were taken from each plot to make a composite sample. Four core samples were taken from the top of the hills, and eight were taken from the shoulder of the hills within each plot. Samples were dried at 50C for approximately 1 week and ground, then stores at 4C until they were analyzed.

Approximately 1 week prior to desiccation, two whole potato plants were removed from the field. Fresh biomass was measured and the plants were dried in a forage dryer at 50C. Dry biomass was measured and the plant material was ground using a plant tissue grinder and held at 4C until analyzed for N.

Reglone (1.0 L/ac) was applied Sept 15 and again September 19 to desiccate potato vines. All treatments were harvested mechanically September 29 using a one-row Grimme harvester. Immediately following the potato harvest, soil samples were taken from the soil disturbed by the harvester. These samples were dried and ground and stored at 4C until analyzed.

Tubers were stored at 8˚C until graded. Tubers were graded into size categories (less than 113g, 113 - 170g, 171 – 284g over 284g and deformed). A sample of twenty-five tubers (113 – 284g) from each replicate was used to determine specific gravity using the weight in air over weight in water method. The tubers in the specific gravity sample were cut longitudinally to assess internal defects. Another sub-sample of 25 tubers was washed, diced, freeze dried and ground. Tuber tissue was analyzed for N content as well.

The data presented here have been statistically analyzed using ANOVA and Tukey's Multiple Range Test; ($p \leq 0.05$).

Results:

Petiole Nitrates

In Brooks, petiole nitrate levels for all treatments declined between the first and second sampling date. For pre-plant applied treatments, nitrogen declined between the second and third sampling as well. Treatments including fertigation showed much less of a decline, and in one treatment an increase between the second and third sampling date. Nitrate levels in the petioles at the first sampling date in mid-July ranged from about 9,000 ppm for the check to over 20,000 ppm for treatments with the majority of the N applied pre-plant (Fig 1). As expected, treatments with less nitrogen applied pre-plant started out with lower petiole nitrate levels.

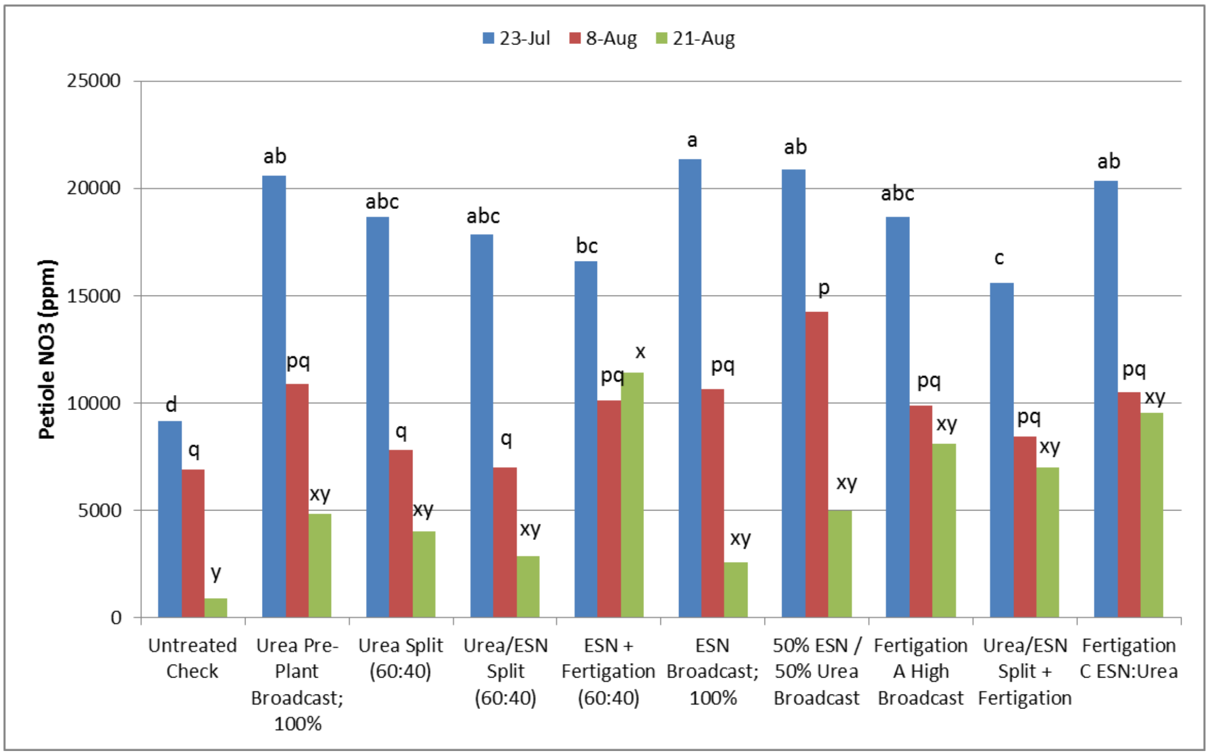

Figure 1: Petiole nitrate levels for each treatment at the Lethbridge, AB location. Samples were taken from the fourth petiole from up to eighty stems at three times during the 2015 growing season.

Potato Yield and Grade

Total yield, mean tuber size and specific gravity are presented in Table 3 for each treatment harvested in Lethbridge in 2015. Only Treatment 6 (ESN 100% pre-plant) resulted in total yield that was significantly greater than the check. Mean tuber size for Treatment #2 (Urea 100% pre-plant), #7 (50% urea and 50% ESN pre-plant) and #9 (urea plus ESN pre-plant followed by fertigation) was significantly greater than the check. This implies that supplying too little N (check) or providing N later in the growing season can reduce the mean tuber size. Only Treatment #2 (100% Urea pre-plant) reduced specific gravity significantly relative to the check. Highest specific gravity was measured for the check (Treatments #1), the 100% ESN pre-plant (Treatments #6), and the urea/ESN split application (Treatment #4).

Table 3: Total yield (estimated ton/ac), mean tuber size (oz.) and specific gravity of potatoes harvested from plots in Lethbridge, AB grown with different nitrogen strategies in 2014

Trt #		Treatment	Total Yld (ton/ac)	Mean tuber size (oz.)	SG
1	Untreated Check	Untreated Check	12.6 b	5.7 c	1.088 a
2	Urea Pre-Plant Broadcast; 100%	Urea Pre-Plant Broadcast; 100%	14.7 ab	7.5 a	1.078 b
3	Urea Split (60:40)	Urea Split (60:40)	15.5 ab	6.7 abc	1.084 ab
4	Urea/ESN Split (60:40)	Urea/ESN Split (60:40)	15.9 ab	6.0 bc	1.086 a
5	ESN + Fertigation D (60:40)	ESN + Fertigation (60:40)	16.8 ab	6.3 abc	1.084 ab
6	ESN Broadcast; 100%	ESN Broadcast; 100%	18.6 a	6.2 abc	1.089 a
7	50% ESN / 50% Urea Broadcast	50% ESN / 50% Urea Broadcast	14.3 b	7.6 a	1.083 ab
8	High Broadcast + Fertigation A	Fertigation A High Broadcast	14.0 b	6.2 abc	1.081 ab
9	Urea/ESN 60:40 Split + Fertigation B	Urea/ESN Split + Fertigation	13.4 b	7.3 ab	1.084 ab
10	ESN:Urea 50:50 Split + Fertigation C	Fertigation C ESN:Urea	12.7 b	6.5 abc	1.081 ab

Yield of potatoes in different size categories and marketable yield are summarized in Table 4. Marketable yield (over 4 oz.) was significantly greater for most of the treatments relative to the check. Three of the treatments that included fertigation (Treatments 8, 9 and 10) resulted in marketable yields that were not significantly better than the check. This is likely related to the shorter growing season and the relative lateness of the applied fertigation treatments. The greatest marketable yield was observed with Treatment #6 (100% ESN pre-plant), but this yield was nor statistically different treatments other than the check. Treatments #2 (100% urea pre-plant), #7 (50% urea/50% ESN pre-plant), and Treatment #9 (Urea/ESN split plus fertigation) resulted in the largest tuber profiles. None of the treatments affected the yield of deformed tubers.

The data suggests that urea applied earlier in the season encourages larger tubers, while treatments with less N available after planting may produce more small tubers.

Table 4: Estimated yield (ton/ac) in each weight category (< 4oz., 4 to 6 oz., 6 to 10 oz. > 10 oz., and deformed) for each variety grown at Lethbridge, AB in 2014. Data shown is the mean of four replicates. Data followed by the same letter in each column of the table are not significantly different at the $p < 0.05$ level.

	< 4oz.	4 to 6 oz.	6 to 10 oz.	> 10 oz.	Deformed	Marketable Yield
Treatment						
Untreated Check	5.5 a	4.2 ab	2.1 b	0.2 c	0.5 a	6.6 c
Urea Pre-Plant Broadcast; 100%	2.9 cd	3.2 b	5.2 a	2.3 ab	1.1 a	10.7 ab
Urea Split (60:40)	3.6 bcd	4.0 ab	5.5 a	1.9 abc	0.6 a	11.3 ab
Urea/ESN Split (60:40)	4.3 abc	5.0 ab	5.4 a	0.8 bc	0.5 a	11.1 ab
ESN + Fertigation (60:40)	5.2 a	4.6 ab	5.0 a	1.3 bc	0.7 a	11.0 ab
ESN Broadcast; 100%	4.9 ab	6.6 a	5.3 a	1.2 bc	0.7 a	13.0 a
50% ESN / 50% Urea Broadcast	2.6 d	2.9 b	4.5 a	3.3 a	1.0 a	10.7 ab
Fertigation A High Broadcast	3.3 cd	4.3 ab	4.6 a	1.3 bc	0.4 a	10.3 abc
Urea/ESN Split + Fertigation	2.8 cd	2.8 b	4.7 a	2.5 ab	0.5 a	10.1 abc
Fertigation C ESN:Urea	3.6 bcd	3.8 ab	3.5 ab	1.2 bc	0.6 a	8.5 bc

This data is from the first year of a four-year trial. A minimum of 2 and a maximum of 4 site years of data will be generated and should provide sufficient information to develop recommendations for various fertilizer approaches as part of a nitrogen management strategy for Russet Burbank. An economic analysis of the results is planned. Nitrogen use efficiency will also be calculated once plant and tuber N data has been analyzed.

Project Reach:

A target audience for this research is the processing potato growers in southern Alberta. Producers need tools to improve nitrogen use efficiency and reduce cost of production for potatoes. The Potato Growers of Alberta (PGA) comprises more than 120 potato producers, 70 of whom grow processing potatoes. The PGA provided research funding toward this project. Information will provided annually to the growers via producer meetings.

Potato processors may also benefit by keeping contract prices in a range that maintains their competitiveness in a global market. Improvements in crop quality may also be realized with timely nitrogen applications. Processors will be kept apprised of the results of the project via PGA meetings.

Indirectly, members of the public may benefit from the efficient use of resources and the prudent use of nitrogen fertilizers. The impact of the study on this group is difficult to estimate. The results of the trial may be disseminated via popular press articles at the end of the research project depending on the outcome of the trials.

Project Impact:

With new tools becoming available to producers, timing is as important as quantity for producing good yield and good processing quality. There has been some contradictory information about the use of ESN and fertigation for potato N management and impartial information for Alberta producers is essential. There is a need to determine the best approach to optimize potato yield and quality while refining costs of production. Additional data from the second and third year of the trial will:

- be useful in the development of Beneficial N Management Practices for potato production in Alberta;
- determine whether polymer coated urea can reduce total nitrogen applied or reduce the number of in-season nitrogen applications required for optimal potato yield and quality;
- provide economic evaluations of the use of polymer coated urea;
- determine whether fertigation is necessary or beneficial for optimal potato yield and quality; and
- address using the fertilizer strategies under soil type and environmental conditions specific to Alberta.

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Appendix A: Plot plan of AITC Nitrogen Trial 2015.

BMP 2014

N →

Planted May 27

	0m		12	24	36		
1	Guard		Guard	Guard	Guard		
2	4001		3001	2001	1001	T3	Urea 115 Pre-plant
3	4002		3002	2002	1002	T3	
4	Guard		Guard	Guard	Guard		
5	Guard		Guard	Guard	Guard		
6	4003		3003	2003	1003	T4	Urea 115 Pre-plant
7	4004		3004	2004	1004	T4	
8	Guard	3m	Guard	Guard	Guard		
9	Guard		Guard	Guard	Guard		
10	4005		3005	2005	1005	T8	
11	4006		3006	2006	1006	T8	Urea 115 Pre-plant
12	Guard	3m	Guard	Guard	Guard		
	9m						
13	Guard		Guard	Guard	Guard		
14	4007		3007	2007	1007	T2	Urea Prepl
15	4008		3008	2008	1008	T2	
16	Guard		Guard	Guard	Guard		
17	Guard		Guard	Guard	Guard		
18	4009		3009	2009	1009	T9	Urea Pre-p
19	4010		3010	2010	1010	T9	
20	Guard	3m	Guard	Guard	Guard		
21	Guard		Guard	Guard	Guard		
22	40011		3011	2011	1011	T7	Urea & E Pre-plan
23	4012		3012	2012	1012	T7	
24	Guard	3m	Guard	Guard	Guard		
25	Guard		Guard	Guard	Guard		
26	4014		3013	2013	1013	T10	Urea & ESN Pre-plant
27	4015		3014	2014	1014	T10	
28							
29							
30	4016		3015	2015	1015	T5	ESN Pre-plant
31	4017		3016	2016	1016	T5	
32							
33							
34	4017		3017	2017	1017	T6	ESN Pre-plant
35	4018		3018	2018	1018	T6	
36							
	4019		3019	2019	1019	T1	P only Pre-plant
	4020		3020	2020	1020	T1	
16	Guard	3m	Guard	Guard	Guard		

23-May Hilling

Nitrogen Strategies for Russet Burbank

2015 Alberta

Michele Konschuh
Alberta Agriculture and Forestry

- The competitiveness of Canada's potato industry is dependent upon the production of high quality tubers in the most cost-efficient manner possible.
- Management of nitrogen fertilizer additions is one of the most practical means by which growers have to improve the economics of their production system and limit environmental impacts of potato production.

Nitrogen Uptake

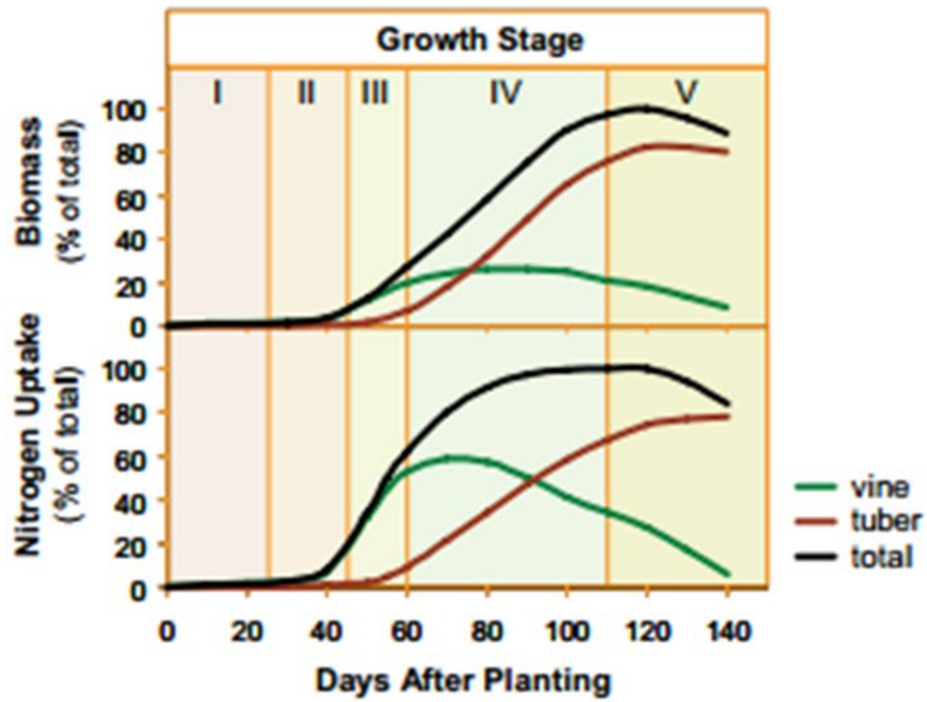


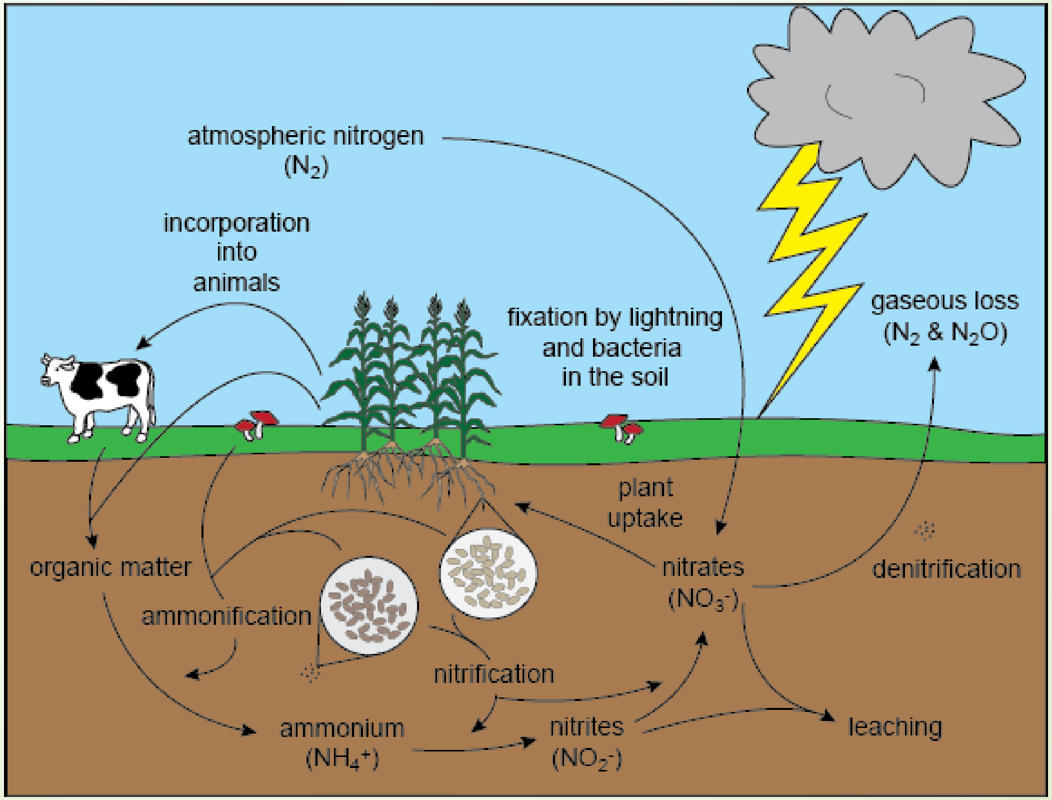
Figure 1. Generalized dry matter accumulation (as percent of total maximum dry matter) and nitrogen uptake (as percent of total nitrogen uptake) by a Russet Burbank crop. The five stages of growth are provided for reference: I = sprouting, II = vegetative, III = tuber initiation, IV = tuber bulking, V = maturation. Growth stages are approximate and may vary with variety and environment.

From C. Rosen, Univ. of Minnesota, 2006.

Environmental Impact

- If nitrogen is not applied as the crops uses it, N is subject to environmental losses:
  - Volatilization (greenhouse gases)
  - Denitrification (greenhouse gases)
  - Leaching (ground water contamination)
  - Runoff (surface water contaimination)

Nitrogen Cycle



Fertilizer Strategies

- Fall applied; fall bedding
- Pre-plant incorporated
- Banded at planting (Manitoba)
- Broadcast at hilling (forms of N); incorporated
- Fertigation periodically; often conducted based on petiole sampling results
- Alternate products (slow-release, controlled release, urease inhibitors, nitrification inhibitors)

Objectives

- Determine optimal timing and source of N fertilizers for irrigated potato.
- Evaluate the effectiveness of monitoring plant N status to adjust fertigation additions.
- To determine the effect of combinations of urea and polymer coated urea on yield, specific gravity and quality of Russet Burbank potatoes; and
- To determine whether polymer coated urea can replace the need for in-season N applications (top-dressing, side-dressing or fertigation).

Treatments

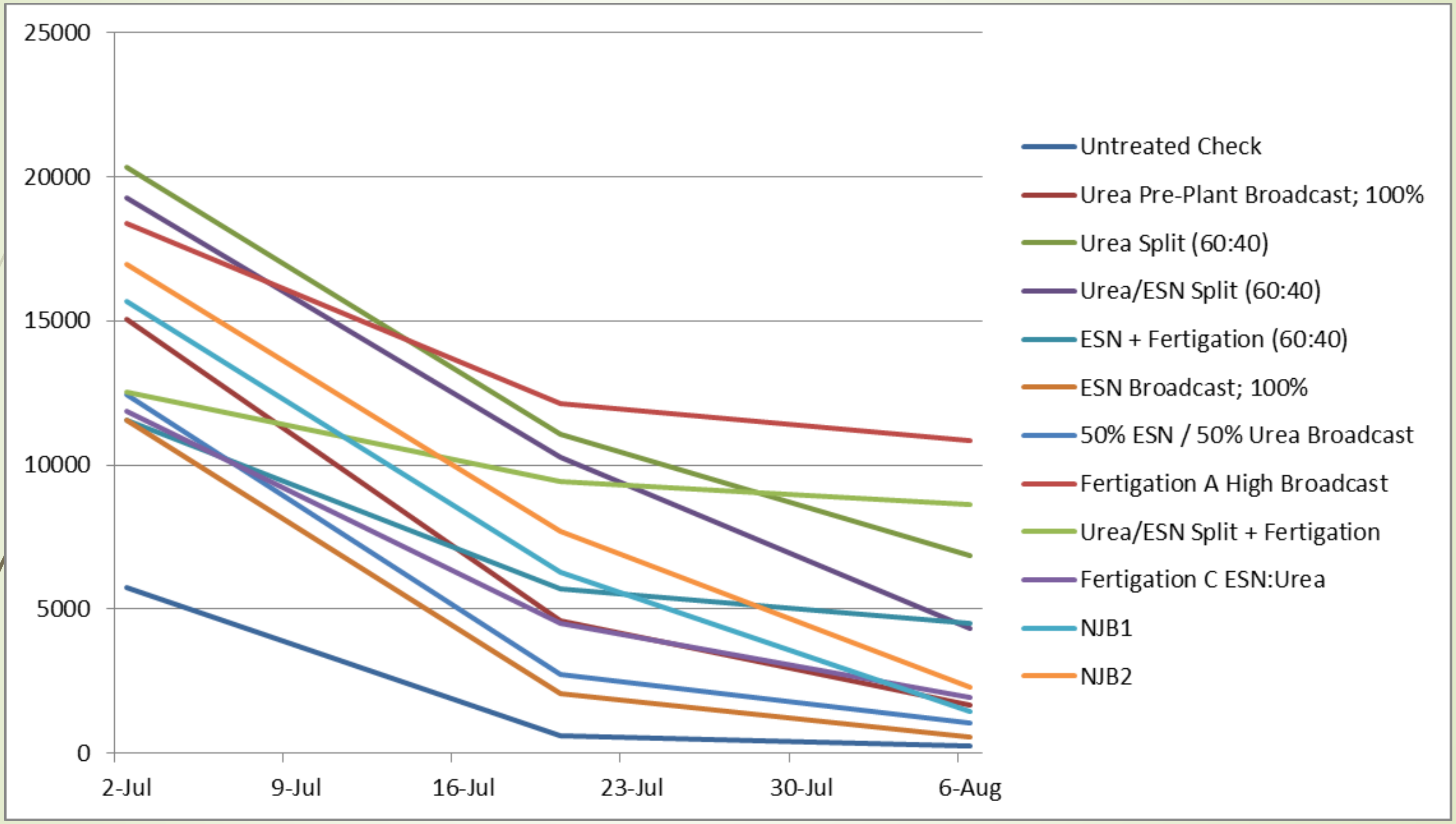
Treatments 2015		Planned applications						
		Pre-plant		Top-Dress				
		Urea	ESN		Simulated Fertigation (AN)			
1	Untreated Check	0	0					0
2	Urea Pre-Plant Broadcast; 100%	150						150
3	Urea Split (60:40)	90		60				150
4	Urea/ESN Split (60:40)	90		60				150
5	ESN + Fertigation (60:40)		90		20	20	20	150
6	ESN Broadcast; 100%		150					150
7	50% ESN / 50% Urea Broadcast	75	75					150
8	Fertigation A High Broadcast	90			20	20	20	150
9	Urea/ESN Split + Fertigation	54		36	20	20	20	150
10	Fertigation C ESN:Urea	45	45		20	20	20	150
11	NJB1	0	0	90:60				150
12	NJB2	0	0	60:90				150

Fertilizer applications

Trial at AITC - Lethbridge

Petiole sampling

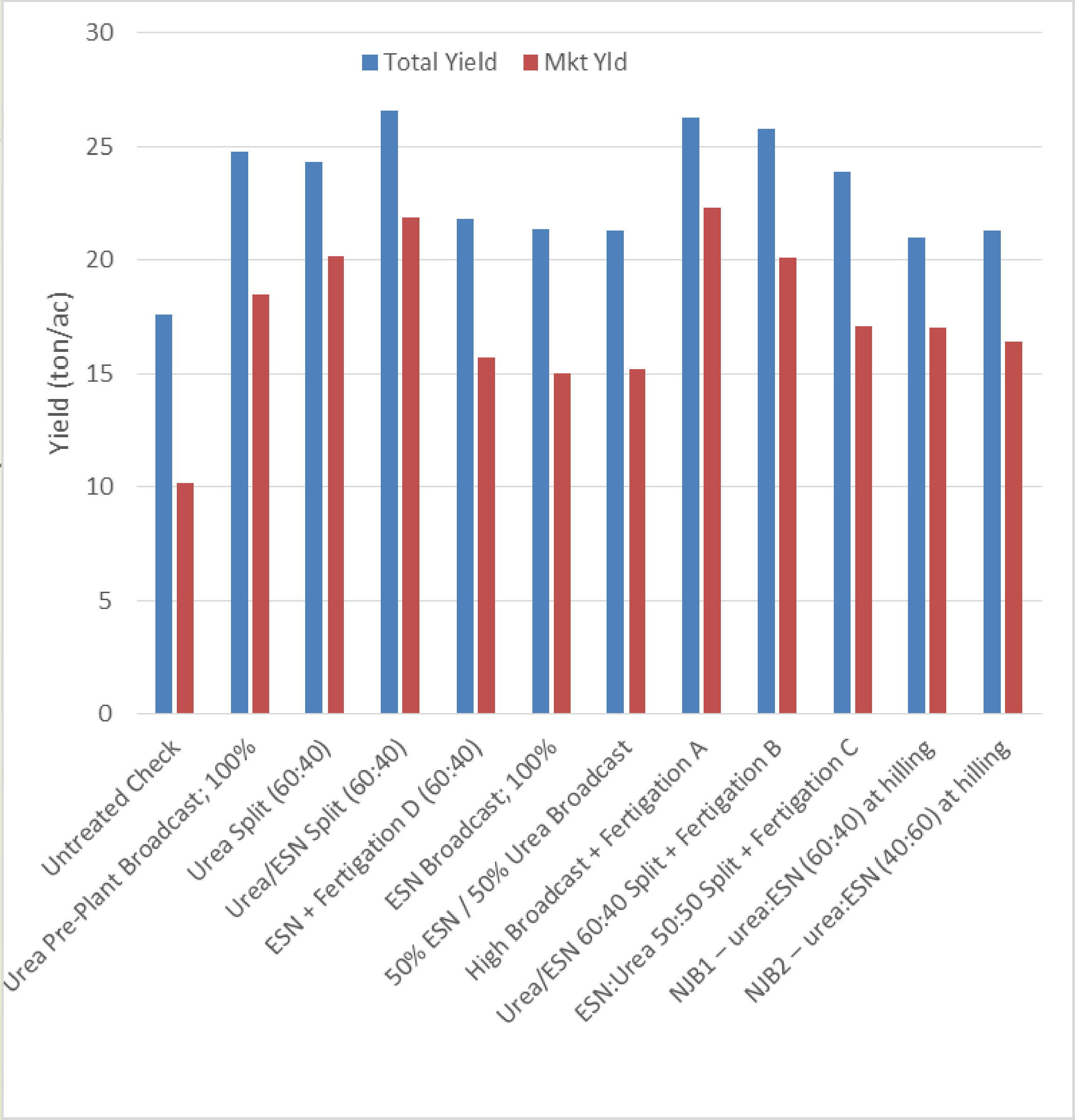
Petioles


25000
20000
15000
10000
5000
0
2-Jul
9-Jul
16-Jul
23-Jul
30-Jul
6-Aug
Untreated Check
Urea Pre-Plant Broadcast; 100%
Urea Split (60:40)
Urea/ESN Split (60:40)
ESN + Fertigation (60:40)
ESN Broadcast; 100%
50% ESN / 50% Urea Broadcast
Fertigation A High Broadcast
Urea/ESN Split + Fertigation
Fertigation C ESN:Urea
NJB1
NJB2

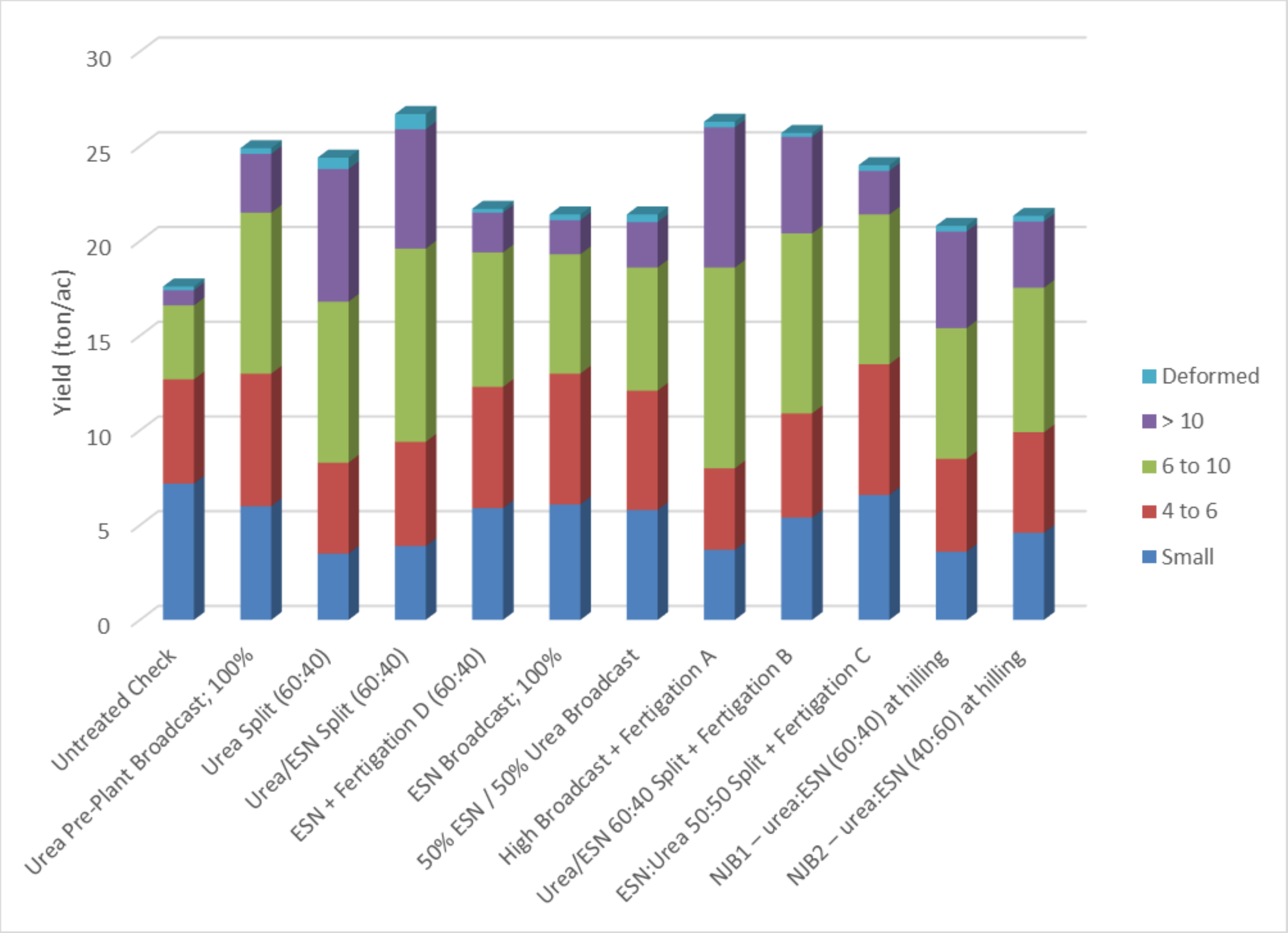
Petiole N

- All fertilizer treatments resulted in higher petiole nitrates than the check
- Fertigation treatments maintained higher petiole N throughout the season
- Split applications of N were almost as effective at maintaining petiole N as fertigation treatments
- ESN treatments typically had lower petiole N

Total Yield/Marketable Yield



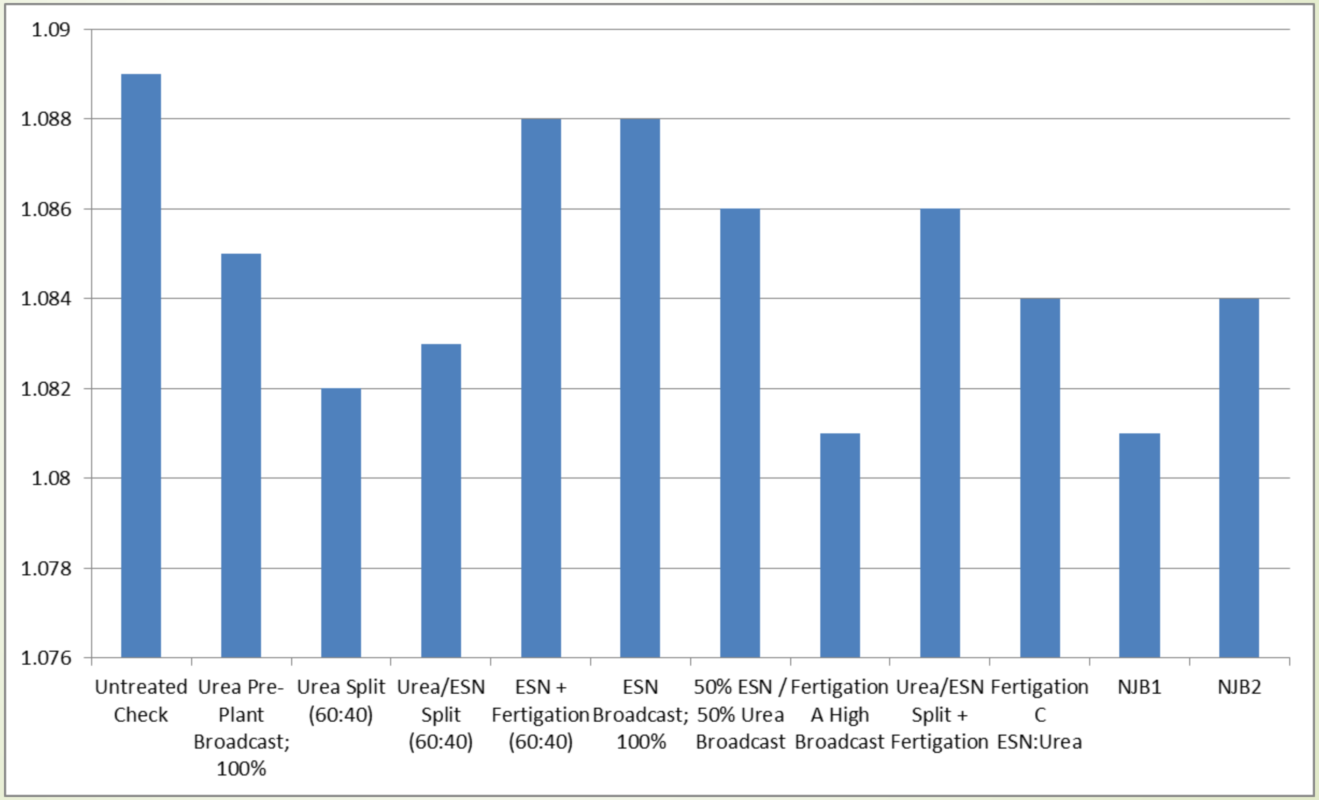
Graded yield



Potato Yield

- Fertilizer strategy affects tuber size distribution
- Split application N and most fertigation treatments resulted in greater total yield
- Greatest marketable yield was achieved with fertigation and with a split N treatment using urea and ESN

Specific Gravity



Potato quality

- The use of ESN seems to affect specific gravity less than urea and ammonium nitrate

Nitrogen Use Efficiency

- Efficiency = more N taken up by the crop
- Nitrogen applied is taken up in the plants (biomass) or the tubers (yield), left behind in the soil (soil test) or lost
- Greater yield with less N is higher NUE
- Greater yield reduces environmental footprint
- Less "leftover" N means less potential for negative environmental impacts

Next steps

- Use best nitrogen application strategies to fine-tune rates for different varieties of potato
- Share strategies with producers
- Explore some of the other strategies for improving NUE and reducing environmental impact

Acknowledgements

- This work was supported through funding by Agriculture and Agri-food Canada, Alberta Agriculture and Forestry, the Potato Growers of Alberta, and Canadian Horticultural Council.
- I would like to acknowledge technical assistance from a variety of seasonal employees over the past two years: Mary Lou Benci, William Lai, Courtney Lepp, Murray Unruh, Ben Friesen, Joanne Beecroft, Dustin Tillapaugh, Samantha Vogt, and Harlen Dahl

Questions?

Thank you

Nitrogen for Improved Yield, Quality, and Profitability of Potato
Alberta Location – Interim Report
March 22, 2017

Project Description:

Introduction

The competitiveness of Canada's potato industry is dependent upon the production of high quality tubers in the most cost-efficient manner possible. Management of nitrogen fertilizer additions is one of the most practical means by which growers have to improve the economics of their production system and limit environmental impacts of potato production (Zebarth and Rosen 2007). Reviews of nitrogen management in potato stress the importance of matching crop demand for N by controlling the timing, placement, source and rate of additions and considering the N supply capacity of soil (Davenport et al. 2005, Monoz et al. 2005, Zebarth and Rosen 2007, Vos 2009).

Matching crop N demand with N availability in soil is the best means of optimizing nitrogen use efficiency and marketable yield of potato (Zebarth and Rosen 2007). Splitting the application of N to applying some at planting and then later as top-dressing at hilling or in irrigation water as fertigation can improve nitrogen use efficiency in soils prone to leaching of nitrate (Errebhi et al. 1998) and similar to conditions in eastern Canada and irrigated potato in the west. How to assess in crop N status to set fertigation amounts however is uncertain. Tools such as nitrate concentration of petioles (Goffart et al. 2008), reflectance of the crop (van Evert et al. 2012), and chlorophyll content (Olivier et al. 2006) relate well to N status of the crop. How to use these in crop measures to best adjust N additions at hilling or with fertigation however remains to be resolved. A different approach to matching N demand and N availability relies upon slowing the release of N from fertilizer added at planting such banding products near the seed so it is less prone to leaching prior to the period of greatest N demand, tuber bulking (Westermann and Sojka (1996). Recently available enhanced efficiency fertilizers that either stabilize N for longer in soil as ammonium with soil enzyme inhibitors or retard release of urea by coating granules with polymer (Trenkel 2010), are new options to growers. If the price premium of these products over regular urea granules is warranted remains to be resolved for our growing conditions.

Matching the availability of added fertilizer to potato N demand should result in maximizing nitrogen use efficiency. It is recommended that potato growers apply fertilizer N partly at planting and later once plants have emerged (Province of Manitoba Soil Fertility Guide). This is usually achieved by split application of fertilizer with some at planting and remainder at hilling or fertigated with irrigation water. Split application of fertilizer N is beneficial in soils prone to leaching of nitrate such as in sand soil and humid conditions (Errebhi et al. 1998). Split application of fertilizer increases production costs such as labour and fuel. Thus, it is important to growers to insure maximal return in investment for these added costs. One example is of increased production costs is the increasing use of fertigation in the Prairie Provinces though hard evidence to the benefit to nitrogen use efficiency and returns is lacking. Further, fertigation during hot summer periods likely will promote volatilization of urea in the urea ammonium nitrate solution applied. Fertigation is actively promoted in the Pacific NorthWest of the U.S.A. (Lang et al. 1999) and the processers familiar with that production system are promoting the practice in the Prairies where they also manage processing facilities.

Recently, enhanced efficiency fertilizers such as SuperU (slow release urea with urease and nitrification inhibitors) and ESN (controlled release with polymer coated urea) have become available to growers. It remains uncertain if the price premium for the products is justified by increased returns. In Minnesota, Hyatt et al. (2010) reported polymer coated urea did not increase yield but did decrease emissions of the greenhouse gas, nitrous oxide. In the same state, Wilson et al. (2009) reported lower N rates with polymer coated urea (ESN) were required to achieve maximum. However, Kelling et al. (2011) reported that for 3 of 6 site years in Wisconsin, the nitrification inhibitor, DCD with ammonium sulfate, increased gross yield but for 4 of 6 site year's marketable yield decreased. The decrease was because of ammonium accumulation in soil deforming tubers resulting increased culls.

The purpose of the current research is to provide data to determine whether ESN, split applications, fertigation or a combination of these strategies can be used in potato production to improve nitrogen use efficiency while maintaining yield and quality.

The objectives include:

1. Determine optimal timing and source of N fertilizers for irrigated potato.
2. Evaluate the effectiveness of monitoring plant N status to adjust fertigation additions.
3. To determine the effect of combinations of urea and polymer coated urea on yield, specific gravity and quality of Russet Burbank potatoes; and
4. To determine whether polymer coated urea can replace the need for in-season N applications (top-dressing, side-dressing or fertigation).

Approach Taken

The trial was conducted on Russet Burbank potatoes at the Alberta Irrigation Technology Centre in Lethbridge, AB to ensure that background N was low, N applications could be controlled, and the crop was irrigated using a pivot system. The trial is planned for 2 - 4 years to determine the impact of the treatments under a variety of environmental conditions. This trial is part of a larger initiative being led by Dr. Mario Tenuta of the University of Manitoba.

Six soil samples were taken at depths of 0 to 15cm and 15 to 120cm to make a composite soil sample in the fall of 2015. Soil N (35 kg/ha) was taken into account when calculating N applications for each treatment.

Various quantities of urea and ESN (polymer-coated urea) were used pre-plant. Some of the treatments also involved N applications at the time of hilling and others included simulated fertigation treatments to reach the same total N applied. The nitrogen treatments were applied using a Conserv-a-Pak machine May 2, 2016. Top-dressed N was applied by hand prior to power hilling May 18 and fertigation was simulated by applying ammonium nitrate and irrigating on three dates, June 30, July 21 and August 15, 2016 (Table 1). All treatments included an application of mono-ammonium phosphate (MAP) to provide starter P. Approximately 10 kg/ha N was supplied with the MAP and is included in the total N column (soil plus applied). The target N was intended to be approximately 80% of an agronomist recommended rate for Russet Burbank Production in southern Alberta (200 kg/ha).

Table 1: Nitrogen treatments (kg/ha) used to determine the effects of fertilization strategies on irrigated Russet Burbank in Alberta.

		Pre-plant		At Hilling		Simulated Fertigation		
	Treatments	Urea	ESN	Urea	ESN	30 Jun	21 Jul	15 Aug
1	Untreated Check	0	0					
2	Urea Pre-Plant Broadcast; 100%	157						
3	Urea Split (60:40)	95		62				
4	Urea/ESN Split (60:40)	95			62			
5	ESN + Fertigation (60:40)		95			23	21	18
6	ESN Broadcast; 100%		157					
8	Fertigation A High Broadcast	95				23	21	18
9	Urea/ESN Split + Fertigation	57			38	23	21	18
10	Fertigation C ESN:Urea	48	48			23	21	18
11	NJB1	0	0	95	62			

Treatments included:

1. No additional nitrogen (approximately 35 kg/ha soil test plus MAP) – check
2. Urea applied pre-plant (157 kg/ha N) – urea 100% pp
3. 60% N applied as urea pre-plant; 40% N applied as urea at hilling – urea split
4. 60 % N applied as urea pre-plant; 40% N applied as ESN at hilling – urea/ESN split
5. 60% N applied pre-plant as ESN; 40% N applied via three fertigation events – ESN + fertigation
6. ESN applied pre-plant (157 kg/ha) – ESN 100% pp
7. Omitted in 2016
8. 60% N applied pre-plant as urea; 40% N applied via three fertigation events – Urea + fertigation A
9. Urea applied pre-plant; ESN applied at hilling; three fertigation events – Split + fertigation B
10. Urea and ESN applied pre-plant; three fertigation events – 50:50 + fertigation C
11. NJB1 – Urea:ESN blend (60:40) at hilling
12. Omitted in 2016

2016

Russet Burbank seed (E3) was cut (approximately 70 to 85 g seed pieces), suberized, and treated with MaximMZ^{TM} seed piece treatment (500g/100kg seed) prior to planting. Tubers were planted approximately 13 to 14 cm deep and 30 cm apart in rows spaced 0.90 metres apart using a four-row cup planter in Lethbridge on April 28, 2016. Treatments were set up as a split plot, with pre-plant N as a main treatment. Each treatment was 4 rows wide. The centre two rows were used for petiole sampling. Only one of the centre rows was harvested for yield estimates and tuber evaluations. Each treatment was replicated 4 times to reduce some of the variability inherent in small plot research (Appendix A).

The plots were scouted and managed following recommendations of a contract agronomist, ProMax Agronomy Services. The plots were irrigated with a centre pivot and low-pressure nozzles as required to maintain soil moisture close to 70% capacity, typically once or twice per week.

The potatoes were hilled May 18 with a power hiller. Lorox (1L/ac) was applied prior to emergence (May 25) to control weeds. Sencor 75DF (125 g/ac) and Select (76mL/ac + Amigo 0.5% v/v) were applied June 8 to control weeds. The plots were irrigated to maintain soil moisture close to 70%. Plots were sprayed with Prism (24 g/ac) with Amigo (0.5%) post-emergence (June 23) to control weeds.

Foliar fungicides were applied several times during the growing season to prevent early and late blight from developing (Table 2).

Table 2: Foliar fungicides applied to the potato crop in 2016 to prevent early and late blight development.

Date of Application	***Fungicide***	***Rate***
30 June	Luna Tranquility	240 mL/ac
30 June	Bravo	0.88 L/ac
8 July	Dithane	900 g/ac
15 July	Dithane	900 g/ac
22 July	Bravo	0.88 L/ac
28 July	Dithane	880 g/ac
5 Aug	Bravo	1 L/ac
12 Aug	Dithane	880 g/ac
19 Aug	Dithane	880 g/ac
26 Aug	Dithane	880 g/ac
7 Sept	Bravo	1 L/ac

Additional ESN and urea were applied (top-dressed) to treatments 3, 4, and 9 prior to hilling May 18th.

Petiole samples were taken at three times (June 28, July 19 and August 9, 2016) during the season to follow the N-status of the crop throughout the season. Soil samples were taken at depths of 0 to 30cm shortly after the petiole samples were collected (June 30, July 21 and August 15) and before the fertigation events. Twelve cores were taken from each plot to make a composite sample. Four core samples were taken from the top of the hills, and eight were taken from the shoulder of the hills within each plot. Samples were dried at 50C for approximately 1 week and ground, then stored at 4C until they were analyzed. Simulated fertigation treatments (ammonium nitrate broadcast) were applied immediately after soil sampling (June 30, July 21, and August 15) and irrigated in.

Prior to desiccation (Sept. 6), two whole potato plants were removed from the field. Fresh biomass was measured and the plants were dried in a forage dryer at 50C. Dry biomass was measured and the plant material was ground using a plant tissue grinder and held at 4C until analyzed for N.

Reglone (1.4 L/ac) was applied Sept 7 to desiccate potato vines. All treatments were harvested mechanically September 14 using a one-row Grimme harvester. Immediately following the potato harvest, soil samples were taken from the soil disturbed by the harvester. These samples were dried and ground and stored at 4C until analyzed.

Tubers were stored at 8˚C until graded. Tubers were graded into size categories (less than 113g, 113 - 170g, 171 – 284g over 284g and deformed). A sample of twenty-five tubers (113 – 284g) from each replicate was used to determine specific gravity using the weight in air over weight in water method. The tubers in the specific gravity sample were cut longitudinally to assess internal defects. Another sub-sample of 8 tubers was washed, diced, freeze dried and ground. Tuber tissue was analyzed for N content as well.

The data presented here have been statistically analyzed using ANOVA and Tukey’s Multiple Range Test; ($p \leq 0.05$).

Results:

Petiole Nitrates

Petiole nitrate levels for all treatments declined between the first and second sampling date. The decline was less dramatic for split N treatments and treatments involving fertigation. Nitrogen declined between the second and third sampling as well, but treatments involving fertigation maintained higher petiole N at the third sampling date than treatments where N was all applied pre-plant. Treatments including fertigation showed much less of a decline, and in several treatments an increase between the second and third sampling date. Nitrate levels in the petioles at the first sampling date in mid-July ranged from about 15,000 ppm for the check to over 20,000 ppm for most of the fertilized treatments (Fig 1). As expected, treatments with ESN applied pre-plant started out with slightly lower petiole nitrate levels.

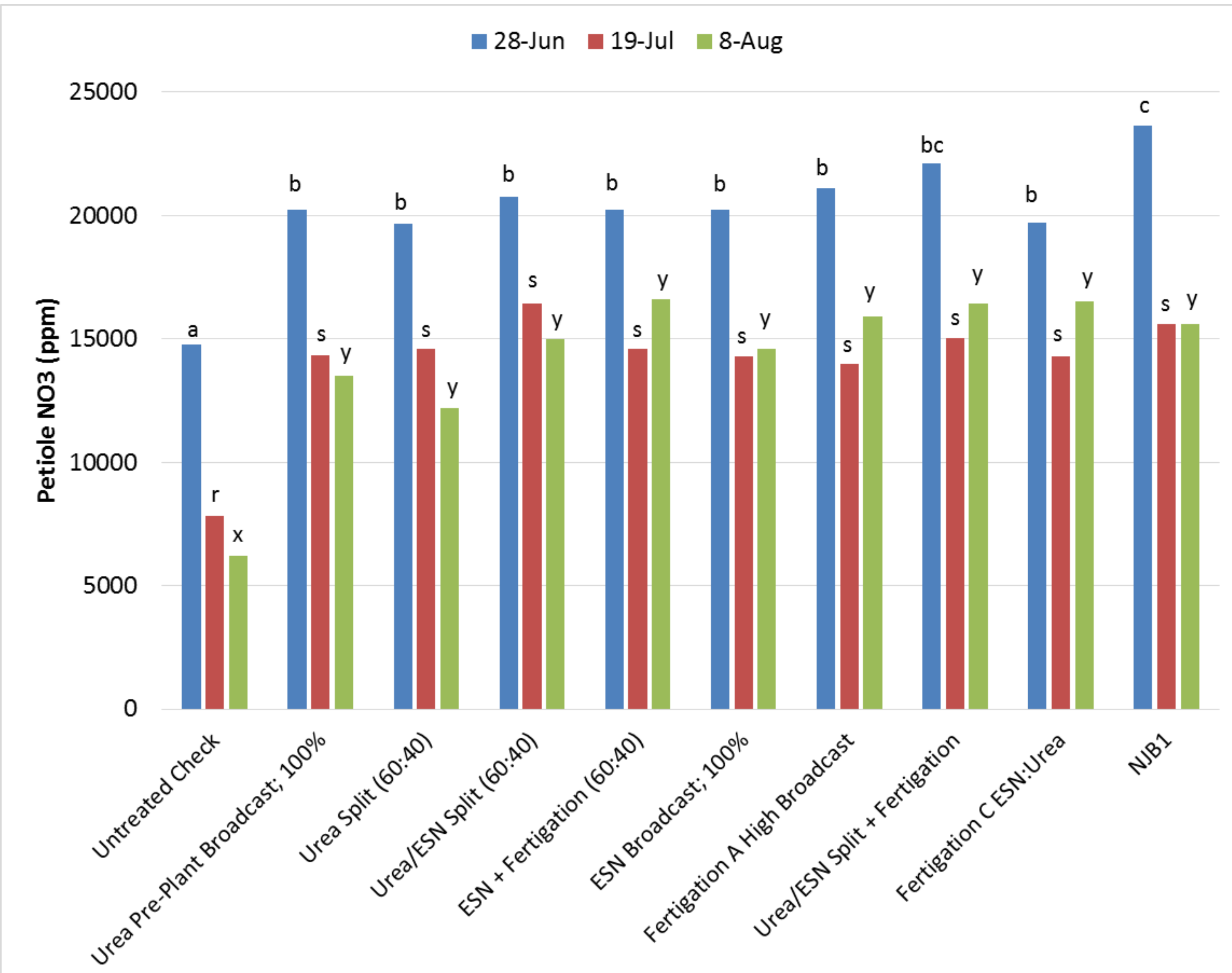


Figure 1: Petiole nitrate levels for each treatment at the Lethbridge, AB location. Samples were taken from the fourth petiole from up to eighty stems at three times during the 2016 growing season.

Potato Yield and Grade

Total yield, mean tuber size and specific gravity are presented in Table 3 for each treatment harvested in Lethbridge in 2016. In 2016, there were no significant differences in total yield or mean tuber size between treatments. There were no statistically significant differences in specific gravity between treatments in 2016 either. The trial was harvested earlier in 2016 than in other years, possibly before tubers had finished bulking.

Table 3: Total yield (estimated ton/ac), mean tuber size (oz.) and specific gravity of potatoes harvested from plots in Lethbridge, AB grown with different nitrogen strategies in 2016

Trt #		Total Yld (ton/ac)	Mean tuber size (oz.)	SG
1	Untreated Check	18.8 a	6.2 a	1.090 a
2	Urea Pre-Plant Broadcast; 100%	20.0 a	6.7 a	1.089 a
3	Urea Split (60:40)	20.1 a	6.6 a	1.088 a
4	Urea/ESN Split (60:40)	19.7 a	6.5 a	1.090 a
5	ESN + Fertigation D (60:40)	18.1 a	6.5 a	1.087 a
6	ESN Broadcast; 100%	17.1 a	6.2 a	1.088 a
8	High Broadcast + Fertigation A	19.7 a	6.8 a	1.084 a
9	Urea/ESN 60:40 Split + Fertigation B	21.2 a	6.5 a	1.088 a
10	ESN:Urea 50:50 Split + Fertigation C	19.3 a	6.0 a	1.088 a
11	NJB1 – urea:ESN (60:40) at hilling	19.9 a	6.5 a	1.089 a

Yield of potatoes in different size categories and marketable yield are summarized in Table 4. None of the size categories yielded statistically significant differences from one another or the check. There was more variability in the data collected in 2016 and the crop was harvested before many of the potatoes had bulked up. The size profile in the check treatments was shifted toward smaller tubers, but was not statistically different from the other treatments. The greatest marketable yield was harvested from Treatments 2 (urea pre-plant), 3 urea split application), 4 urea/ESN split application), 8 (urea plus fertigation) and 11 (urea and ESN at hilling). There was no significant difference in yield of tubers in each size category, although shifts were evident with the different nitrogen strategies. As with previous years, treatments with the highest marketable yield, tended to have greater yields of tubers in the larger size categories as well.

Table 4: Estimated yield (ton/ac) in each weight category (< 4oz., 4 to 6 oz., 6 to 10 oz. > 10 oz., and deformed) for each variety grown at Lethbridge, AB in 2016. Data shown is the mean of four replicates. Data followed by the same letter in each column of the table are not significantly different at the p < 0.05 level.

Treatment	< 4oz.	4 to 6 oz.	6 to 10 oz.	> 10 oz.	Deformed	Marketable Yield
Untreated Check	5.3 a	5.7 a	5.9 a	1.2 a	0.6 a	12.9 a
Urea Pre-Plant Broadcast; 100%	3.4 a	5.0 a	8.0 a	2.8 a	0.8 a	15.8 a
Urea Split (60:40)	4.3 a	5.7 a	7.3 a	2.4 a	0.4 a	15.4 a
Urea/ESN Split (60:40)	3.2 a	5.1 a	7.6 a	2.9 a	0.9 a	15.6 a
ESN + Fertigation (60:40)	4.0 a	4.8 a	6.2 a	2.5 a	0.5 a	13.6 a
ESN Broadcast; 100%	4.9 a	5.2 a	4.9 a	1.4 a	0.7 a	11.5 a
Fertigation A High Broadcast	4.0 a	5.4 a	6.9 a	2.5 a	0.9 a	14.8 a
Urea/ESN Split + Fertigation	4.6 a	6.2 a	6.7 a	2.8 a	0.8 a	15.7 a
Fertigation C ESN:Urea	5.7 a	6.2 a	5.4 a	1.2 a	0.9 a	12.8 a
NJB1 – urea:ESN (60:40) at hilling	3.9 a	5.8 a	7.0 a	2.5 a	0.6 a	15.4 a

This data is from the third year of a four-year trial. Four site years of data will be generated and should provide sufficient information to develop recommendations for various fertilizer approaches as part of a nitrogen management strategy for Russet Burbank. An economic analysis of the results is planned. Nitrogen partitioning and nitrogen use efficiency will also be calculated once plant and tuber N data has been analyzed.

Project Reach:

A target audience for this research is the processing potato growers in southern Alberta. Producers need tools to improve nitrogen use efficiency and reduce cost of production for potatoes. The Potato Growers of Alberta (PGA) comprises more than 120 potato producers, 70 of whom grow processing potatoes. The PGA provided research funding toward this project. Information will be provided annually to the growers via producer meetings.

Potato processors may also benefit by keeping contract prices in a range that maintains their competitiveness in a global market. Improvements in crop quality may also be realized with timely nitrogen applications. Processors will be kept apprised of the results of the project via PGA meetings.

Indirectly, members of the public may benefit from the efficient use of resources and the prudent use of nitrogen fertilizers. The impact of the study on this group is difficult to estimate. The results of the trial may be disseminated via popular press articles at the end of the research project depending on the outcome of the trials.

Project Impact:

With new tools becoming available to producers, timing is as important as quantity for producing good yield and good processing quality. There has been some contradictory information about the use of ESN and fertigation for potato N management and impartial information for Alberta producers is essential. There is a need to determine the best approach to optimize potato yield and quality while refining costs of production. Additional data from the third and fourth years of the trial will:

- be useful in the development of Beneficial N Management Practices for potato production in Alberta;
- determine whether polymer coated urea can reduce total nitrogen applied or reduce the number of in-season nitrogen applications required for optimal potato yield and quality;
- provide economic evaluations of the use of polymer coated urea;
- determine whether fertigation is necessary or beneficial for optimal potato yield and quality; and
- address using the fertilizer strategies under soil type and environmental conditions specific to Alberta.

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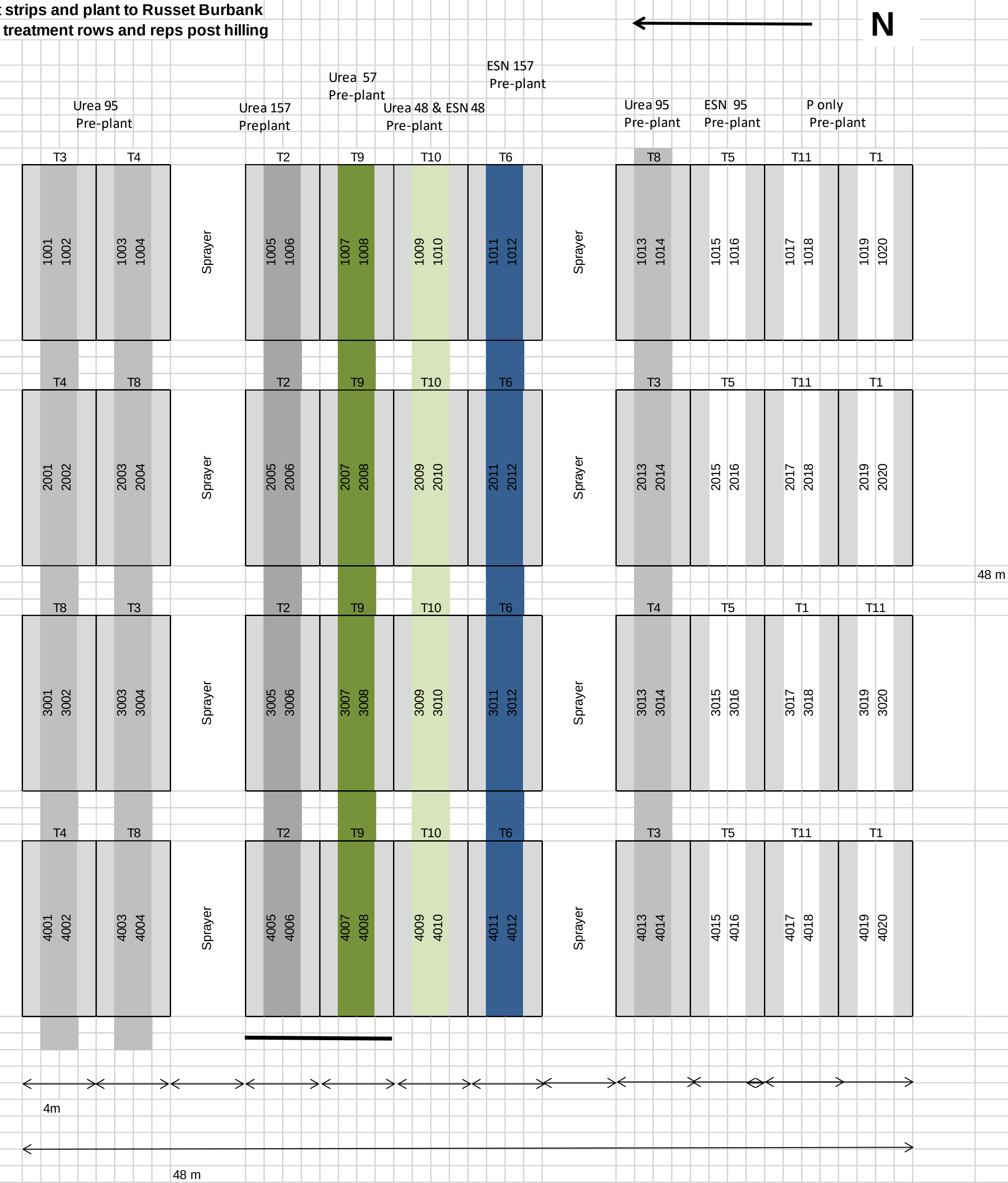
Appendix A: Plot plan of AITC Nitrogen Trial 2016.

2016 Nitrogen BMP Trial

Treat strips and plant to Russet Burbank
Mark treatment rows and reps post hilling



Applications April 28 Planted

1	Treatment 1	Untreated check. 11-52-0 at 96 lbs/ac (50 lbs/ac P)
2	Treatment 2	Urea Broadcast pre-plant 46-0-0 (341 kg/ha)
3	Treatment 3	Urea split application 46-0-0 207 kg/ha pre-plant
4	Treatment 4	Urea /ESN split application 46-0-0 207 kg/ha pre-plant
5	Treatment 5	ESN + fertigation 44-0-0 205 kg/ha pre-plant
6	Treatment 6	ESN boradcast 44-0-0 341 kg/ha (2 passes of XXX)
8	Treatment 8	High broadcast + fertigation 117 kg/ha urea pre-plant
9	Treatment 9	Urea/ESN + fertigation 104 kg/ha 46-0-0 pre-plant
10	Treatment 10	Urea/ESN + fertigation 48kg/ha of 46-0-0 and 48 kg/ha ESN pre-plant
11	NJB1	MAP at Planting + Urea:ESN at Hilling 60:40 (95:62)

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A problem with elucidating if controlled released or stabilized products increase yield in the aforementioned studies has been the lack of comparison of the performance of the same N form (ex. urea) with or without being controlled release (ESN) or stabilized (ex. SuperU). Thus, it is difficult to determine the impact of the enhanced efficiency fertilizers when treatment comparisons vary in the form of the N.

The purpose of the current research is to provide data to determine whether ESN, split applications, fertigation or a combination of these strategies can be used in potato production to improve nitrogen use efficiency while maintaining yield and quality.

The objectives include:

1. Determine optimal timing and source of N fertilizers for irrigated potato.
2. Evaluate the effectiveness of monitoring plant N status to adjust fertigation additions.
3. To determine the effect of combinations of urea and polymer coated urea on yield, specific gravity and quality of Russet Burbank potatoes; and
4. To determine whether polymer coated urea can replace the need for in-season N applications (top-dressing, side-dressing or fertigation).

Approach Taken

The trial was conducted on Russet Burbank potatoes at the Alberta Irrigation Technology Centre in Lethbridge, AB to ensure that background N was low, N applications could be controlled, and the crop was irrigated using a pivot system. The trial is planned for 2 - 4 years to determine the impact of the treatments under a variety of environmental conditions. This trial is part of a larger initiative being led by Dr. Mario Tenuta of the University of Manitoba.

Six soil samples were taken at depths of 0 to 15cm and 15 to 120cm to make a composite soil sample in the fall of 2015. Soil N (35 kg/ha) was taken into account when calculating N applications for each treatment.

Various quantities of urea and ESN (polymer-coated urea) were used pre-plant. Some of the treatments also involved N applications at the time of hilling and others included simulated fertigation treatments to reach the same total N applied. The nitrogen treatments were applied using a Conserv-a-Pak machine April 27, Top-dressed N was applied by hand prior to power hilling May 18 and fertigation was simulated by applying ammonium nitrate and irrigating on three dates, June 30, July 21 and August 15, 2016 (Table 1). All treatments included an application of mono-ammonium phosphate (MAP) to provide starter P. Approximately 10 kg/ha N was supplied with the MAP and is included in the total N column (soil plus applied). The target N was intended to be approximately 80% of an agronomist recommended rate for Russet Burbank Production in southern Alberta (193 kg/ha).

Table 1: Nitrogen treatments (kg/ha) used to determine the effects of fertilization strategies on irrigated Russet Burbank in Alberta.

Treatments 2016		Planned applications							Total N
		Pre-plant		Top-Dress					Kg/ha
		Urea	ESN		Simulated Fertigation (AN)				
1	Untreated Check	0	0					0	46
2	Urea Pre-Plant Broadcast; 100%	157						157	203
3	Urea Split (60:40)	95		62				157	203
4	Urea/ESN Split (60:40)	95		62				157	203
5	ESN + Fertigation (60:40)		95		23	21	18	157	198
6	ESN Broadcast; 100%		157					157	196
8	Fertigation A High Broadcast	95			23	21	18	157	203
9	Urea/ESN Split + Fertigation	57		38	23	21	18	157	196
10	Fertigation C ESN:Urea	48	48		23	21	18	158	200
11	NJB1	0	0	95:62				157	203

Treatments included:

1. No additional nitrogen (approximately 36 kg/ha soil test plus MAP) – check
2. Urea applied pre-plant (193 kg/ha) – urea 100% pp
3. 60% N applied as urea pre-plant; 40% N applied as urea at hilling – urea split
4. 60 % N applied as urea pre-plant; 40% N applied as ESN at hilling – urea/ESN split
5. 60% N applied pre-plant as ESN; 40% N applied via three fertigation events – ESN + fertigation
6. ESN applied pre-plant (193 kg/ha) – ESN 100% pp
7. Omitted in 2106
8. 60% N applied pre-plant as urea; 40% N applied via three fertigation events – Urea + fertigation A
9. Urea applied pre-plant; ESN applied at hilling; three fertigation events – Split + fertigation B
10. Urea and ESN applied pre-plant; three fertigation events – 50:50 + fertigation C
11. NJB1 – Urea:ESN blend (60:40) at hilling
12. Omitted in 2016

2016

Russet Burbank seed (E3) was cut (approximately 70 to 85 g seed pieces), suberized, and treated with MaximMZ™ seed piece treatment (500g/100kg seed) prior to planting. Tubers were planted approximately 13 to 14 cm deep and 30 cm apart in rows spaced 0.90 metres apart using a four-row cup planter in Lethbridge on April 28, 2016. Treatments were set up as a split plot, with pre-plant N as a main treatment. Each treatment was 4 rows wide. The centre two rows were used for petiole sampling. Only one of the centre rows was harvested for yield estimates and tuber evaluations. Each treatment was replicated 4 times to reduce some of the variability inherent in small plot research (Appendix A).

The plots were scouted and managed following recommendations of a contract agronomist, ProMax Agronomy Services. The plots were irrigated with a centre pivot and low-pressure nozzles as required to maintain soil moisture close to 70% capacity, typically once or twice per week.

The potatoes were hilled May 18 with a power hiller. Lorox (1L/ac) was applied prior to emergence (May 25) to control weeds. Sencor 75DF (125 g/ac) and Select (76 mL/ac + Amigo 0.5% v/v) were applied June 8 to control weeds. The plots were irrigated to maintain soil moisture close to 70%. Plots were sprayed with Prism (24 g/ac) with Amigo (0.5%) post-emergence (June 23) to control weeds.

Foliar fungicides were applied several times during the growing season to prevent early and late blight from developing (Table 2).

Table 2: Foliar fungicides applied to the potato crop in 2016 to prevent early and late blight development.

Date of Application	***Fungicide***	***Rate***
30 June	Luna Tranquility	240 mL/ac
30 June	Bravo	0.88 L/ac
8 July	Dithane	900 g/ac
15 July	Dithane	900 g/ac
22 July	Bravo	0.88 L/ac
28 July	Dithane	880 g/ac
5 Aug	Bravo	1 L/ac
12 Aug	Dithane	880 g/ac
19 Aug	Dithane	880 g/ac
26 Aug	Dithane	880 g/ac
25 Aug	Bravo	0.8 L/ac

Additional ESN and urea were applied (top-dressed) to treatments 3, 4, and 9 prior to hilling May 18th.

Petiole samples were taken at three times (June 28, July 19 and August 9, 2016) during the season to follow the N-status of the crop throughout the season. Soil samples were taken at depths of 0 to 30cm shortly after the petiole samples were collected (June 30, July 21 and August 15) and before the fertigation events. Twelve cores were taken from each plot to make a composite sample. Four core samples were taken from the top of the hills, and eight were taken from the shoulder of the hills within each plot. Samples were dried at 50C for approximately 1 week and ground, then stores at 4C until they were analyzed. Simulated fertigation treatments (ammonium nitrate broadcast) were applied immediately after soil sampling (June 30, July 21, and August 15) and irrigated in.

Prior to desiccation (Sept. 6), two whole potato plants were removed from the field. Fresh biomass was measured and the plants were dried in a forage dryer at 50C. Dry biomass was measured and the plant material was ground using a plant tissue grinder and held at 4C until analyzed for N.

Reglone (1.4 L/ac) was applied Sept 7 to desiccate potato vines. All treatments were harvested mechanically September 14 using a one-row Grimme harvester. Immediately following the potato harvest, soil samples were taken from the soil disturbed by the harvester. These samples were dried and ground and stored at 4C until analyzed.

Tubers were stored at 8˚C until graded. Tubers were graded into size categories (less than 113g, 113 - 170g, 171 – 284g over 284g and deformed). A sample of twenty-five tubers (113 – 284g) from each replicate was used to determine specific gravity using the weight in air over weight in water method. The tubers in the specific gravity sample were cut longitudinally to assess internal defects. Another sub-sample of 8 tubers was washed, diced, freeze dried and ground. Tuber tissue was analyzed for N content as well.

The data presented here have been statistically analyzed using ANOVA and Tukey's Multiple Range Test; ($p \leq 0.05$).

Results:

Petiole Nitrates

Petiole nitrate levels for all treatments declined between the first and second sampling date. The decline was less dramatic for split N treatments and treatments involving fertigation. Nitrogen declined between the second and third sampling as well, but treatments involving fertigation maintained higher petiole N at the third sampling date than treatments where N was all applied pre-plant. Treatments including fertigation showed much less of a decline, and in several treatments an increase between the second and third sampling date. Nitrate levels in the petioles at the first sampling date in mid-July ranged from about 15,000 ppm for the check to over 20,000 ppm for most of the fertilized treatments (Fig 1). As expected, treatments with ESN applied pre-plant started out with slightly lower petiole nitrate levels.

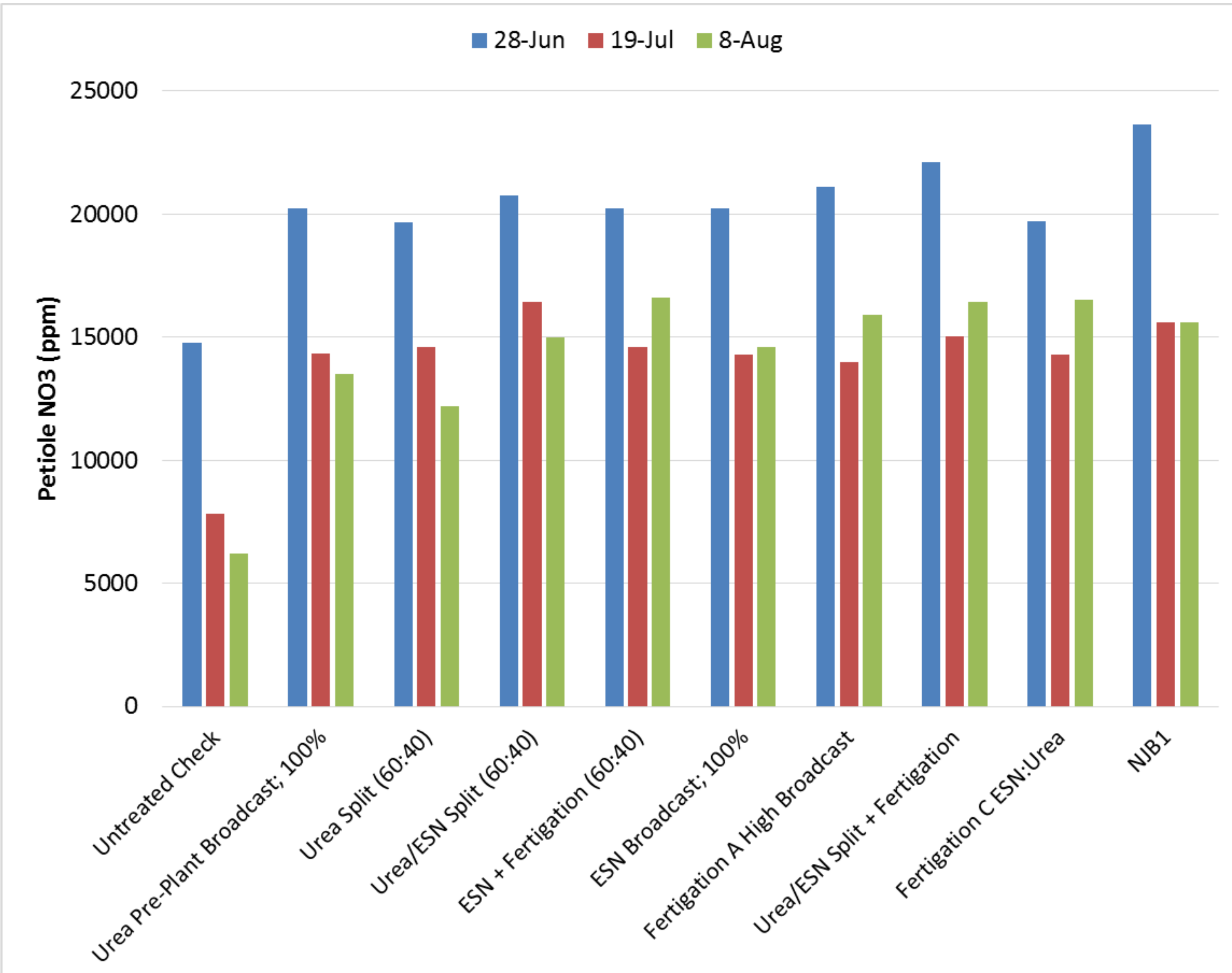

Figure 1: Petiole nitrate levels for each treatment at the Lethbridge, AB location. Samples were taken from the fourth petiole from up to eighty stems at three times during the 2016 growing season.

Potato Yield and Grade

Total yield, mean tuber size and specific gravity are presented in Table 3 for each treatment harvested in Lethbridge in 2016. In 2016, there were no significant differences in total yield or mean tuber size between treatments. There were not statistically significant differences in specific gravity between treatments in 2016 either. The trial was harvested earlier in 2016 than in other years, possibly before tubers had finished bulking.

Table 3: Total yield (estimated ton/ac), mean tuber size (oz.) and specific gravity of potatoes harvested from plots in Lethbridge, AB grown with different nitrogen strategies in 2016

Trt #		Total Yld (ton/ac)	Mean tuber size (oz.)	SG
1	Untreated Check	18.8 a	6.2 a	1.090 a
2	Urea Pre-Plant Broadcast; 100%	20.0 a	6.7 a	1.089 a
3	Urea Split (60:40)	20.1 a	6.6 a	1.088 a
4	Urea/ESN Split (60:40)	19.7 a	6.5 a	1.090 a
5	ESN + Fertigation D (60:40)	18.1 a	6.5 a	1.087 a
6	ESN Broadcast; 100%	17.1 a	6.2 a	1.088 a
8	High Broadcast + Fertigation A	19.7 a	6.8 a	1.084 a
9	Urea/ESN 60:40 Split + Fertigation B	21.2 a	6.5 a	1.088 a
10	ESN:Urea 50:50 Split + Fertigation C	19.3 a	6.0 a	1.088 a
11	NJB1 – urea:ESN (60:40) at hilling	19.9 a	6.5 a	1.089 a

Yield of potatoes in different size categories and marketable yield are summarized in Table 4. None of the size categories yielded statistically significant differences from one another or the check. There was more variability in the data collected in 2016 and the crop was harvested before many of the potatoes had bulked up. The size profile in the check treatments was shifted toward smaller tubers, but was not statistically different from the other treatments. The greatest marketable yield was harvested from Treatments 2 (pre-plant urea), 3 (urea split application), 4 (urea/ESN split application), 8 (urea plus fertigation) and 11 (urea and ESN at hilling). There was no significant difference in yield of tubers in each size category, although shifts were evident with the different nitrogen strategies. As with previous years, treatments with the highest marketable yield, tended to have greater yields of tubers in the larger size categories as well.

Table 4: Estimated yield (ton/ac) in each weight category (< 4oz., 4 to 6 oz., 6 to 10 oz. > 10 oz., and deformed) for each variety grown at Lethbridge, AB in 2016. Data shown is the mean of four replicates. Data followed by the same letter in each column of the table are not significantly different at the p < 0.05 level.

	< 4oz.	4 to 6 oz.	6 to 10 oz.	> 10 oz.	Deformed	Marketable Yield
Treatment						
Untreated Check	5.3 a	5.7 a	5.9a	1.2 a	0.6 a	12.9 a
Urea Pre-Plant Broadcast; 100%	3.4 a	5.0 a	8.0 a	2.8 a	0.8 a	15.8 a
Urea Split (60:40)	4.3 a	5.7 a	7.3 a	2.4 a	0.4 a	15.4 a
Urea/ESN Split (60:40)	3.2 a	5.1 a	7.6 a	2.9 a	0.9 a	15.6 a
ESN + Fertigation (60:40)	4.0 a	4.8 a	6.2 a	2.5 a	0.5 a	13.6 a
ESN Broadcast; 100%	4.9 a	5.2 a	4.9 a	1.4a	0.7 a	11.5 a
Fertigation A High Broadcast	4.0 a	5.4 a	6.9 a	2.5 a	0.9 a	14.8 a
Urea/ESN Split + Fertigation	4.6 a	6.2 a	6.7 a	2.8 a	0.8 a	15.7 a
Fertigation C ESN:Urea	5.7 a	6.2 a	5.4 a	1.2 a	0.9 a	12.8 a
NJB1 – urea:ESN (60:40) at hilling	3.9 a	5.8 a	7.0 a	2.5 a	0.6 a	15.4 a

This data is from the second year of a four-year trial. A minimum of 2 and a maximum of 4 site years of data will be generated and should provide sufficient information to develop recommendations for various fertilizer approaches as part of a nitrogen management strategy for Russet Burbank. An economic analysis of the results is planned. Nitrogen use efficiency will also be calculated once plant and tuber N data has been analyzed.

Project Reach:

A target audience for this research is the processing potato growers in southern Alberta. Producers need tools to improve nitrogen use efficiency and reduce cost of production for potatoes. The Potato Growers of Alberta (PGA) comprises more than 120 potato producers, 70 of whom grow processing potatoes. The PGA provided research funding toward this project. Information will be provided annually to the growers via producer meetings.

Potato processors may also benefit by keeping contract prices in a range that maintains their competitiveness in a global market. Improvements in crop quality may also be realized with timely nitrogen applications. Processors will be kept apprised of the results of the project via PGA meetings.

Indirectly, members of the public may benefit from the efficient use of resources and the prudent use of nitrogen fertilizers. The impact of the study on this group is difficult to estimate. The results of the trial may be disseminated via popular press articles at the end of the research project depending on the outcome of the trials.

Project Impact:

With new tools becoming available to producers, timing is as important as quantity for producing good yield and good processing quality. There has been some contradictory information about the use of ESN and fertigation for potato N management and impartial information for Alberta producers is essential. There is a need to determine the best approach to optimize potato yield and quality while refining costs of production. Additional data from the third and fourth years of the trial will:

- be useful in the development of Beneficial N Management Practices for potato production in Alberta;
- determine whether polymer coated urea can reduce total nitrogen applied or reduce the number of in-season nitrogen applications required for optimal potato yield and quality;
- provide economic evaluations of the use of polymer coated urea;
- determine whether fertigation is necessary or beneficial for optimal potato yield and quality; and
- address using the fertilizer strategies under soil type and environmental conditions specific to Alberta.

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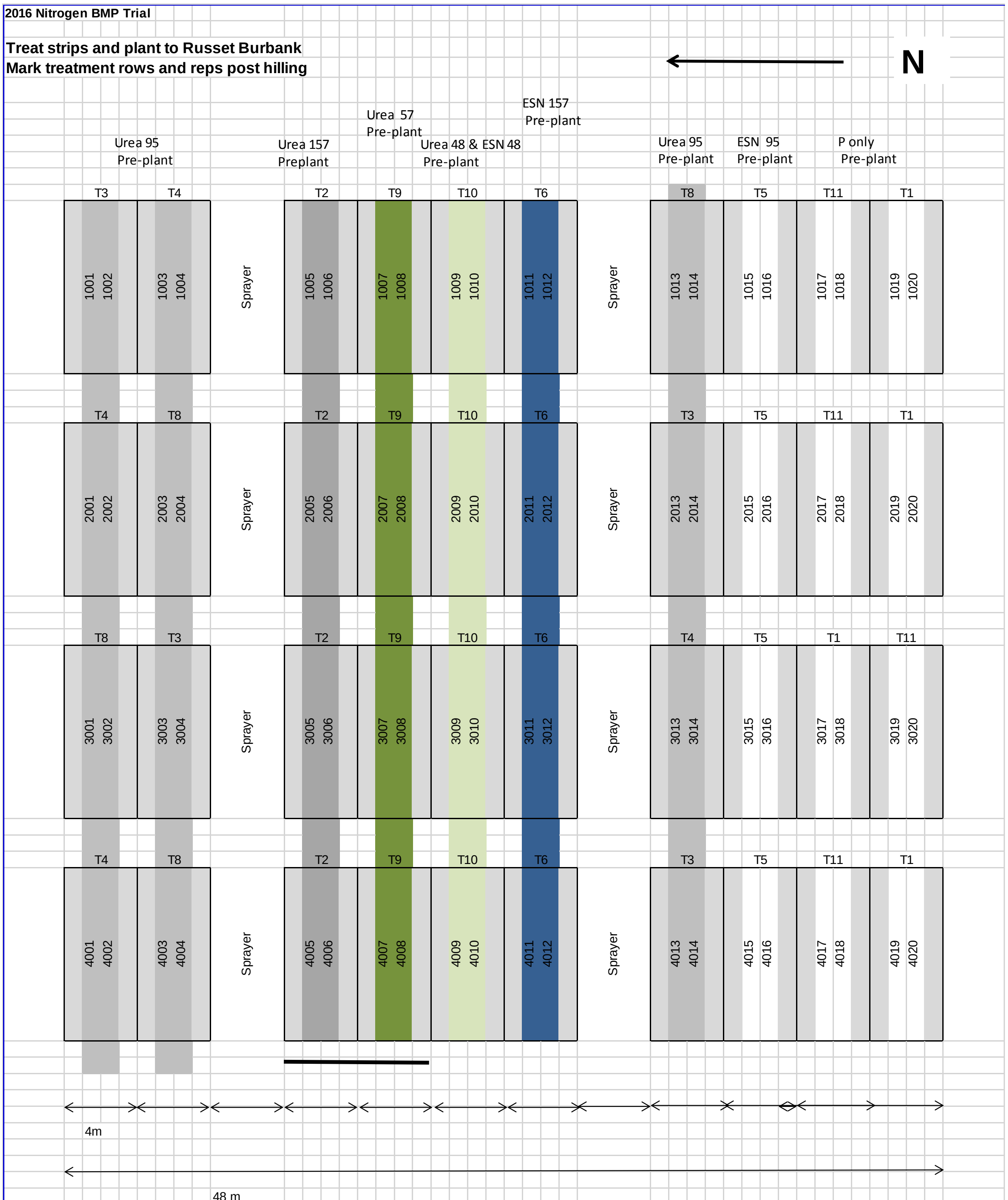
Appendix A: Plot plan of AITC Nitrogen Trial 2016.



Applications April 28 Planted

1	Treatment 1	Untreated check. 11-52-0 at 96 lbs/ac (50 lbs/ac P)
2	Treatment 2	Urea Broadcast pre-plant 46-0-0 (341 kg/ha)
3	Treatment 3	Urea split application 46-0-0 207 kg/ha pre-plant
4	Treatment 4	Urea /ESN split application 46-0-0 207 kg/ha pre-plant
5	Treatment 5	ESN + fertigation 44-0-0 205 kg/ha pre-plant
6	Treatment 6	ESN boradcast 44-0-0 341 kg/ha (2 passes of XXX)
8	Treatment 8	High broadcast + fertigation 117 kg/ha urea pre-plant
9	Treatment 9	Urea/ESN + fertigation 104 kg/ha 46-0-0 pre-plant
10	Treatment 10	Urea/ESN + fertigation 48kg/ha of 46-0-0 and 48 kg/ha ESN pre-plant
11	NJB1	MAP at Planting + Urea:ESN at Hilling 60:40 (95:62)

Nitrogen for Improved Yield, Quality, and Profitability of Potato
Alberta Location – Interim Report
January 10, 2018

Project Description:

Introduction
The competitiveness of Canada's potato industry is dependent upon the production of high quality tubers in the most cost-efficient manner possible. Management of nitrogen fertilizer additions is one of the most practical means by which growers have to improve the economics of their production system and limit environmental impacts of potato production (Zebarth and Rosen 2007). Reviews of nitrogen management in potato stress the importance of matching crop demand for N by controlling the timing, placement, source and rate of additions and considering the N supply capacity of soil (Davenport et al. 2005, Monoz et al. 2005, Zebarth and Rosen 2007, Vos 2009).

Matching crop N demand with N availability in soil is the best means of optimizing nitrogen use efficiency and marketable yield of potato (Zebarth and Rosen 2007). Splitting the application of N to applying some at planting and then later as top-dressing at hilling or in irrigation water as fertigation can improve nitrogen use efficiency in soils prone to leaching of nitrate (Errebhi et al. 1998) and similar to conditions in eastern Canada and irrigated potato in the west. How to assess in crop N status to set fertigation amounts however is uncertain. Tools such as nitrate concentration of petioles (Goffart et al. 2008), reflectance of the crop (van Evert et al. 2012), and chlorophyll content (Olivier et al. 2006) relate well to N status of the crop. How to use these in crop measures to best adjust N additions at hilling or with fertigation however remains to be resolved. A different approach to matching N demand and N availability relies upon slowing the release of N from fertilizer added at planting such banding products near the seed so it is less prone to leaching prior to the period of greatest N demand, tuber bulking (Westermann and Sojka (1996). Recently available enhanced efficiency fertilizers that either stabilize N for longer in soil as ammonium with soil enzyme inhibitors or retard release of urea by coating granules with polymer (Trenkel 2010), are new options to growers. If the price premium of these products over regular urea granules is warranted remains to be resolved for our growing conditions.

Matching the availability of added fertilizer to potato N demand should result in maximizing nitrogen use efficiency. It is recommended that potato growers apply fertilizer N partly at planting and later once plants have emerged (Province of Manitoba Soil Fertility Guide). This is usually achieved by split application of fertilizer with some at planting and remainder at hilling or fertigated with irrigation water. Split application of fertilizer N is beneficial in soils prone to leaching of nitrate such as in sand soil and humid conditions (Errebhi et al. 1998). Split application of fertilizer increases production costs such as labour and fuel. Thus, it is important to growers to insure maximal return in investment for these added costs. One example of increased production costs is the increasing use of fertigation in the Prairie Provinces though hard evidence to the benefit to nitrogen use efficiency and returns is lacking. Further, fertigation during hot summer periods likely will promote volatilization of urea in the urea ammonium nitrate solution applied. Fertigation is actively promoted in the Pacific NorthWest of the U.S.A. (Lang et al. 1999) and the processers familiar with that production system are promoting the practice in the Prairies where they also manage processing facilities.

Recently, enhanced efficiency fertilizers such as SuperU (slow release urea with urease and nitrification inhibitors) and ESN (controlled release with polymer coated urea) have become available to growers. It remains uncertain if the price premium for the products is justified by increased returns. In Minnesota, Hyatt et al. (2010) reported polymer coated urea did not increase yield but did decrease emissions of the greenhouse gas, nitrous oxide. In the same state, Wilson et al. (2009) reported lower N rates with polymer coated urea (ESN) were required to achieve maximum yield. Kelling et al. (2011) reported that for 3 of 6 site years in Wisconsin, the nitrification inhibitor, DCD with ammonium sulfate, increased gross yield but for 4 of 6 site year's marketable yield decreased. The decrease was because of ammonium accumulation in soil deforming tubers resulting increased culls.

The purpose of the current research is to provide data to determine whether ESN, split applications, fertigation or a combination of these strategies can be used in potato production to improve nitrogen use efficiency while maintaining yield and quality.

The objectives include:

1. Determine optimal timing and source of N fertilizers for irrigated potato.
2. Evaluate the effectiveness of monitoring plant N status to adjust fertigation additions.
3. To determine the effect of combinations of urea and polymer coated urea on yield, specific gravity and quality of Russet Burbank potatoes; and
4. To determine whether polymer coated urea can replace the need for in-season N applications (top-dressing, side-dressing or fertigation).

Approach Taken

The trial was conducted on Russet Burbank potatoes at the Alberta Irrigation Technology Centre in Lethbridge, AB to ensure that background N was low, N applications could be controlled, and the crop was irrigated using a pivot system. The trial was planned for 2 - 4 years to determine the impact of the treatments under a variety of environmental conditions. This trial is part of a larger initiative being led by Dr. Mario Tenuta of the University of Manitoba.

Six soil samples were taken at depths of 0 to 15cm and 15 to 120cm to make a composite soil sample in the fall of 2016. Soil N (77 kg/ha) was taken into account when calculating N applications for each treatment.

Various quantities of urea and ESN (polymer-coated urea) were used pre-plant. Some of the treatments also involved N applications at the time of hilling and others included simulated fertigation treatments to reach the same total N applied. The nitrogen treatments were applied using a Conserv-a-Pak machine May 3, 2017. Top-dressed N was applied by hand prior to power hilling May 31 and fertigation was simulated by applying ammonium nitrate and irrigating on three dates, July 5, July 26 and August 16, 2017 (Table 1). All treatments included an application of mono-ammonium phosphate (MAP) to provide starter P. Approximately 10 kg/ha N was supplied with the MAP and is included in the total N column (soil plus applied). The target N was intended to be approximately 80% of an agronomist recommended rate for Russet Burbank Production in southern Alberta (200 kg/ha).

Table 1: Nitrogen treatments (kg/ha) used in 2017 to determine the effects of fertilization strategies on irrigated Russet Burbank in Alberta.

		Pre-plant		At Hilling		Simulated Fertigation		
	Treatments	Urea	ESN	Urea	ESN	5 Jul	26 Jul	16 Aug
1	Check	0	0					
2	Urea Pre-Plant Broadcast; 100%	105						
3	Urea Split (60:40)	63		42				
4	Urea/ESN Split (60:40)	63			42			
5	ESN + Fertigation D		63			15	14	13
6	ESN Pre-plant Broadcast; 100%		105					
8	High Broadcast +Fertigation A	63				15	14	13
9	Urea/ESN Split + Fertigation B	38			25	15	14	13
10	ESN/Urea pre-plant+ Fertigation C	32	32			15	14	13
11	Urea: ESN (60:40) at Hilling	0	0	63	42			

Treatments included:

1. No additional nitrogen (approximately 88 kg/ha soil test plus MAP) – check
2. Urea applied pre-plant (105 kg/ha N) – urea 100% pp
3. 60% N applied as urea pre-plant; 40% N applied as urea at hilling – urea split
4. 60 % N applied as urea pre-plant; 40% N applied as ESN at hilling – urea/ESN split
5. 60% N applied pre-plant as ESN; 40% N applied via three fertigation events – ESN + fertigation
6. ESN applied pre-plant (105 kg/ha) – ESN 100% pp
7. Omitted in 2017
8. 60% N applied pre-plant as urea; 40% N applied via three fertigation events – Urea + fertigation A
9. Urea applied pre-plant; ESN applied at hilling; three fertigation events – Split + fertigation B
10. Urea and ESN applied pre-plant; three fertigation events – 50:50 + fertigation C
11. No pre-plant N; Urea:ESN blend (60:40) at hilling
12. Omitted in 2017

2017

Russet Burbank seed (E2 was cut (approximately 70 to 85 g seed pieces), suberized, and treated with MaximD^{TM} seed piece treatment (500g/100kg seed) prior to planting. Tubers were planted approximately 13 to 14 cm deep and 30 cm apart in rows spaced 0.90 metres apart using a four-row cup planter in Lethbridge on May 10, 2017. Treatments were set up as a split plot, with pre-plant N as a main treatment. Each treatment was 4 rows wide. The centre two rows were used for petiole sampling. Only one of the centre rows was harvested for yield estimates and tuber evaluations. Each treatment was replicated 4 times to reduce some of the variability inherent in small plot research (Appendix A).

The plots were scouted and managed following recommendations of a contract agronomist, ProMax Agronomy Services. The plots were irrigated with a centre pivot and low-pressure nozzles as required to maintain soil moisture close to 70% capacity, typically once or twice per week.

The potatoes were hilled May 31 with a power hiller. Roundup (0.48L/ac) was applied prior to planting (May 26) to control weeds. Sencor 75DF (125 g/ac) and Prism (24 g/ac + Agral 90 0.2% v/v) were applied June 22 to control weeds. The plots were irrigated to maintain soil moisture close to 70% (25 irrigation events between June 20 and September 23; total of 386mm).

Foliar fungicides were applied several times during the growing season to prevent early and late blight from developing (Table 2).

Table 2: Foliar fungicides applied to the potato crop in 2017 to prevent early and late blight development.

Date of Application	***Fungicide***	***Rate***
6 July	Luna Tranquility	240 mL/ac
6 July	Penncozeb	0.91 kg/ac
20 July	Penncozeb	0.88 kg/ac
8 Aug	Bravo	0.88 L/ac
10 Aug	Penncozeb	0.88 kg/ac
17 Aug	Bravo	0.88 L/ac
25 Aug	Penncozeb	0.91 kg/ac
1 Sept	Bravo	0.88 L/ac
8 Sept	Bravo	0.88 L/ac

Additional ESN and urea were applied (top-dressed) to treatments 3, 4, and 9 prior to hilling May 31st.

Petiole samples were taken at three times (July 5, July 26 and August 15, 2017) during the season to follow the N-status of the crop throughout the season. Soil samples were taken at depths of 0 to 30cm around the same time as the petiole samples were collected (July 4, July 27 and August 16) and before the fertigation events. Twelve cores were taken from each plot to make a composite sample. Four core samples were taken from the top of the hills, and eight were taken from the shoulder of the hills within each plot. Samples were dried at 50C for approximately 1 week and ground, then stored at 4C until they were analyzed. Simulated fertigation treatments (ammonium nitrate broadcast) were applied immediately after soil sampling (July 5, July 27, and August 16) and irrigated in.

Prior to desiccation (Sept. 20), two whole potato plants were removed from the field. Fresh biomass was measured and the plants were dried in a forage dryer at 50C. Dry biomass was measured and the plant material was ground using a plant tissue grinder and held at 4C until analyzed for N.

No desiccation was required in 2017 as a light frost helped condition potato vines. All treatments were harvested mechanically September 27 using a one-row Grimme harvester. Immediately following the potato harvest, soil samples were taken from the soil disturbed by the harvester. These samples were dried and ground and stored at 4C until analyzed.

Tubers were stored at 8˚C until graded. Tubers were graded into size categories (less than 113g, 113 - 170g, 171 – 284g over 284g and deformed). A sample of twenty-five tubers (113 – 284g) from each replicate was used to determine specific gravity using the weight in air over weight in water method. The tubers in the specific gravity sample were cut longitudinally to assess internal defects. Another sub-sample of 8 tubers was washed, diced, freeze dried and ground. Tuber tissue was analyzed for N content as well.

The data presented here have been statistically analyzed using ANOVA and Tukey's Multiple Range Test; ($p \leq 0.05$).

Results:

Petiole Nitrates

Petiole nitrate levels for all treatments declined between the first and second sampling date. The decline was less dramatic for split N treatments and treatments involving fertigation. Nitrogen declined between the second and third sampling as well, but treatments involving fertigation maintained higher petiole N at the third sampling date than treatments where N was all applied pre-plant. Treatments including fertigation showed much less of a decline, and in several treatments an increase between the second and third sampling date. Nitrate levels in the petioles at the first sampling date in mid-July ranged from about 15,000 ppm for the check to over 20,000 ppm for most of the fertilized treatments (Fig 1). As expected, treatments with ESN applied pre-plant started out with slightly lower petiole nitrate levels.

Figure 1: Petiole nitrate levels for each treatment at the Lethbridge, AB location. Samples were taken from the fourth petiole from up to eighty stems at three times during the 2017 growing season.

Potato Yield and Grade

Total yield, mean tuber size and specific gravity are presented in Table 3 for each treatment harvested in Lethbridge in 2017. In 2017, there were no significant differences in total yield between treatments. Mean tuber size ranged from 6.0 oz. for the split urea treatment (Trt. 3) to 7.9 oz. for the urea pre-plant treatment (Trt. 2). Mean tuber size from other treatments were not statistically different from these or one another. There were no statistically significant differences in specific gravity between treatments in 2017.

Table 3: Total yield (estimated ton/ac), mean tuber size (oz.) and specific gravity of potatoes harvested from plots in Lethbridge, AB grown with different nitrogen strategies in 2017

Trt #		Total Yld (ton/ac)	Mean tuber size (oz.)	SG
1	Untreated Check	22.1 a	6.4 ab	1.087 a
2	Urea Pre-Plant Broadcast; 100%	18.7 a	7.9 b	1.082 a
3	Urea Split (60:40)	19.3 a	6.0 a	1.085 a
4	Urea/ESN Split (60:40)	20.5 a	7.1 ab	1.086 a
5	ESN + Fertigation D (60:40)	19.5 a	7.0 ab	1.087 a
6	ESN Broadcast; 100%	20.8 a	7.1 ab	1.084 a
8	High Broadcast + Fertigation A	20.2 a	7.2 ab	1.084 a
9	Urea/ESN 60:40 Split + Fertigation B	21.1 a	7.1 ab	1.085 a
10	ESN:Urea 50:50 Split + Fertigation C	20.9 a	6.9 ab	1.086 a
11	NJB1 – urea:ESN (60:40) at hilling	22.6 a	7.0 ab	1.085 a

Yield of potatoes in different size categories and marketable yield are summarized in Table 4. There were some significant differences in yield of specific size categories. The check treatment and the urea broadcast pre-plant were shifted toward the smaller categories. A significantly greater yield of small potatoes was observed in the check treatment compared to Trt 2 (urea broadcast pre-plant) and the high broadcast plus fertigation (Trt 8). There were no significant differences between treatments in size categories over 6 oz., and no significant differences in the marketable yield.

Table 4: Estimated yield (ton/ac) in each weight category (< 4oz., 4 to 6 oz., 6 to 10 oz. > 10 oz., and deformed) for each variety grown at Lethbridge, AB in 2017. Data shown is the mean of four replicates. Data followed by the same letter in each column of the table are not significantly different at the $p < 0.05$ level.

Treatment	< 4oz.	4 to 6 oz.	6 to 10 oz.	> 10 oz.	Deformed	Marketable Yield
Untreated Check	5.1 a	6.7 a	7.3 a	2.1 a	0.8 a	16.1 a
Urea Pre-Plant Broadcast; 100%	2.3 c	3.2 b	7.8 a	4.6 a	0.7 a	15.6 a
Urea Split (60:40)	4.3 abc	4.4 ab	7.4 a	2.4 a	0.7 a	14.3 a
Urea/ESN Split (60:40)	3.9 bca	4.9 ab	7.3 a	3.6 a	0.8 a	15.8 a
ESN + Fertigation (60:40)	3.5 abc	5.2 ab	7.8 a	2.6 a	0.5 a	15.5 a
ESN Broadcast; 100%	3.1 abc	5.1 ab	8.0 a	3.9 a	0.6 a	17.0 a
Fertigation A High Broadcast	2.9 bc	4.9 ab	7.9 a	3.8 a	0.7 a	16.6 a
Urea/ESN Split + Fertigation	4.0 abc	5.2 ab	7.8 a	3.6 a	0.6 a	16.5 a
Fertigation C ESN:Urea	3.9 abc	5.5 ab	8.3 a	2.7 a	0.4 a	16.6 a
NJB1 – urea:ESN (60:40) at hilling	4.6 ab	5.2 ab	8.4 a	3.5 a	0.9 a	17.1 a

This data is from the fourth year of a four-year trial. Four site years of data were generated and provide information to develop recommendations for various fertilizer approaches as part of a nitrogen management strategy for Russet Burbank. An economic analysis of the results is planned. Nitrogen partitioning and nitrogen use efficiency will also be calculated once plant and tuber N data has been analyzed.

Project Reach:

A target audience for this research is the processing potato growers in southern Alberta. Producers need tools to improve nitrogen use efficiency and reduce cost of production for potatoes. The Potato Growers of Alberta (PGA) comprises more than 120 potato producers, 70 of whom grow processing potatoes. The PGA provided research funding toward this project. Information will be provided annually to the growers via producer meetings.

Potato processors may also benefit by keeping contract prices in a range that maintains their competitiveness in a global market. Improvements in crop quality may also be realized with timely nitrogen applications. Processors will be kept apprised of the results of the project via PGA meetings.

Indirectly, members of the public may benefit from the efficient use of resources and the prudent use of nitrogen fertilizers. The impact of the study on this group is difficult to estimate. The results of the trial may be disseminated via popular press articles at the end of the research project depending on the outcome of the trials.

Project Impact:

With new tools becoming available to producers, timing is as important as quantity for producing good yield and good processing quality. There has been some contradictory information about the use of ESN and fertigation for potato N management and impartial information for Alberta producers is essential. There is a need to determine the best approach to optimize potato yield and quality while refining costs of production. Data from the trial will:

- be useful in the development of Beneficial N Management Practices for potato production in Alberta;
- determine whether polymer coated urea can reduce total nitrogen applied or reduce the number of in-season nitrogen applications required for optimal potato yield and quality;
- provide economic evaluations of the use of polymer coated urea;
- determine whether fertigation is necessary or beneficial for optimal potato yield and quality; and
- address fertilizer strategies under soil type and environmental conditions specific to Alberta.

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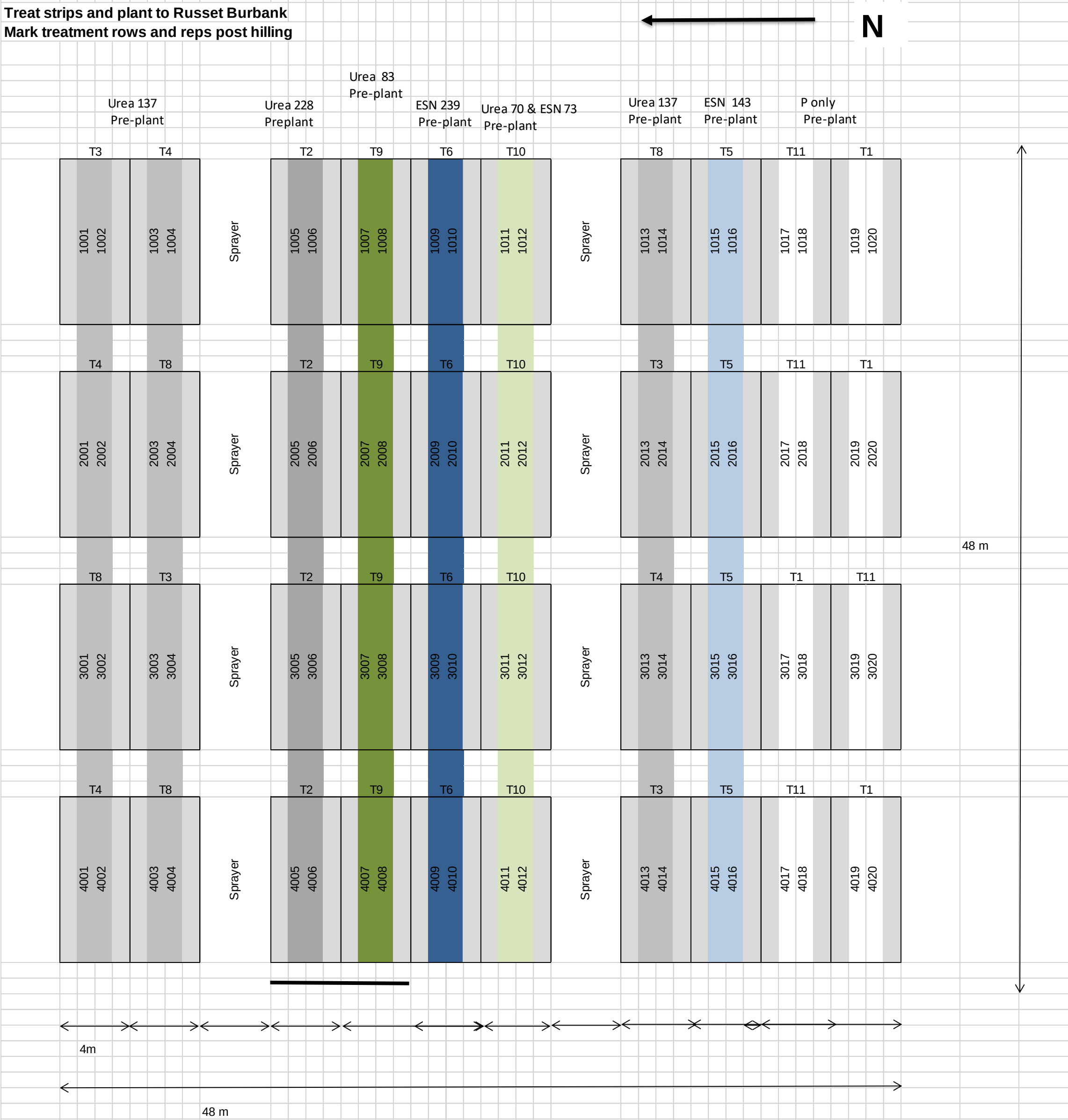
Appendix A: Plot plan of AITC Nitrogen Trial 2017.

2017 Nitrogen BMP Trial

Treat strips and plant to Russet Burbank
Mark treatment rows and reps post hilling



Applications May 3 Planted

1	Treatment 1	Untreated check. 11-52-0 at 96 lbs/ac (50 lbs/ac P)
2	Treatment 2	Urea Broadcast pre-plant 46-0-0 (228 kg/ha)
3	Treatment 3	Urea split application 46-0-0 (137 kg/ha) pre-plant
4	Treatment 4	Urea /ESN split application 46-0-0 (137 kg/ha) pre-plant
5	Treatment 5	ESN + fertigation 44-0-0 (143 kg/ha) pre-plant
6	Treatment 6	ESN boradcast 44-0-0 (239 kg/ha) (2 passes of XXX)
8	Treatment 8	High broadcast + fertigation (137 kg/ha) urea pre-plant
9	Treatment 9	Urea/ESN + fertigation (83 kg/ha) 46-0-0 pre-plant
10	Treatment 10	Urea/ESN + fertigation (70 kg/ha) of 46-0-0 and (73 kg/ha) ESN pre-plant
11	NJB1	MAP at Planting + Urea:ESN at Hilling 60:40 (63:42)

A COST BENEFIT ANALYSIS OF SELECTED NITROGEN FERTILIZER TREATMENTS FOR COMMERCIAL POTATO PRODUCTION

Katherine Rogers & Ron Gietz, Alberta Agriculture and Forestry

Based on field research conducted at Alberta Irrigation Technology Centre (AITC), Lethbridge, AB, by Michele Konshuch, Alberta Agriculture and Forestry

The profitability of 11 different nitrogen treatments were examined based on the results of a four-year research study conducted at AITC, Lethbridge, AB from 2014-2017.

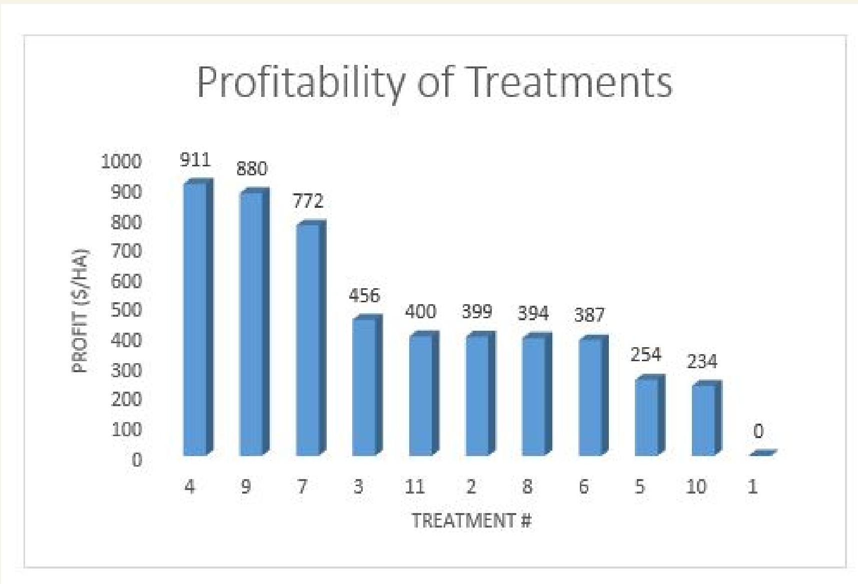


Figure 1. This graph displays the treatments ranked from highest profitability to lowest.

Treatment #	Description
1	Check
2	Urea pre-plant
3	Urea split
4	Urea/ESN split
5	ESN + Fertigation
6	ESN pre-plant
7	Urea/ESN pre-plant
8	Pre-plant Urea + fertigation
9	Urea/ESN split + fertigation
10	Urea/ESN pre-plant + fertigation
11	Urea/ESN @ hilling

TOP RANKED

Using a cost-benefit analysis of the study data, the most beneficial treatment was Treatment 4 - **Urea/ESN split**, where 60% N applied as urea pre-plant and 40% N applied as ESN (slow release polymer coated urea) at the time of hilling.

Following closely behind is Treatment 9 - Urea/ESN split + fertigation. Treatment 7 - Urea/ESN pre-plant came in third.

The lowest ranked treatment is the control treatment, which reaffirms the **importance of N fertilization** for commercial potato production.

Ranked by timing, split treatments (pre-plant + hilling) averaged about **twice the return** of pre-plant and fertigation treatments.

Ranked by type of fertilizer, returns for Urea/ESN combinations averaged $699/ha, **more than twice the returns** for ESN alone ($321/ha) or Urea alone ($316/ha).

Based on these data and assumptions, the application of 60% of N as Urea at time of planting, followed by the application of 40% of recommended N as ESN at hilling is expected to result in the highest producer returns.

The economics of fertigation, a common industry practice, are not apparent.

For more info please contact Michele Konshuch
michele.konshuch@gov.ab.ca 403-362-1314

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PROJECT REPORT

Project overview

1. Project number: 2016045R - RES0035051 - Potato Growers of Alberta - PGA
2. Project title: Effects of Nitrification Inhibitor and Biostimulant on reduction of Nitrous Oxide (N2O) emissions and increase of Nutrient Use Efficiency in Intensive Potato Crops in Alberta, Canada
3. Abbreviations: Define ALL abbreviations used.
4. Project start date: 2/1/2017 Finish Date: 12/31/2019
5. Project completion date: 12/31/2019
6. Report submission date: 01/07/2021
7. Research team information
a) Principal investigator: (Requires personal data sheet (refer to Section 14) only if Principal Investigator has changed since last report.)

Name	Institution	Expertise added
Guillermo Hernandez Ramirez	Associate Professor, University of Alberta, Faculty of Agriculture, Life and Environmental Sciences	Soil science & greenhouse gases fluxes

b) Research team members (List names of all team members. For each new team member, *i.e.*, joined since the last report, include a personal data sheet [refer to Section 14]. Additional rows may be added if necessary.)

Name	Institution	Expertise added
Dr. Shakila K. Thilakarathna	University of Alberta	Postdoctorate in Soil fertility & gasesous fluxes
Dr. Michele Konschuh	Department of Biological Sciences, University of Lethbridge	Irrigation specilist
Dr. Shelley A. Woods	Alberta Agriculture and Forestry, Lethbridge Research Centre	Irrigation management

Principal Investigator and Authorised Representative's Signatures

The Principal Investigator and an authorised representative from the Principal Investigator's organisation of employment must sign this form.

By signing as an authorised representative of the Principal Investigator's employing organisation and/or the research team member's(s') employing organisation(s), the undersigned hereby acknowledge submission of the information contained in this report to the funder(s).

Principal Investigator

Principal Investigator	
Name: **Guillermo Hernandez Ramirez**	**Title/Organisation:** **University of Alberta**
Signature: **SEE SEPARATE FILE**	**Date:** **4 January 2021**
Principal Investigator's Authorised Representative's Approval	
Name: **David Bressler**	**Title/Organisation:** **Associated Dean Research – Faculty of Agriculture, Life and Environmental Sciences University of Alberta**
Signature: **SEE SEPARATE FILE**	**Date:** **4 January 2021**

Financial Project Report

M - 10AUG2020-YT

UNIVERSITY OF ALBERTA

Research Services Office
222 Campus Tower, 8625 - 112 Street, Edmonton, AB T6G 2E1 Canada

Statement of Award & Expenditures

For the Period Ending December 31, 2019

Name of Grantee	Department		Project/Grant	
Hernandez Ramirez,Guillermo - Principal Investigator	100400	ALES RR General	Start Date:	End Date:
University Project/Grant Number	Project/Grant Description		Feburary 1, 2017	December 31, 2019
RES0035051	MULTI/2 PGA 2016C045R Hernande			

	Reporting Period Feburary 1, 2017 December 31, 2019
OPENING BALANCE	**0.00**
AWARD	
Direct Costs	**177,000.00**
Indirect Costs	**0.00**
Total funds available	**177,000.00**
EXPENDITURE	
Salaries & Benefits	
Undergrad Stu Salary & Benefit	0.00
Grad Student Salary & Benefits	0.00
Graduate Student Salaries	0.00
Graduate Student Benefits	0.00
Postdoctoral Salary & Benefits	0.00
Postdoctoral Fellows Salaries	0.00
Postdoctoral Fellows Benefits	0.00
Other Sal & Adj (all benefits)	0.00
Other Salaries	81,837.82
Other Benefits	6,087.86
Professional & Technical Svcs	19,364.32
Equipment	22,724.37
Materials Supplies & Other Exp	35,722.53
Travel	11,263.10
Transfers Out	0.00
	0.00
Total Funds Expended	**177,000.00**
Indirect Cost Expenses 0%	**0.00**
Total Expenditures	**177,000.00**
PROJECT/GRANT BALANCE AS AT: December 31, 2019	**0.00**
Amount Received from Sponsor:	**177,000.00**

SIGNATURES

I hereby certify that the above statement is correct and that the expenditures shown were for the purpose for which the grant was made and disbursements conform to University policy and are in compliance with all terms and conditions imposed by the sponsoring agency.

Project Manager - Role: Hernandez Ramirez,Guillermo - Principal Investigator

12 Aug. 2020

Date

I certify that the expenditures summarized above were incurred and paid wholly on behalf of the grantee, and that the vouchers are available for monitoring purposes.

Michael Walesiak
Associate Director-Finance
Research Services Office

Business Officer, Research Services Office

August 12, 2020

Date

Activity Project Report

Potato productivity and nitrous oxide emissions as a function of nitrogen fertilization options

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Highlights

N_2O emissions from furrow positions were typically greater than from potato hills

Admixing the inhibitor DMPSA with N fertilizers decreased N_2O fluxes and increased yield

Polymer-coated urea also increased potato harvest, but did not reduce the N_2O fluxes

Fertilizer options did not influence the nitrogen use-efficiency or harvest indexes

Potato petiole nitrate concentrations were closely linked with availability of soil N

Abstract

Improved nitrogen management options are needed in intensive agricultural systems to mitigate the risk for N_2O emissions while sustaining high yields. We assessed the effectiveness of a polymer-coated urea (Environmentally Smart N™, ESN), a new nitrification inhibitor 2,4-dimethylpyrazol succinic acid (DMPSA), a novel biostimulant (an existing bacterial and enzymatic combination), and their combinations with granular urea and ammonium sulfate nitrate (ASN) fertilizers to decrease nitrous oxide (N_2O) emissions and to improve potato (*Solanum tuberosum* L.) productivity under irrigation in Southern Alberta, Canada. We measured the emissions of N_2O from potato hills and furrows at two field sites throughout two growing seasons using the manual chamber method. Tuber yield and grade as well as N uptake were also quantified. Peak N_2O emissions as well as increased N concentrations in potato petiole and soils occurred shortly after N fertilizer applications. Although the effects were not always evident, the urea alone treatment generally exhibited the highest N_2O fluxes, whereas the DMPSA inhibitor admixed with either urea or ASN resulted in lower N_2O emissions. In one of the growing seasons at the Brooks site, adding DMPSA reduced the N_2O emissions from urea-amended fields by 57 %. At the Lethbridge site, the N_2O emissions from furrow positions were greater than from hills by 3.2 times in 2017 and 1.7 times in 2018. Compared to the unfertilized controls, 36% higher potato marketable yields were obtained when applying either ASN treated with DMPSA or ESN fertilization options in one of the four experimental site-years (33 versus 45 Mg ha^{-1}). The overall average of growing-season N_2O emission factor was 0.056 %, after accounting for considerable background emissions from unfertilized controls. Results showed that N application strategies utilizing DMPSA admixed with either urea or ASN can maintain high potato yields while reducing N_2O emissions relative to soils receiving these fertilizers without this additive.

Keywords:

Potato, Nitrous oxide, Nitrogen fertilizer, Nitrification inhibitor, Irrigation

Introduction

Global food security and climate change are two crucial challenges inherently associated with land management options. Agricultural lands that receive intensive nitrogen fertilization are important sources of food commodities and also detrimental greenhouse gases such as the potent nitrous oxide (N_2O) (Lin et al., 2017; Thilakarathna et al., 2021; Chai et al., 2020). In fact, the outcomes of N_2O emissions and crop productivity can trade off with each other (Thilakarathna et al., 2021) or even increase concurrently (Chai et al., 2020) under the driving influence of N fertilization choices. Furthermore, in irrigated fertilized croplands (Chai et al., 2020), soils can experience high availabilities of N and moisture simultaneously, which can exacerbate production of N_2O from both exogenous and native N pools (Roman-Perez and Hernandez-Ramirez, 2021). Concerns about N_2O as a greenhouse gas exist because N_2O is 300 times more powerful than CO_2 on mass basis (Daly and Hernandez-Ramirez, 2020). As a highly stable gas, N_2O can persist in the atmosphere for 120 years and depletes the stratospheric ozone layer through catalyzed reactions (Ravishankara et al., 2009). In addition to N_2O emissions, other losses of applied fertilizer-N to the environment can involve dinitrogen from complete denitrification, ammonia (NH_3) volatilization, eutrophication in surface water, and groundwater contamination from nitrate leaching (Hernandez-Ramirez et al., 2011; Lin et al., 2017; Liang et al., 2019).

As a high productivity crop, potato (*Solanum tuberosum* L.) requires significant inputs of N and water to optimize yield, maintain tuber quality, and tolerate diseases (Ghosh et al., 2019). Within Canada, one of the largest concentrations of potato cropping is located in southern Alberta, with a planting area of 22,424 ha (Agricultural Statistics Alberta, 2018). Generally, the application rates of N fertilizer for irrigated potato cropping in the Canadian Prairies are greater than 200 kg N ha^{-1} (Gao et al., 2013); hence, high-input intensity potato cropping can likely be characterized as hot spot for greenhouse gas (GHG) emissions and potentially reduced nutrient use efficiency (NUE). This net outcome from potato production could become detrimental from agronomic, economic, and environmental perspectives. Reduced NUE increases the cost of production and decreases yield per unit area, creating challenges in meeting the global demand for food production (Thilakarathna et al., 2021).

Enhanced crop productivity and a reduced environmental footprint are closely related to efficient N cycling and transformations that result from well-timed nutrient availability in close synchrony with plant requirements (Venterea et al., 2012). Improving N management in intensified cropping systems can create opportunities to simultaneously achieve both sustained productivity and reduced environmental impacts. Such management improvements can emerge through the split application of N fertilizers (Gao et al., 2017; Souza et al., 2020), addition of controlled-release N fertilizers (Akiyama et al., 2010; Thilakarathna et al., 2021), nitrification inhibitors admixed with N fertilizers (Lin et al., 2017; Thilakarathna et al., 2021), and novel biostimulants of the soil N cycling that can combine beneficial bacterial and enzymatic actions (Calvo et al., 2013; Calvo et al., 2014; Souza et al., 2019). A microbial biostimulant containing beneficial free-living N-fixing and mineralizing microbes could potentially increase the amount and availability of N for crops while stimulating root growth and increased nutrient uptake (Souza et al., 2019; Zarzecka et al., 2019).

Compared to the common use of urea fertilizer in agriculture (Guenette et al., 2019), ammonium sulfate nitrate (ASN) could potentially deliver higher N availability per added N unit to crops as an alternative fertilizer. Furthermore, treating urea or ammonium-based fertilizers with a nitrification inhibitor, such as 2,4-dimethylpyrazol succinic acid (DMPSA), has the capacity to retain available N in ammonium form (Guardia et al., 2017; Thilakarathna and Hernandez-Ramirez, 2021). After evaluating urea treated with the inhibitor 2,4-dimethylpyrazol phosphate in a potato crop in Minnesota, Souza et al. (2019) reported that N_2O emissions decreased by half compared with urea alone. To the best of our knowledge, there is a paucity of studies examining the effects of the newly-formulated inhibitor DMPSA on potato production. It is unclear how beneficial implementing DMPSA additive would be on both potato yield and N_2O emissions. Our study endeavors to address this knowledge gap.

Controlled-release N fertilizers may also prevent N losses and improve timely N availability in cropping systems (Li et al., 2012; Li et al., 2016; Thilakarathna et al., 2021; Ziadi et al., 2011). A common controlled-release fertilizer is the polymer-coated urea (PCU) known as Environmentally Smart N™ (ESN). To date, only a few studies have determined the effectiveness of ESN on N_2O emissions in potato production fields, and these existing studies reported inconsistent results (Motavalli et al., 2008; Perron et al., 2019; Ziadi et al., 2011). Hyatt et al. (2010) reported that PCU reduced N_2O emissions or had no effect in irrigated potato in Minnesota, while Zebarth et al. (2012) found no significant effect of PCU on N_2O emissions from rain-fed potato production on a medium-textured soil in Eastern Canada. These inconsistent, scarce reports point to the need for further research to determine the effectiveness of ESN as available results were highly influenced by specific soil, weather, and management practices.

The N_2O emissions within potato fields are highly spatially variable because of the creation of hills and furrows during hilling operations (Burton et al., 2008; Gao et al., 2013). Burton et al. (2008) reported N_2O emissions from potato hills to be greater than furrows during the first two years of an N banded field experiment conducted in Orthic Humo Ferric Podzols in

Eastern Canada. By contrast, both Ruser et al. (2006) in Southern Germany and Smith et al. (1998) in the United Kingdom observed higher N_2O emissions from furrows relative to potato hills. These conflicting reports highlight the need for better understanding of spatial and temporal patterns of N_2O fluxes from hills and furrows within potato fields across a range of environments. This investigation needs to be conducted along with examination of N availability in soils during the growing season in order to identify, develop and improve mitigation options.

The objectives of this study were (i) to determine the N_2O emission reduction potential of several N fertilization options in irrigated potato production, (ii) assess the temporal fluctuations over the cropping season and spatial variability of N_2O emissions in hills and furrows within the potato management zone, and (iii) to evaluate the effects of the several N fertilizer formulations on potato productivity and N utilization.

Materials and methods

Site Description

Field experiments were conducted during the growing seasons of 2017 and 2018 near Lethbridge (49° 41' 12.12" N, 112° 44' 41.64" W) and Brooks (50° 32' 60" N, 111° 50' 60" W), Alberta, Canada. Soil classifications are Dark Brown Chernozem for Lethbridge and Brown Chernozem for Brooks. Initial soil properties of the 0-15 cm depth increment were pH of 7.6 and 7.8 (1:5 soil: water), electric conductivity of 0.50 and 0.62 dS m^{-1}, total organic carbon content of 14±0.7 and 10±0.9 g C kg^{-1}, and a total N content of 1.4±0.1 and 1.1±0.1 g N kg^{-1} for Lethbridge and Brooks, respectively. Organic C and total N were measured via dry combustion method (Li et al., 2018). Both sites were characterized with a sandy clay loam soil texture as measured with the hydrometer method.

Experimental Design

The experiments used a randomized complete block design with four replicates. Experimental plots had dimensions of 3.6 m wide and 9 m long for a plot area of 32 m^2. Blocks were separated from each other by a 4 m wide buffer zone.

Eleven experimental treatments were applied consistently within each of the four site-years in the study. The assessed treatments were: (1) control (no fertilizer or additives), (2) biostimulant (Eurochem Group, Mannheim, Germany) (no N fertilizer added), (3) granular urea (46% N), (4) urea + DMPSA (Eurochem Group, Germany), (5) urea + biostimulant, (6) urea + DMPSA + biostimulant, (7) ammonium sulfate nitrate (ASN) (26% N), (8) ASN + DMPSA, (9) ASN + biostimulant, (10) ASN + DMPSA + biostimulant, and (11) ESN 44% N (polymer coated urea) (Nutrien, Saskatoon, SK, Canada). The nitrification inhibitor DMPSA was admixed with urea and ASN a rate of 0.8 kg a.i. ha^{-1}. The biostimulant was surface sprayed at a rate of 2.5 L ha^{-1} and incorporated at the time of hilling.

All N fertilizer treatments were applied at the uniform rate of 200 kg N ha^{-1} yr^{-1}, which was 80% of the commercially-recommended rate based on soil sampling and N analyses. For all N fertilizer treatments with the sole exception of ESN, split N fertilization was conducted with 65% of the N at pre-planting and 35% as post-planting N at hilling operation. In the only case of ESN, all N was applied at pre-planting. Pre-planting N additions were applied and incorporated mechanically with a Conserva-Pak. Subsequently, a Russet Burbank potato cultivar was planted at a soil depth of 15 cm and four rows per experimental plot, with a 2-row Checci tuber-unit planter at Brooks and a 4 row cup planter at Lethbridge. Seed potato were planted at a rate of 1 Mg ha^{-1} with 0.9 m row spacing and 0.3 m seed spacing. Hilling operation was conducted with a mechanical power hiller. This hilling operation aims at preventing tuber greening as well as it facilitates weed control and subsequent potato harvesting. The fertilizer-N added at hilling was surface applied with a portable broadcasting device just prior to the mechanical hilling operation. Harvest was done with a one-row Grimme harvester. In both experimental years, tuber grading was done by weighing and separating tubers into the following mass categories of <113, 113-170, 170-284 and >284 g. All tubers >113 g were considered as marketable tubers. Water content in the potato tubers was measured by oven-drying samples.

Other fertilizers such as phosphorus (triple super phosphate), potassium, and sulphur were broadcasted and incorporated prior to planting at Lethbridge at a rate of 136 kg P ha^{-1}, 136 kg K ha^{-1}, and 18 kg S ha^{-1}, respectively. The Brooks site received broadcasted and incorporated phosphorus in the form of monoammonium phosphate (MAP).

Irrigation water was added to both study sites. This represents a common agronomic management as commercial potato crops in Southern Alberta can be grown only under irrigation. All experimental fields were irrigated via overhead low-pressure sprinklers. Irrigation water was sourced from the St. Mary's River Irrigation District near Lethbridge, and from the Eastern Irrigation District near Brooks. The frequency and amount of irrigation were based on evapotranspiration replacement and estimated by the Alberta irrigation management model (AIMM) − an evapotranspiration-based method of determining irrigation requirements.

Weeds, insects, and fungal diseases in the potato fields were controlled using recommended pesticides and rates.

In the first experimental year, the Lethbridge site received N fertilizer treatments on 8-9 May 2017, while fertilizer application at the Brooks site was on 23 May 2017. Planting took place on 10 and 26 May in 2017 at Lethbridge and Brooks, respectively. Post-planting N fertilizer addition and hilling operation were conducted on 31 May 2017 at Lethbridge and 8

June 2017 at Brooks. At the end of the growing season, potatoes were harvested on 27 and 29 Sept. 2017 at Lethbridge and Brooks, respectively.

For the second study year 2018, experimental plots were moved to a new adjacent location within a distance of 200 m. All fertilizer treatments and agronomic practices were conducted in 2018 in the same manner as in 2017. Pre-planting N fertilizers were applied on 8 and 15 May 2018 at Brooks and Lethbridge, respectively. Planting occurred on 17 and 25 May 2018 at Lethbridge and Brooks, respectively. Post-planting fertilization and hilling operation were conducted on 4 and 7 June 2018 at Lethbridge and Brooks, respectively. Potato was harvested mechanically on 26 and 28 Sept. 2018 at Lethbridge and Brooks, respectively.

Soil moisture and temperature was recorded every 30 minutes using dataloggers and sensors (5TM, Meter, Pullman, WA) at the soil depths of 10 and 22.5 cm in hills, and 7.5 and 22.5 cm in the furrow.

Nitrous oxide flux measurements

The N_2O fluxes at the soil surface were measured using a manual nonsteady-state closed chamber methodology (Lin et al., 2017; Thilakarathna et al., 2021). To capture N_2O emissions in the hills and furrows of the potato fields, sets of chambers were installed separately at potato hill and furrow positions. Within an experimental plot, one chamber base was placed in the potato hill, and one chamber in the furrow position. Chamber bases in the hills were installed in the middle potato rows and at a 7 cm soil depth after planting. Chamber bases were removed prior to post-planting fertilization and hilling operation as well as for potato harvesting and reinstalled immediately in the same locations.

We used circular chamber bases with 10 cm in height and 20 cm in inner diameter. Circular detachable chamber lids with 10 cm in height were used to generate a headspace for gas sample collection. Three gas samples of 20 mL were collected through a rubber septum port fitted in the chamber lid with a syringe. Gas samples were withdrawn at 11, 22, and 33 minutes following chamber enclosure. The collected gas samples were immediately injected into a 12 mL pre-evacuated glass vial (Exetainer, Labco, UK). To estimate the gas concentrations at time zero (Time 0), ambient air samples from outside of the headspace at chamber height were collected at the start, middle, and end of the sampling period.

Flux measurements were conducted weekly. Depending on the weather (e.g., heavy rainfall events) and farming activities (e.g., hilling, post planting fertilization), gas sampling frequency was increased to twice per week. On dates of gas sample collection, flux measurements were conducted between 1030 and 1430 h. On every sampling date during the growing season, we collected gas samples from chambers located in both hills and furrows. Post-harvest fluxes were measured from each experimental plot using one chamber per plot as there were no hills and furrows after potato harvesting.

In 2017, fluxes were quantified in all experimental treatments. Based on the flux results quantified in 2017, flux measurements in 2018 specifically focused in six selected experimental treatments − i.e., treatments 1, 3, 4, 7, 8, and 11 as listed above.

The N_2O concentration of gas samples were analyzed using an electron capture detector in a Varian 3800 gas chromatograph system (Varian Inc., Walnut Creek, CA) (Lin et al., 2017). The minimum analytical detectable concentrations was 10 ppb precision for N_2O (n= 30) (Lin and Hernandez-Ramirez, 2020). To further ensure quality control, the gas chromatography in each analytical run was calibrated with certified reference gases of N_2O with concentrations ranging from 0.25 to 4.84 $\mu L\ L^{-1}$ and N_2 as balance (Praxair Specialty Gases, Edmonton, AB). Fluxes were determined using the change of N_2O concentration over the 33-minute chamber enclosure period (with four gas sample collection times of 0, 11, 22, and 33 min) (Lin et al., 2017; Chai et al., 2020; Thilakarathna et al., 2021). Fluxes were estimated via fitting linear or quadratic relationships basis of the highest coefficient of determination (R^2) and the lowest p-value. An alpha critical value of 0.20 was used to determine the non-significant fluxes, which were retained in the data set. The N_2O flux was calculated as:

$$N_2O\ Flux = \frac{S \times P \times V}{R \times T \times A} \qquad [1]$$

The N_2O flux is the flux rate of N_2O (μmol m^{-2} min^{-1}), S is the slope of the line from either the simple linear regression or the first-order derivative at Time 0 from the quadratic curve (μL L^{-1} min^{-1}), P is the gas pressure (Pa), V is the volume of the chamber (L), A is the surface area of the chamber (m^2), R is the gas constant (Pa μL K^{-1} $μmol^{-1}$), and T is the temperature of the gas (K) (Thilakarathna et al., 2021).

The cumulative N_2O emissions for each growing season were calculated using simple linear interpolations of the time series of flux measurements. The integration of fluxes from hills and furrows into a flux representative of the whole management zone in potato was done by averaging the N_2O emissions from hills and furrows. This accounts for 50% of the potato fields being represented by flux measurements taken in the potato hills and with the other 50% of the field area corresponding to furrows.

Area-based emission factors (EF_{area}) are the percentages of N applied as fertilizer emitted as N_2O-N and calculated accounting for baseline N_2O-N emissions from the control plot within each experimental block in every site-year as follows:

$$EF_{area} = \frac{(N_2O\ treatment - N_2O\ control)}{fertilizer\ applied} * 100 \qquad [2]$$

For comparison purposes, N_2O EF were also estimated as a function of total water addition of rainfall and irrigation based on the exponential equation postulated by Rochette et al. (2018) and Liang et al. (2020) as follows: N_2O EF % = $e^{(0.00558 \times H2O - 7.701)} \times 100$.

Soil N measurements

Composite baseline soil samples (four cores per block replicate) were collected from the depth increments of 0-15, 15-30, 30-60, and 60-90 cm prior to the beginning of the growing season. Baseline soil samples were analyzed for ammonium and nitrate concentrations. These baseline N results were taking into consideration when establishing the N fertilization rate.

To capture N transformations and changes in ammonium and nitrate concentrations during the growing seasons, soil samples were repeatedly collected from the 0 to 15 cm depth increments with a push probe (2.5 cm inner diameter). From each plot, composite samples (n= 3) were collected separately from potato hills and furrows.

All soil samples were air-dried, ground, and passed through a 2 mm sieve. A 5 g subsample was extracted with 50 mL of 2 M KCl (1:10 soil:extractant) with 30 minutes of horizontal reciprocal shaking. The concentrations of NO_3–N and NH_4–N were measured colorimetrically on a SmartChem discrete wet chemistry analyzer (Westco Scientific Instruments Inc., Brookfield, CT).

Plant N measurements

Similar to soil samples, potato petiole samples were also collected and analyzed for nitrate concentration to examine the plant N status throughout the growing season. In 2017, field sample collections of both soils and petioles from each experimental plot were performed on 12 July, 3 and 17 of Aug. at Brooks, and on 28 June, 17 July and 8 Aug. at Lethbridge. In 2018, soils and petioles were collected on 6 and 24 July and 15 Aug at Brooks, and on 26 June, 17 July and 7 Aug. at Lethbridge.

Petioles were collected from the fourth leaf from the growing tip of the potato plants. During field collection of petiole samples, the corresponding leaflets were removed. Petiole tissue samples were kept in a cooler on ice until delivered to the analytical laboratory within 24 h of sample collection. Petioles were oven dried at 55°C to determine the dry matter content. Samples were ground with a Wiley grinding mill, and N concentrations in the petiole were measured using a nitrate-ion specific electrode (Vitosh and Silva, 1994). Results were expressed as mg nitrate-N per kg dry matter (DM) petiole tissue.

Composite samples of aboveground whole plants were collected from each experimental plot immediately prior to harvest, and subsequently oven dried, weighted and ground. A subsample of plant material was analyzed by total Kjeldahl N digestion-distillation-titration method. Eight marketable potato tubers were randomly collected after grading, hand-washed and diced using a Hobbart commercial mixer with a dicing attachment. A subsample of diced tubers was freeze dried and ground before conducting total N analyses. N uptake in potato tubers and canopy were determined as the product using DM and N content data.

Yield-based emission factors (EF_{yield}), which is growing-season N_2O emission per kg of potato tuber, were estimated (Chai et al., 2020; Thilakarathna et al., 2021). The partitioning of DM and N between tubers and aboveground canopy was calculated as harvest index (HI) and N harvest index (NHI), respectively (Geremew et al., 2007; Hernandez-Ramirez et al., 2011). Since the parameters of marketable yield can vary between geographic regions worldwide, NUE, HI, NHI and EF_{yield} calculations were done based on the total tuber yield (Milroy et al., 2019). The yield-based emission factor (EF_{yield}), fertilizer NUE, HI, and NHI were determined as:

$$EF_{yield} = \frac{N_2O\ treatment}{Tuber\ yield} \quad [3]$$

$$Fertilizer\ NUE\ = \frac{Tuber\ yield_{treatment} - Tuber\ yield_{control}}{N\ rate} * 100 \quad [4]$$

$$HI\ = \frac{Tuber\ yield\ DM}{Total\ biomass\ DM} \quad [5]$$

$$NHI\ = \frac{Tuber\ N}{Total\ biomass\ N} \quad [6]$$

Statistical analyses

All the data were tested for the assumptions of normality and homoscedasticity using the Shapiro-Wilk and Bartlett tests, respectively. Data was Box-Cox transformed when needed to meet the assumptions. The effects of the fertilizer treatment, hill vs. furrow positions and their interaction on N_2O emissions and soil available N was assessed using two-way analysis of variance (ANOVA). The treatment effects on cumulative N_2O emissions, potato tuber productivity, and petiole nitrate concentrations were tested using one-way ANOVA. Post-hoc tests were conducted with Tukey's Honest Significant Difference (HSD). Simple regressions were performed to assess the strength of relationships between soil available N and petiole N. All statistical analyses were conducted with SigmaStat (4.0) software at an alpha critical level of 0.05.

Results

Heat and water inputs over the growing seasons

The thirty-year normal mean air temperature for May to September (growing season) at Lethbridge and Brooks are 14.9 ^{o}C and 15.2 ^{o}C, respectively. During the growing season of May-September 2017 and 2018, the average monthly air temperature in both study sites were slightly greater than the thirty-year normal monthly averages (Fig. 1).

Lethbridge and Brooks have a thirty-year normal total growing season (May to September) precipitations of 252 mm and 211 mm, respectively. The distribution of precipitation differed between the years 2017 and 2018. In 2017, May and June received high rainfall at both sites whereas throughout July-September the sites experienced lower precipitation (Fig. 1). Moreover, during the growing season 2018, overall precipitation was lower than normal.

The Lethbridge site received 368 mm of irrigation water in 2017 and 379 mm in 2018. The amount of irrigation for the Brooks site were 366 mm in 2017 and 322 mm in 2018. It is noted that the Lethbridge site received more irrigation and total water input (i.e., rainfall + irrigation) in comparison to the Brooks (Table 1).

Based on heat units available for potato growth within the two growing seasons during the study, potato physiological days (P-Days) at Lethbridge in 2017 and 2018 were 911.9 and 917.4, respectively. The Brooks site received 895.2 of P-Days in 2017 and 859.4 in 2018.

Daily and growing-season N_2O emissions in response to N additions

In both years (2017 and 2018) and experimental sites (Lethbridge and Brooks), episodes of N_2O emissions occurred after pre-planting fertilizer and post-planting fertilizer applications (Fig. 2E, Fig. 2F, Fig. 3E, and Fig. 3F). The magnitude of the N_2O emission peaks in response to the pre-planting fertilizer application was greater than after the post-planting fertilizer addition. Furthermore, the N_2O emission peaks following the post-planting N addition were more evident in the furrow positions than in the potato hills. The urea alone treatment displayed the highest fluxes in the hill position at both experimental sites. At Lethbridge, on 24 May 2018, the N_2O flux from the urea alone treatment in the hill position was significantly greater than the control, urea + DMPSA, ASN + DMPSA, and ESN treatments ($P< 0.011$) (Fig. 2E and Fig. 2F). On 7 June 2018, at Lethbridge, we also observed significantly higher emissions from the urea alone treatment over the control treatment by 6-fold ($P< 0.031$) (Fig. 2E and 2F). Likewise, the urea alone treatment exhibited an elevated N_2O flux at Brooks on 20 June 2018 that was significantly greater than the control, urea + DMPSA, ASN, and ASN + DMPSA treatments ($P< 0.007$) (Fig. 3E and Fig. 3F). Even though no statistically significant difference was detected, N_2O emissions from the urea + biostimulant treatment were noticeably elevated on 6 June 2017 in both the hill and furrow positions at Lethbridge.

The application of urea largely increased the growing-season cumulative N_2O emissions regardless of the study site (Fig. 4). In the hill positions at the Lethbridge site, the mean cumulative N_2O emissions from the urea treatment (289 g N_2O-N ha^{-1}) were significantly greater than the control treatment (101 g N_2O-N ha^{-1}) ($P < 0.015$). In 2018, the highest cumulative N_2O emissions at Brooks were observed in the urea treatment (352 g N_2O-N ha^{-1}), which was significantly greater than all the other N treatments in the hill position ($P < 0.001$). In the furrow position, N_2O emissions from ASN (186 g N_2O-N ha^{-1}) were 3.8 times greater than the control treatment (46 g N_2O-N ha^{-1}) ($P < 0.032$) (Fig. 3). It is noticeable that significant higher N_2O emissions were observed from the furrow position in comparison to the hill position at Lethbridge, reporting 3.2 times greater emissions in 2017 and 1.7 times greater in 2018 (Fig. 4). There were no significant differences between the hill or furrow positions at Brooks.

The average growing-season cumulative emissions across all treatments in the Lethbridge site was 578 g N_2O ha^{-1} in 2017 and 256 g N_2O ha^{-1} in 2018. The mean cumulative emissions for the Brooks site was 94 g N_2O ha^{-1} in 2017 and 165 g N_2O ha^{-1} in 2018. The mean cumulative emissions for all treatments were significantly different between the two experimental years at both sites. In 2017 at the Lethbridge site, the average growing-season cumulative emission of all treatments were significantly higher than in 2018 ($P < 0.001$), whereas opposite results were observed for the Brooks site (2017 < 2018) ($P < 0.001$). When N_2O emissions in both experimental years were averaged across experimental sites, the mean cumulative N_2O emissions at Lethbridge were higher than at Brooks ($P < 0.001$).

Area- and yield-based N_2O emission factors

Across N fertilizers, experimental years and sites, the area-based emission factors (EF_{area}) were consistent and low, with an overall average of 0.056 % and with treatment means ranging between -0.079 and 0.100 % kg N_2O-N kg^{-1} N fertilizer (Table 2). During the experimental year 2017, all N fertilizer treatments in the Lethbridge site exhibited a high EF_{yield}, which differed significantly across experimental years and sites ($P< 0.05$) (Table 2).

Nitrogen dynamics in soil solution and plant tissues

Available soil N (NH_4 + NO_3) became high with the pre-planting fertilization and decreased over the growing season (Fig. 2C and Fig. 3C). Even though higher N_2O fluxes were observed at Lethbridge furrow positions than hill positions, no significant differences were found in available N between hill and furrow positions. Comparing the two study sites, overall available N concentrations trended higher at Lethbridge than at Brooks.

Similar to available soil N, petiole nitrate concentrations for all treatments gradually declined over the growing season (Fig. 2D and Fig. 3D). As expected, the control treatment had the lowest petiole nitrate concentrations in all four site-years. At Brooks-2018, petiole nitrate concentrations were significantly higher in the urea, ASN, and ESN treatments than the unamended control ($P< 0.001$) (Fig. 3D). Likewise, at Brooks-2017, several fertilized treatments had significantly greater petiole nitrate than the control and biostimulant alone treatments in the first (i.e., urea, urea + biostimulant, urea + DMPSA + biostimulant, ASN, and ASN + DMPSA) and second (i.e., urea + DMPSA, urea + biostimulant, ASN, and ESN) sample collections over the growing season ($P< 0.001$). Petiole nitrate concentrations in 2018 at Lethbridge were overall significantly greater than in 2017 ($P< 0.001$) (Fig. 2D). Overall, petiole nitrate concentrations at Lethbridge were greater than at Brooks. At Brooks, the nitrate concentrations in potato petiole at the first tissue sample collections (early July) in 2017 and 2018 were similar; however, the N decline between second and third tissue sample collections was more pronounced in 2018 than in 2017 ($P< 0.001$). At the third petiole sample collection date within the two growing seasons, the range of nitrate concentrations showed a significant difference between 2017 (3000-8000 mg N kg^{-1}) and 2018 (250-3000 mg N kg^{-1}).

Since soil available N and petiole N both declined over the growing season (Fig. 2 and Fig. 3), their inter-relationship was evaluated. Significant linear regressions were found between soil available N (ammonium plus nitrate) and petiole nitrate concentration for each of the four site-years in our study ($P< 0.001$) (Fig. 5).

Within each experimental site and year, total N contents (%) in tuber and canopy at potato maturity stage were not statistically different across N treatments (Table 3). At the Lethbridge site, N in both canopy and tuber were significantly different between experimental years (2017 vs. 2018) ($P< 0.001$), where tuber N concentration was lower and canopy N concentration was higher in 2018 than in 2017.

Potato productivity, NUE, N uptake, HI and NHI

In all experimental sites and years, both urea with DMPSA and ASN generated the highest total and marketable tuber yields while the control and biostimulant treatments resulted in the lowest (Table 4). The mean tuber mass of both ASN and ESN treatments (193 g) at the Lethbridge site in 2018 were significantly greater than the ASN + biostimulant (162 g). The N fertilizer sources did not significantly affect total yield, marketable yield, or specific gravity; except for the above noted differences in mean tuber mass in Lethbridge-2018 (Table 4).

Among year comparisons, potato productivity at both sites were numerically greater in 2018 than in 2017. Statistically significant differences in mean total yield and marketable yield at Brooks were observed between 2018 (57 Mg ha^{-1}, 38 Mg ha^{-1}) and 2017 (77 Mg ha^{-1}, 64 Mg ha^{-}

^{1}), respectively ($P < 0.001$) (Table 4). When comparing the two experimental sites, the mean total yield in 2017 and marketable yield in 2018 were significantly greater at Brooks than at Lethbridge ($P < 0.001$).

The total N uptake, encompassing both tuber-N and canopy-N, differed across treatments in one of the four site-years. In Brooks-2018, urea + DMPSA resulted in a much greater total N uptake than that of biostimulant alone treatment (i.e., 407 vs. 293 kg N ha^{-1}; Table 5). Across the four site-years, potato tuber N uptake at harvest average 181 ± 6 kg N ha^{-1} yr^{-1}, which is comparable to the applied rate of N fertilizer (i.e., 200 kg N ha^{-1} yr^{-1}).

The estimates of NUE, HI and NHI in our study showed no significant effects across fertilizer treatments (Table 6). Overall, NUE varied between experimental years at Lethbridge (2017 < 2018) and between sites in 2017 (Lethbridge < Brooks) ($P < 0.001$). The treatment means of HI and NHI ranged from 0.55 to 0.71 and 0.41 to 0.67, respectively (Table 6).

Discussion

Impacts of N fertilization options on N_2O emissions

Major N_2O effluxes following N fertilizer addition in our study showed that the availability of soil N strongly influences the occurrence of peak N_2O emissions, which is consistent with previous studies (Burton et al., 2008; Gao et al., 2013). Most of these earlier studies evaluated only the influence of conventional fertilizers such as urea on N_2O emissions. Hutchinson et al. (2003) assessed the effect of ammonium nitrate (AN), urea, sulfur-coated urea and PCU on potato, but they focused only on the influence of these N sources on N use efficiency. Perron et al. (2019) measured denitrification rate from irrigated potato production on a coarse-textured soil in Eastern Canada when using fertilizers such as ammonium sulfate, AN and PCU. Our study documents, for the first time in the literature, how alternative N fertilizer formulations such as granular ASN and the novel DMPSA inhibitor impacts both N_2O fluxes and productivity in potato fields. When focusing on mitigation of N_2O emissions, the fact that the DMPSA inhibitor admixed with granular urea resulted in N_2O emissions comparable in magnitude with the emissions from unfertilized fields, and also much lower than in fields receiving urea alone supports the effectiveness of this new inhibitor formulation (Table 2, Fig. 4D). In one of the four site-years at Brooks-2018, DMPSA reduced the N_2O emissions from urea-amended fields by 57% (Table 2, Fig. 4D). Thilakarathna and Hernandez-Ramirez (2021) asserted that DMPSA effectively delivers emission reductions, conserves N in the soil, and inhibits the first enzymatic step of nitrification in part because the presence of the succinyl group in DMPSA decreases molecule volatility and extends its activity (Lin and Hernandez-Ramirez, 2020; Thilakarathna and Hernandez-Ramirez, 2021).

Among the different fertilizer treatments, both urea and ASN were applied with and without additives in this study. Overall, the urea treatment showed more N_2O emissions than the ASN treatment. Urea alone treatment resulted in greater concentrations of available N in both the soil solution and plant petioles in comparison to ASN (Fig. 2C and Fig. 2D). Van Groenigen et al. (2010) and Chai et al. (2020) concurrently reported that N surpluses can raise N_2O emissions by generating a higher risk for N losses. Although the mitigating effects of DMPSA were not always evident, using DMPSA admixed with either urea or ASN tended to reduce overall N_2O emissions.

Previous studies have shown the beneficial role of ESN in enhancing potato yield and simultaneously reducing N_2O emissions (Gao et al., 2015; Ghosh et al., 2019; Hutchinson et al., 2003). In contrast, some studies showed no significant reduction of N_2O emissions and yield improvement when using ESN (Gao et al., 2017; Zebarth et al., 2012). In our study, even though

N_2O emissions from ESN were not statistically different from other treatments, the magnitude of N_2O emissions from the furrows in 2017 at Lethbridge was considerably high. The N released from ESN involves movement of soil water to the fertilizer granule, dissolution of urea inside the ESN granule, and diffusion of urea-N to the soil solution. In other words, the role of ESN in minimizing N_2O emissions and enhancing NUE is highly regulated by soil moisture fluctuations (Thilakarathna et al., 2021). Sharp moisture increases in the furrows following a major rainfall or irrigation event can contribute to high N_2O fluxes in Lethbridge as triggered by higher soil moisture. The ESN in our study was also applied all as a single pre-planting fertilizer application, which may have resulted under certain cases in no significant reduction of N_2O emissions and null yield improvement by ESN. Hence, future research could evaluate the responses of coated N fertilizers applied at the emergence of potato seedlings instead of full applications at pre-planting.

Our field data provide regional N_2O EF_{area} for potato crops under a broad range of N fertilizer formulation options (Table 2). Thilakarathna et al. (2021) reported EF_{area} for numerous fertilizer formulations in spring wheat fields fertilized at 100 kg N kg^{-1} in Central Alberta. Their study estimated mean EF_{area} of 0.31% while accounting for the whole annual cycle. In the present study, EFs were much lower than reported by both Thilakarathna et al. (2021) and Chai et al. (2020) based on EF_{area} calculated encompassing flux measurements during the potato growing seasons (i.e., ~May to October). It is noted that the relatively elevated cumulative N_2O emissions from our control plots were also drivers of the low growing-season EF_{area} found in the present study, which averaged 0.056 % (Table 2). By contrast, based on estimations of EF using an exponential equation model proposed by Rochette et al. (2018) and Liang et al. (2020), the growing-season 2-year mean N_2O EF as a function of total water addition (rainfall + irrigation) resulted in 0.77% and 0.60% at Lethbridge and Brooks, respectively (Table 1). In comparison to our study, Chai et al. (2020) recently reported a lower estimate of N_2O EF (0.41%) as a function of total water input in irrigated wheat and canola sites also located in Lethbridge. Essentially, irrigations of 373 mm in Lethbridge and 344 mm in Brooks (Table 1) are much higher than the 162 mm irrigation used by Chai et al. (2020). Compared to other irrigated crops such as wheat and canola, irrigated potato soils can stay relatively wetter over longer periods – a condition known to be conducive to increase N_2O production (Roman-Perez and Hernandez-Ramirez, 2021; Thilakarathna et al., 2021).

Distinct microenvironments between hills and furrows within potato fields affect N_2O emissions (Burton et al., 2008). In our study, calculations of EFs for hill and furrow positions separately (data not shown) further showed that emissions from furrows (e.g., Lethbridge-2017; Fig. 4) were the main contributors to high EFs. This clearly indicated the need of implementing management practices targeted at mitigating these hot spots of N_2O emissions from the furrows.

In potato production, the in-crop hilling operation is done to further provide loosened and well aerated soils for better tuber growth, tuber greening prevention by covering from sunlight, weed control, and to subsequently facilitate potato harvesting (Gao et al., 2013). Additionally, hilling can also cause the formation of differential microsites within potato fields (i.e., hills vs. furrows within the crop management zone). These differences between hills and furrows include soil bulk density, aeration, water-filled pore space, C and N concentrations, microbial communities, and N_2O production processes (Zebarth and Milburn, 2003). Greater N_2O emissions observed from furrows at Lethbridge can be primarily associated with denitrification source. Water from rainfall and irrigation accumulates more in furrows than in potato hills (Harms and Konschuh, 2010). Broadcast N fertilizer enters furrows as well as N runoff from hills. The water and N accumulation in furrows can be further enhanced by the low uptake of water and N from the furrows by potato plants as the root systems are mainly concentrated in the hills. It is postulated that precise placement of pre-plant N fertilizer localized only where potato hills would be formed can increase N utilization by plants and probably reduce losses to the environment. This hypothesis requires further field testing.

In comparison to Brooks, Lethbridge soils have greater C and N substrates (10 ± 0.9 vs. 14 ± 0.7 g C kg^{-1} soil, and 1.1 ± 0.1 vs. 1.4 ± 0.1 g N kg^{-1}, respectively). This different across sites in soil organic C and N concentrations can imply greater mineralization of organic matter and associated N, leading to increased background N in Lethbridge soils, which likely contribute to overall N_2O production over the growing seasons (Daly and Hernandez-Ramirez, 2020; Roman-Perez and Hernandez-Ramirez, 2021). When C and N are available simultaneously in hypoxic furrows, greater fluxes of N_2O can be produced due to denitrification (Smith et al., 1998; Thilakarathna and Hernandez-Ramirez, 2021). When comparing the two experimental sites, C availability could become a limiting factor for N_2O production from furrows at Brooks. When a soil is characterized by relatively lower C, the potato rhizosphere in the hills, being an important C source in the hills in comparison to the furrows, can enhance the N_2O production from hills via heterotrophic denitrification. Furthermore, it is possible that any produced N_2O can easily escape from the hills because mechanical soil loosening had temporally improved porosity and pore connectivity (Burton et al., 2008).

Our experiment examined a biostimulant that contained primary N-fixing microorganisms (*Azotobacter vinelandii* and *Clostridium pasteurianum*) as well as secondary microbes (e.g., *Nitrosomonas, Nitrobacter, Nitrococcus, Rhizobium*) with the aim of raising soil N availability, root growth and plant uptake. These putative effects were collectively expected to increase plant productivity, which was not found in our study. Moreover, it was observed that the biostimulant alone as well as the biostimulant in combination with urea or ASN had overall no effect on N_2O emissions. However, in certain cases, these biostimulant treatments even seemed to increase N_2O emissions numerically. For instance, this was noted when comparing cumulative fluxes from biostimulant-urea vs. urea alone. This finding is in line with Souza et al. (2019) who reported increased N_2O emissions in potato fields that had received additions of an N-fixing biostimulant. Additionally, when a biostimulant is applied in fields that also receiving urea additions, the production of toxic NH_3 from urea hydrolysis can detrimentally impact inoculated microbes (Calvo et al., 2013; Calvo et al., 2014). These earlier studies had actually shown a beneficial role of certain biostimulants that contained phenolic compounds in minimizing N_2O emissions when applied specifically with urea-ammonium nitrate (Calvo et al., 2013; Calvo et al., 2014); however, this effect was absent in our study. Furthermore, potato production systems are characterized by high input, productivity, nutrient extraction, and soil disturbance. Therefore, these soils under potato cropping can have a distinct microbial community that has been selected and trained over time to these unfavorable, fluctuating conditions. Adapting rapidly to such adverse environment can be a challenge for the microbes present in applied biostimulants.

Potato productivity as a function of N fertilization choices

This study found that marketable yield of potato was equally enhanced by both ASN admixed with DMPSA and ESN fertilization options, with 36% consistently higher productivity than the unfertilized fields in one of the four site-years (i.e., Lethbridge-2018; 45 vs. 33 Mg ha^{-1}, Table 4). The fact that these two fertilizer alternatives to using urea alone resulted in this coherent productivity advantage is insightful for enhancing N management in potato. For several practical reasons, granular is the most commonly used N fertilizer across Western Canada

(Guenette et al., 2019; Thilakarathna et al., 2021), and hence, this represents an opportunity to enhance potato productivity regionally, with a 25% likelihood based on the four available site-years in our study.

Even though the potato cultivar and seed source were the same at both study sites, we initially expected higher yields from Lethbridge than Brooks. The seeding of potato in Lethbridge took place earlier than Brooks, and Lethbridge also experienced a growing season with more cumulative physiological growing degree days (P-Days). Differences in environmental conditions and soils as noted above can have caused variations in potato productivity between the four experimental site-years in our study. For instance, the Lethbridge site contained high concentrations of organic matter as noted above, which may have also generated additional N mineralization and availability.

In 2017, the marketable yields from both sites were similar. Total yield is in part the reflection of the capacity of the mechanical harvesting equipment to pick up undersized tubers. Different harvesters were used at the two experimental sites in 2017. The harvester used at Lethbridge may have left more small tubers in the field relative to Brooks, which likely resulted in a lower total yield at Lethbridge. In 2018, due to the previous observation of leftover tubers in the field in 2017, tubers missed by the mechanical harvester at both sites were collected by hand to assure improved accountability of potato productivity during the experimental year 2018.

Biomass production, accumulation and partitioning of crops depend on multiple factors such as the cultivar, air temperature, availability of water and nitrogen, and photoperiod (Geremew et al., 2007; Hernandez-Ramirez et al., 2011). In our study, overall potato DM partition to tubers averaged 63%, ranging from 55% to 71% (Table 6). These results were slightly lower than HIs previously reported by Bélanger et al. (2001) who found HIs between

0.62 and 0.77 for potato crops receiving 250 kg fertilizer-N ha^{-1} across varying genotypes and irrigation managements.

In general, potato N use-efficiencies were 3 % of applied fertilizer-N at Lethbridge and 7 % at Brooks. The NUE calculations in our study involved the subtraction of potato productivity from the control in the N fertilizer treatment. The low NUE results observed across the four site-years can be explained by the high total tuber yield measured in the unfertilized control fields. More specifically, focusing on the overall lowest NUE result of -0.13 % at Lethbridge-2017 (Table 4), the total tuber yield of the control fields was greater than total tuber yield of most fertilizer treatments, which also indicates greater availability of mineralized N in the Lethbridge soils as noted above.

Plant petioles store and transport nitrate (Vitosh and Silva, 1994). Petiole nitrate analysis has proven to be a sensitive indicator of potato N status temporally throughout the growing season (Meyer and Marcum, 1998). Similar to previous studies, petiole nitrate in our two experimental sites during both years were highest in the early growing season and gradually declined thereafter. High petiole nitrate concentrations in the beginning of the growing season can be caused by the accumulation of soluble N in the haulm prior to potato tuberization. The rapid decrease of petiole N later over the growing seasons indicated the translocation and redistribution of accumulated N as both tuber formation and size expansion gradually become larger N sinks within the plants (Porter and Sisson, 1993). In our study, petiole nitrate concentrations increased in response to N fertilization, which provides evidence for the availability of broadcast-incorporated N in the root zone. Variation of petiole nitrate concentrations across the study sites can indicate the difference in soil and weather conditions among sites to supply available N. It became clearly evident that high N availability in these soils results in greater petiole nitrate concentrations based on established relationships (Fig. 5).

Conclusion

Urea alone typically resulted in the highest N_2O fluxes. This finding is concerning because urea is the most common N fertilizer used in potato production, and also overall within Western Canada across all cropping systems. Nevertheless, the results from our study further showed that DMPSA inhibitor admixed with either granular urea or ASN can effectively reduce N_2O emissions while maintaining potato tuber yield. This supports a change towards improved recommendations in fertilization management. The increased N_2O emissions associated with C and N rich soils and likely-hypoxic furrows suggest that irrigation water can be managed more precisely to minimize water accumulation in furrows, perhaps through localized and variable rate irrigation. Also, more water infiltration into the potato hill can be hypothetically increased by altering hills from the standard round shape into a flat-topped design. By comprehensively assessing the effect of N fertilizer options on N_2O emissions, N dynamics in soil solution and plant tissues, as well as potato productivity and NUE, the present study offers insights and inclusive recommendations for better management of recurrent N fertilization.

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Table 1. Estimated N_2O EF as a function of total water addition of rainfall and irrigation based on exponential equation N_2O EF % = $e^{(0.00558 \times H2O - 7.701)} \times 100$ (Rochette et al., 2018; Liang et al., 2020).

	Lethbridge			Brooks		
Water addition	2017	2018	2-yr mean	2017	2018	2-yr mean
May to Oct						
Rainfall (mm)	175	150	163	148	127	138
Irrigation (mm)	368	378	373	366	322	344
Rainfall + irrigation (mm)	543	529	536	514	450	482
EF_{H2O} (% kg N_2O-N kg^{-1} fertilizer)	0.936	0.865	0.901	0.798	0.557	0.677
May to Sep						
Rainfall (mm)	128	136	132	120	117	118
Irrigation (mm)	368	379	373	366	322	344
Rainfall + irrigation (mm)	496	515	506	486	439	462
EF_{H2O} (% kg N_2O-N kg^{-1} fertilizer)	0.719	0.801	0.760	0.680	0.525	0.602

Table 2. Cumulative growing season N_2O emissions (g N_2O-N ha^{-1}), area-based N_2O emission factors (EF_{area}) (% kg N_2O-N kg^{-1} N fertilizer) and yield-based emission factors (EF yield) (g N_2O-N Mg^{-1} tuber) of potato fields at Lethbridge and Brooks during 2017 and 2018. SE stands for standard error of the means (n= 4).

N treatment	Cumulative N_2O emissions (g N_2O-N ha^{-1})				EF_{area} (% kg N_2O-N kg^{-1} N fertilizer)				EF yield (g N_2O-N Mg^{-1} tuber)			
	Lethbridge		Brooks		Lethbridge		Brooks		Lethbridge		Brooks	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Control	515	208	85	64a§					11.045	3.705	1.641	0.945a
Biostimulant	543	n.d.	73	n.d.	-0.018	n.d.	-0.011	n.d.	11.025	n.d.	1.449	n.d.
Urea	623	279	87	256c	0.023	0.020	-0.004	0.010b	13.782	5.105	1.550	3.098b
Urea + DMPSA †	778	252	85	154a	0.100	-0.001	-0.005	-0.009a	14.454	4.539	1.592	1.774ab
Urea + Biostimulant	544	n.d.	131	n.d.	-0.017	n.d.	0.018	n.d.	11.605	n.d.	2.278	n.d.
Urea + DMPSA + Biostimulant	588	n.d.	85	n.d.	0.005	n.d.	-0.005	n.d.	12.241	n.d.	1.448	n.d.
Ammonium sulfate nitrate (ASN)	443	241	85	171b	-0.067	-0.006	-0.005	0.003ab	9.232	4.363	1.544	2.412ab
ASN + DMPSA	420	260	76	168b	-0.079	0.002	-0.009	0.002ab	9.085	4.333	1.297	1.971ab
ESN‡ (polymer coated urea)	745	296	143	192b	0.084	0.012	0.024	0.040ab	15.373	5.077	2.574	2.310ab
Overall mean ± SE	578±96	256±41	94±27	165±16	0.004±0.05	0.006±0.01	0.001±0.01	0.009±0.008	11.982±2.39	4.683±0.538	1.708±0.532	2.313±0.327
ANOVA P-value												
N treatment	0.300	0.726	0.557	0.001	0.209	0.820	0.460	0.031	0.573	0.110	0.719	0.008

§ Differences across treatments, indicated by different lowercase letters, were determined via Tukey's Honest Significant Difference after significant ANOVAs at the alpha critical level of 0.05.

† DMPSA stands for 2,4-dimethylpyrazol succinic acid.

‡ ESN stands for Environmentally Smart N.

Table 3. Potato tuber and canopy total N concentration at maturity at Lethbridge and Brooks in 2017 and 2018. SE stands for standard error of the means (n= 4).

N treatment	Lethbridge				Brooks			
	2017		2018		2017		2018	
	Tuber N (%)	Canopy N (%)	Tuber N (%)	Canopy N (%)	Tuber N (%)	Canopy N (%)	Tuber N (%)	Canopy N (%)
Control	1.58	1.61	0.83	2.00	1.30	1.59	1.36	1.61
Biostimulant	1.73	1.45	1.03	1.97	1.40	1.58	1.20	1.61
Urea	1.74	1.74	1.07	2.17	1.48	1.75	1.24	1.51
Urea + DMPSA †	1.66	1.62	0.98	2.17	1.45	1.70	1.27	1.67
Urea + Biostimulant	1.76	1.54	0.89	2.06	1.49	1.86	1.16	1.60
Urea + DMPSA + Biostimulant	1.66	1.73	1.07	1.87	1.39	1.86	1.25	1.66
Ammonium sulfate nitrate (ASN)	1.80	1.62	0.92	2.23	1.46	1.70	1.32	1.75
ASN + DMPSA	1.61	1.65	1.07	2.11	1.53	1.84	1.27	1.46
ASN + Biostimulant	1.57	1.52	1.14	2.07	1.37	1.80	1.24	1.51
ASN + DMPSA + Biostimulant	1.65	1.64	0.86	2.01	1.44	1.85	1.30	1.62
ESN ‡ (polymer coated urea)	1.61	1.57	0.99	2.14	1.51	1.85	1.30	1.76
Overall mean ± SE	1.67±0.07	1.61±0.08	0.98±0.09	2.07±0.11	1.44±0.09	1.76±0.11	1.27±0.07	1.61±0.12
ANOVA P-value								
N treatment	0.244	0.438	0.302	0.494	0.780	0.455	0.726	0.741

† DMPSA stands for 2,4-dimethylpyrazol succinic acid.

‡ ESN stands for Environmentally Smart N.

Table 4. Total yield mean tuber mass and specific gravity of potatoes harvested from experimental plots at Lethbridge and Brooks grown with alternative nitrogen fertilizer formulations in 2017 and 2018. These are fresh potato weights. SE stands for standard error of the means (n= 4).

N treatment	Lethbridge								Brooks							
	Total yield (Mg ha^{-1})		Total marketable yield (Mg ha^{-1})		Mean tuber mass (g)		Specific gravity (g mL^{-1})		Total yield (Mg ha^{-1})		Total marketable yield (Mg ha^{-1})		Mean tuber mass (g)		Specific gravity (g mL^{-1})	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Control	49	50	39	33b§	195	167ab	1.082	1.092	54	69	30	51	187	196	1.098	1.098
Biostimulant	48	53	36	34ab	201	170ab	1.083	1.093	51	68	30	53	191	198	1.095	1.097
Urea	46	53	37	39ab	209	181ab	1.082	1.094	58	80	41	69	206	230	1.098	1.088
Urea + DMPSA†	54	54	45	40ab	213	176ab	1.083	1.088	56	83	37	72	194	224	1.101	1.090
Urea + Biostimulant	47	54	38	41ab	208	184ab	1.083	1.094	57	82	41	71	200	230	1.096	1.092
Urea + DMPSA + Biostimulant	51	54	40	38ab	202	176ab	1.084	1.092	59	77	38	64	208	232	1.095	1.090
Ammonium sulfate nitrate (ASN)	48	54	38	41ab	194	193a	1.083	1.093	57	71	39	59	204	218	1.095	1.093
ASN + DMPSA	47	58	37	45a	203	184ab	1.079	1.089	60	84	39	69	196	218	1.092	1.091
ASN + Biostimulant	50	56	43	42ab	222	162b	1.085	1.095	57	75	43	64	215	232	1.097	1.088
ASN + DMPSA + Biostimulant	50	57	38	41ab	197	167ab	1.085	1.091	62	76	43	65	219	221	1.093	1.090
ESN‡ (polymer coated urea)	52	58	43	45a	214	193a	1.083	1.091	57	78	40	67	202	227	1.095	1.093
Overall mean ± SE	49±1	55±1	39±1	40±1	205±3	178±4	1.083±0.0005	1.092±0.0005	57±1	77±2	38±1	64±1	202±3	221±5	1.096±0.0007	1.092±0.0009
ANOVA P-value																
N treatment	0.829	0.434	0.730	0.017	0.593	0.005	0.146	0.271	0.645	0.234	0.329	0.490	0.258	0.690	0.217	0.201

§ Differences across treatments, indicated by different lowercase letters, were determined via Tukey's Honest Significant Difference after significant ANOVAs at the alpha critical level of 0.05.

† DMPSA stands for 2,4-dimethylpyrazol succinic acid.

‡ ESN stands for Environmentally Smart N.

Table 5. Potato tuber, canopy, and total N uptake at harvest at Lethbridge and Brooks in 2017 and 2018. SE stands for standard error of the means (n= 4).

N treatment	Lethbridge						Brooks					
	2017			2018			2017			2018		
	N canopy	N tuber	N uptake	N canopy	N tuber	N uptake	N canopy	N tuber	N uptake	N canopy	N tuber	N uptake
	------ kg N ha^{-1} ------											
Control	93	179	272	134	95	230	113	159	273	104	214	318 ab§
Biostimulant	100	192	293	132	125	257	165	167	332	107	186	293 a
Urea	91	184	275	175	133	308	152	194	345	165	228	394 ab
Urea + DMPSA†	113	206	288	153	122	275	128	189	317	164	243	407 b
Urea + Biostimulant	135	190	325	152	111	264	182	196	378	123	219	341 ab
Urea + DMPSA + Biostimulant	100	192	293	128	130	258	204	188	392	164	220	385 ab
Ammonium sulfate nitrate (ASN)	106	200	306	165	113	278	193	189	382	169	217	386 ab
ASN + DMPSA	102	177	278	167	143	310	229	210	439	136	243	379 ab
ASN + Biostimulant	90	178	267	138	147	285	162	181	343	125	213	337 ab
ASN + DMPSA + Biostimulant	126	187	312	174	112	285	207	205	412	144	230	374 ab
ESN‡ (polymer coated urea)	102	192	298	132	129	261	165	198	362	159	234	393 ab
Mean	105	189	291	150	124	274	173	189	361	142	222	364
S.E.	5	4	7	6	4	8	8	5	11	6	5	9
ANOVA P-value for N treatment	0.737	0.883	0.618	0.779	0.204	0.716	0.102	0.554	0.064	0.098	0.420	0.027

§ Differences across treatments, indicated by different lowercase letters, were determined via Tukey's Honest Significant Difference after significant ANOVAs at the alpha critical level of 0.05.

† DMPSA stands for 2,4-dimethylpyrazol succinic acid.

‡ ESN stands for Environmentally Smart N.

Table 6. Nitrogen use efficiency (NUE), dry matter harvest index (DM HI), and NHI partitioning of potato crops at Lethbridge and Brooks in 2017 and 2018. SE stands for standard error of the means (n= 4).

N treatment	NUE (kg total potato tuber kg^{-1} N fertilizer)				HI (kg tuber DM kg^{-1} tuber+canopy DM)				NHI (kg tuber N kg^{-1} tuber+canopy N)			
	Lethbridge		Brooks		Lethbridge		Brooks		Lethbridge		Brooks	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Control	--	--	--	--	0.66	0.64	0.64	0.71	0.66	0.42	0.60	0.68
Biostimulant	-1.19	2.93	-2.82	-0.96	0.62	0.65	0.60	0.70	0.66	0.49	0.50	0.64
Urea	-4.26	3.16	4.24	13.28	0.66	0.60	0.55	0.63	0.67	0.43	0.56	0.58
Urea + DMPSA†	5.32	4.63	1.88	16.43	0.63	0.64	0.57	0.67	0.63	0.44	0.59	0.61
Urea + Biostimulant	-2.75	4.63	3.71	15.40	0.58	0.63	0.57	0.71	0.59	0.42	0.53	0.63
Urea + DMPSA + Biostimulant	1.51	4.10	6.14	9.30	0.66	0.65	0.58	0.65	0.66	0.51	0.49	0.58
Ammonium sulfate nitrate (ASN)	-1.53	4.28	3.25	2.89	0.63	0.63	0.58	0.63	0.66	0.41	0.50	0.56
ASN + DMPSA	-2.44	8.86	6.69	17.06	0.63	0.63	0.60	0.67	0.63	0.46	0.48	0.64
ASN + Biostimulant	0.92	6.76	3.98	7.21	0.66	0.66	0.56	0.67	0.67	0.51	0.53	0.63
ASN + DMPSA + Biostimulant	0.48	7.47	9.09	8.75	0.60	0.63	0.58	0.67	0.60	0.42	0.50	0.61
ESN‡ (polymer coated urea)	2.64	8.54	3.90	10.97	0.60	0.68	0.56	0.67	0.64	0.50	0.55	0.60
Overall mean ± SE	-0.13±4.28	5.54±2.64	4.01±3.48	10.03±5.04	0.63±0.01	0.64±0.01	0.58±0.01	0.67±0.01	0.64±0.01	0.46±0.01	0.53±0.01	0.62±0.01
ANOVA P-value												
N treatment	0.806	0.692	0.594	0.396	0.921	0.633	0.834	0.099	0.905	0.300	0.412	0.402

† DMPSA stands for 2,4-dimethylpyrazol succinic acid.

‡ ESN stands for Environmentally Smart N

Figures

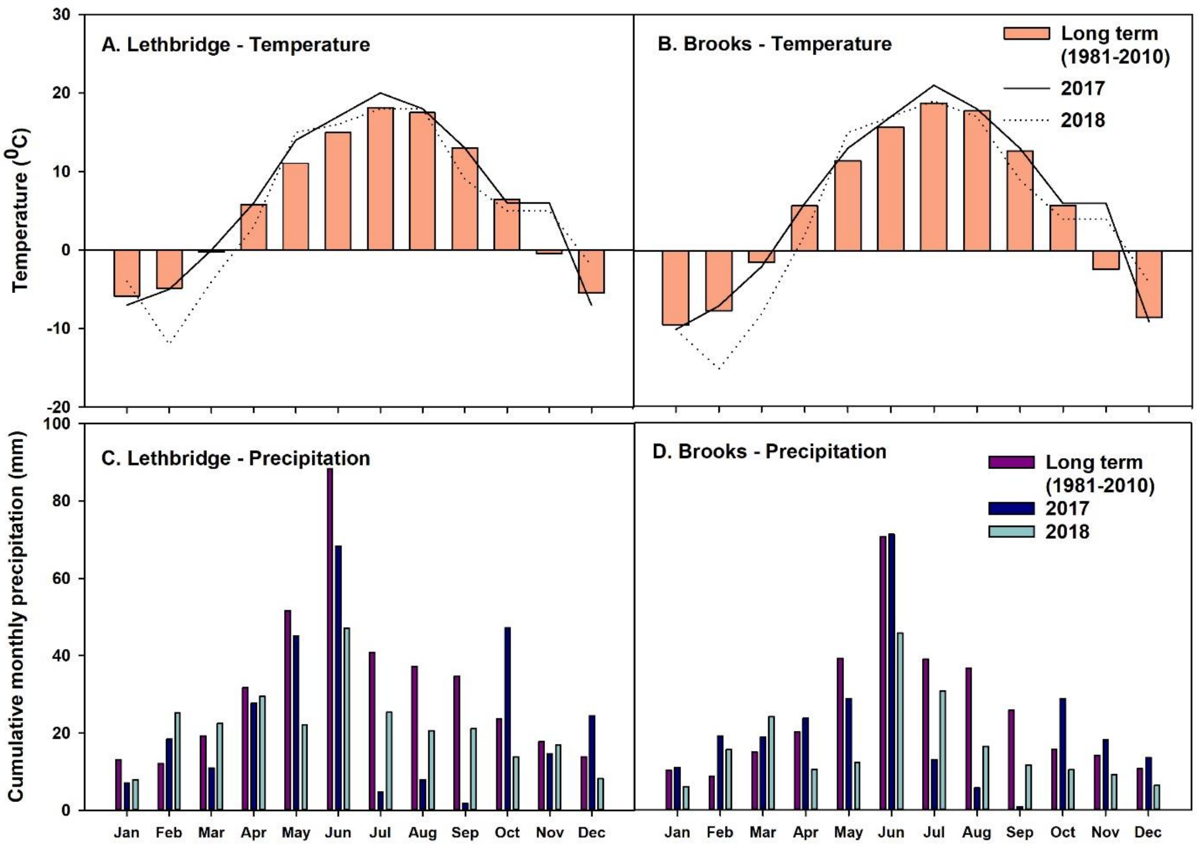

Fig. 1. Monthly average air temperature and cumulative precipitation and at Lethbridge (A, C) and Brooks (B, D) for year 2017, 2018 and the 30-year normal monthly data.

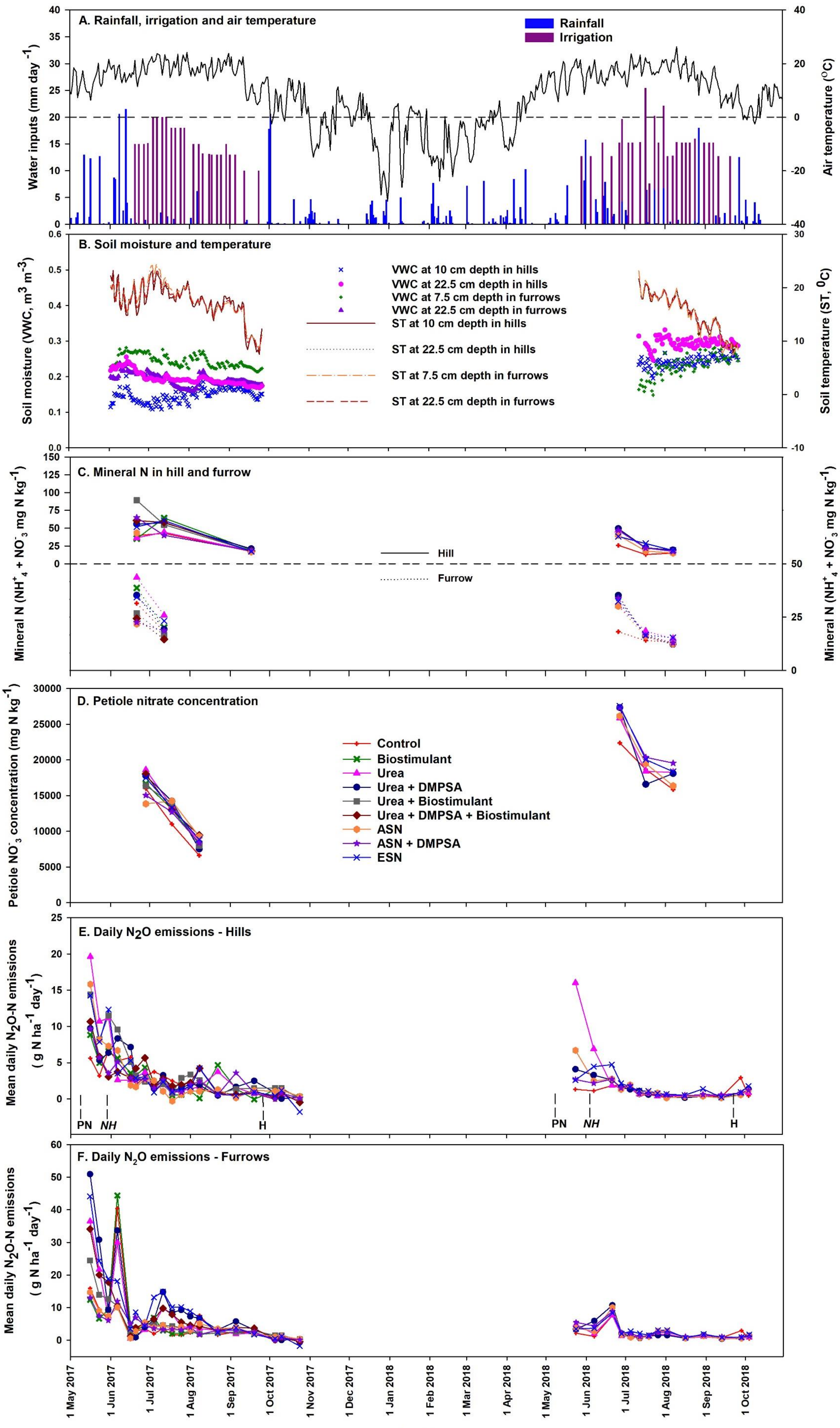

Fig. 2. (A) Daily average air temperature and water inputs (precipitation and irrigation), (B) soil moisture and soil temperature in the potato hills at the depths of 10 and 22.5 cm as well as in the furrows at 7.5 and 22.5 cm, (C) soil ammonium and nitrate concentrations in potato hill and furrow, (D) potato petiole N concentration, daily N_2O fluxes from (E) hills and (F) furrows across N treatments at Lethbridge during 2017 and 2018 growing seasons. All experimental treatments were measured in the growing season 2017, while a subset of selected treatments were measured in the growing season 2018. In panel B, VWC and ST stand for volumetric water content and soil temperature, respectively. In Panel E, the acronyms PN, NH and H near the horizontal axis indicate the dates of pre-planting N fertilization, post-planting N fertilization followed by hilling, and harvesting.

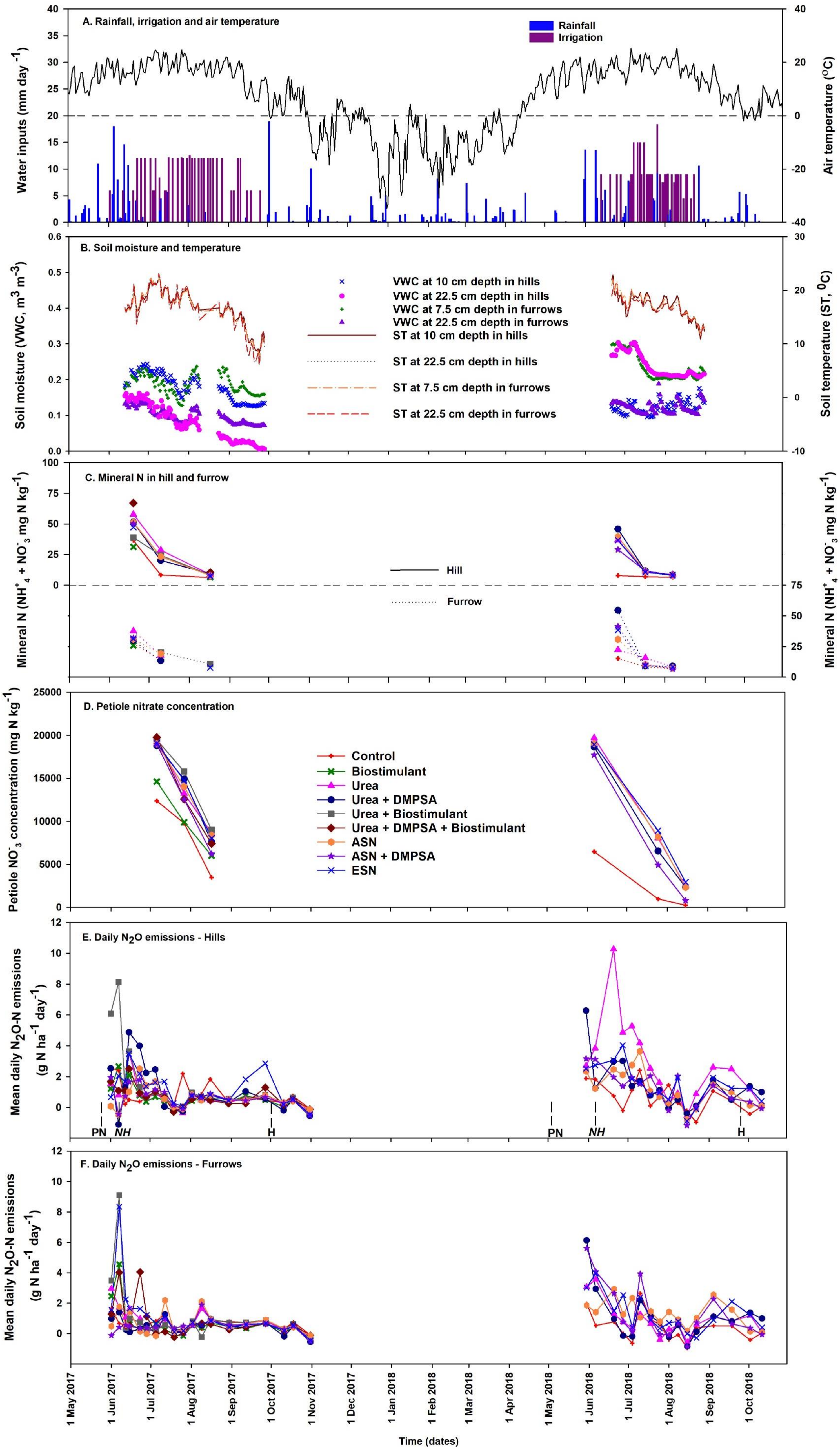

Fig. 3. (A) Daily average air temperature and water inputs (precipitation and irrigation), (B) soil moisture and soil temperature in the potato hills at the depths of 10 and 22.5 cm as well as in the furrows at 7.5 and 22.5 cm, (C) soil ammonium and nitrate concentrations in potato hill and furrow, (D) potato petiole N concentration, daily N_2O fluxes from (E) hills and (F) furrows across N treatments at Brooks during 2017 and 2018 growing seasons. All experimental treatments were measured in the growing season 2017, while a subset of selected treatments were measured in the growing season 2018. In panel B, VWC and ST stand for volumetric water content and soil temperature, respectively. In Panel E, the acronyms PN, NH and H near the horizontal axis indicate the dates of pre-planting N fertilization, post-planting N fertilization followed by hilling, and harvesting.

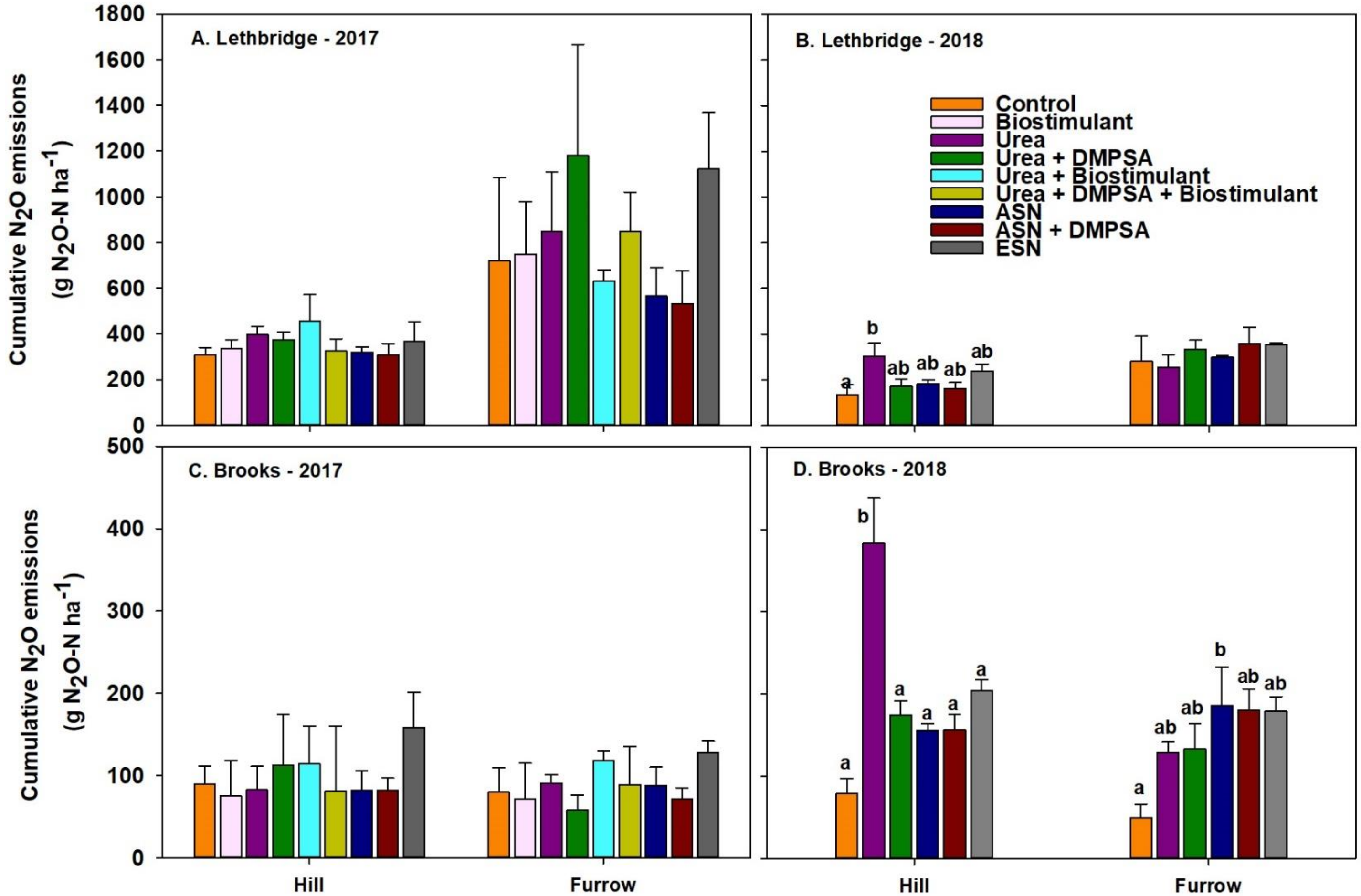

Fig. 4. Cumulative N_2O emissions of different N fertilizers from hill and furrow at Lethbridge (A), (B) and Brooks (C), (D) during the growing seasons of 2017 and 2018. All treatments were measured in 2017, while a subset of selected treatments were measured in 2018. The differences across treatments, indicated by different lowercase letters, were determined via Tukey's Honest Significant Difference at the alpha level 0.05. Error bars correspond to standard errors of the means. In the legend, acronyms ASN, DMPSA, and ESN stand for ammonium sulfate nitrate, 2,4-dimethylpyrazol succinic acid, and Environmentally Smart N.

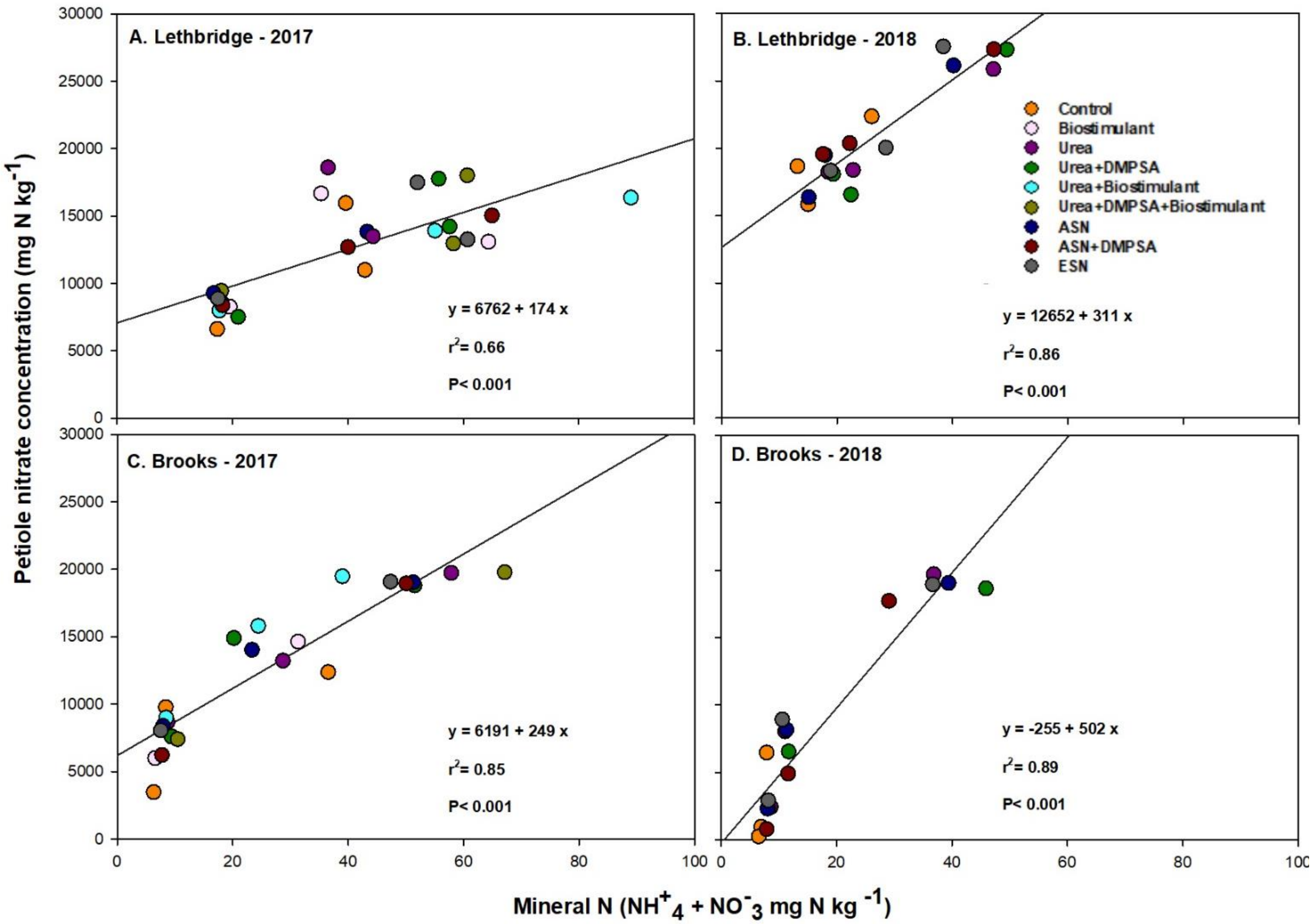

Fig. 5. Relationships between potato petiole nitrate concentration and soil ammonium plus nitrate at Lethbridge (A and B) and Brooks (C and D) over 2017 (A and C) and 2018 (B and D). The datasets are shown as time series in Fig. 2C, Fig. 2D, Fig. 3C, and Fig. 3D. All treatments were measured in 2017, while a subset of selected treatments were measured in 2018.