PGA RESEARCH ARCHIVE

BEST MANAGEMENT PRACTICES

POTATO GROWERS OF ALBERTA

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Russet Burbank

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Profile

A summary of the main management inputs used by successful Russet Burbank producers in southern Alberta

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March 1999

Russet Burbank Management Profile

Introduction

This factsheet describes some of the main management practices and inputs used in 1998 by southern Alberta potato growers who produce Russet Burbank potatoes for processing. The information summarized here was supplied by 14 growers who provided details on 18 Russet Burbank fields that were both high yielding and of good quality.

Note that not all results in this factsheet total 18 as not all questions were answered by all growers.

Special thanks to those growers who participated in this project.

Clive Schaupmeyer
Brooks, Alberta
March, 1999

Where necessary, comments have been added to various sections of this factsheet and appear in boxes like this.

Yield and quality of surveyed fields

This factsheet describes inputs for 18 fields with an average marketable yield of between 20 and 21 tons per acre. Responding growers reported marketable yields ranging from 18 to 23 tons per acre. (Marketable yield was defined as the yield the growers would be paid for if they were shipped to a french fry plant at the time of the survey in January.)

Growers were asked to rate the overall quality as fair, good or very good. All growers described the quality as good (10) or very good (8) and none as fair quality.

The specific gravity of the 18 lots ranged from 1.093 to 1.103 with a mean specific gravity of 1.097.

French-fry processors pay a premium for Russet Burbank potatoes with a specific gravity of 1.090 or higher. Specific gravity is the density of potatoes compared to water (1.0) and is an accurate measure of the dry matter of potatoes. Generally the higher the dry matter, the better the quality of the resulting frozen french fries. Very high specific gravities (above 1.100) are not as desirable as those between 1.090 and 1.099.

Summary of management inputs

Following is a description of how a typical Russet Burbank field was grown for french fry processing in 1998. ***The following descriptions are based on averages, and in some cases "the majority" input is described below. These may not reflect management in a significant number of fields. (For example, the majority of growers do not use micronutrients, however just under half do.) The descriptions may not apply to a specific field in the future and they may not conform to current recommendations.***

Input	*Description*
Rotation and previous crop	The potatoes were planted in a field where no potatoes had been grown since 1994 and the previous crop was soft wheat.
Seed	Elite 3 seed was cut and treated with preventative fungicidal seed treatment to prevent seed-piece decay. (Use of seed treatments was not determined in the survey.)
Nitrogen fertility	A total of 190 pounds of nitrogen was applied: 120 pounds were broadcast and worked in prior to planting; 35 pounds were top-dressed and worked in at hilling; and an additional 35 pounds were added with the irrigation water. The resulting *lowest* fourth-petiole, nitrate-nitrogen level in August was 8,000 ppm.
Phosphorous fertility	A total of 100 pounds of phosphorus (P_2O_5) were broadcast and cultivated in prior to planting. The resulting *lowest* fourth-petiole total-P level in August was 0.21 percent which is considered marginal.
Potassium fertility	70 pounds of potassium were broadcast and worked in prior to planting.
Sulphur	30 pounds of sulphur were broadcast and worked in prior to planting.
Micronutrients	No micronutrients were added.
Planting	The field was planted with a six-row pick planter traveling 3.5 mph. Planting took three days starting on April 27 and was complete on April 29. Seed pieces were spaced at 12 inches in the row and final stand was 92 percent.
Cultivation/hilling	The first hilling (dammer dyking) was done before the plants emerged and the second hilling was done when the plants were about 4 inches high.
Irrigation	A total of 16 to 18 inches of water was applied during the growing season in 16 or 18 revolutions of the pivot.
Weed control	Two or three herbicides were used to control a wide range of broadleaf and grassy weeds plus volunteer wheat.
Blight prevention	Four different fungicides were applied a total of eight times starting in late June at 2-week intervals and every week in August through to top kill.
Insect control	Thimet was applied at planting and the field was sprayed once in mid summer with a pyrethroid insecticide for Colorado beetle control.
Top killing	The field was sprayed with 1.25 L of Reglone once on September 13.

Cultivation

Participating growers were asked to describe the field preparation/cultivation practices between taking off the previous crop in the fall of 1997 and planting in the spring of 1998. Information was reported for 16 of the 18 fields. Few growers prepare land exactly the same way, however, common practices include:

- Fall and spring bedding was reported for 9 fields
- Fall irrigation was reported for 13 fields
- Grain straw was chopped and harrowed in 10 fields prior to other tillage
- In either the fall or spring, all fields had at least one deep-tillage operation (paraplow, bedding or plowing).

Following are nine different cultivation sequences reported in the fall.

Soil preparation/cultivation method	Sequence								
Chop and harrow grain straw	1	1	1	1		1			1
Deep chisel		3	2						2
Double disc		2			2		2	3	
Cultivate			3	3			4		
Plow								2	
Paraplow	2	4					3		
Fall bed				4	3	3			3
Fall irrigate	3		4	2	1	2	1/5	1/4	4

Fall applied fertilizers are applied prior to the first field tillage operation. Most growers using fall and spring bedding equipment apply some nitrogen and most (or all) phosphorous and potassium fertilizer prior to fall bedding. In virtually all cases growers work in fertilizers by discing or cultivation prior to bedding.

Common spring practices include:

- Where fall bedding was done, the only spring operation is typically the spring bedding.
- Growers who are not fall or spring bedding are universally rototilling (or rotovating).

Following are common cultivation sequences reported in the spring.

Soil preparation/cultivation	Sequence				
Cultivate		1			1
Disc					
Fall/spring bed	1				
Rotovating/rototilling		2	2	1	3
Paratill			1		
Plow					2
Spring applied fertilizers are applied prior to the first field tillage operation.					

Trade names are used for convenience. The use of specific trade names constitutes neither an endorsement nor a suggestion that similar products are not effective or available.

Fertility

Following is a summary of the amounts of actual fertilizers added to the fields. No attempt was made to determine soil residues.

Nitrogen

Nutrient description	***Average (mean)***	***Range of all growers***	***Normal range***[1]	***Comments***
	Pounds per acre			
Total nitrogen applied	188	140 to 225	160 to 210	Does not include soil residues based on soil analysis
Pre-planting nitrogen	120	70 to 200	90 to 150	
After planting and/or at hilling topdressed nitrogen	35	8 to 60	20 to 50	14 of 17 fields had N applied at hilling
N applied with irrigation (fertigation)	38	20 to 65	25 to 50	All growers fertigated
Minumum petiole nitrate nitrogen levels for August	8,300	800 to 17,100	4,100 to 12,500	Data reported for 14 of the 18 fields

Note 1. ***Normal range*** is defined as the range withing one standard deviation from the mean. In simple terms, it is the range in which the majority fall, and excludes those at the high and low ends.

Phosphorous

Nutrient description	*Average (mean)*	*Range of all growers*	*Normal range*[1]	*Comments*
	Pounds per acre			
Total P all sources	96	20 to 150	60 to 135	***Growers should plan to add all of the projected P needs prior to or at planting.*** Tissue P should be monitored and more added if it appears P will be deficient in two or three weeks.
Pre-planting broadcast P	82	20 to 150	45 to 115	
Banded P	-	-	30 to 60	Two growers reported banding three fields
At hilling P	-	-	20 to 40	Two growers reported adding P to three fields at hilling
P applied with irrigation (fertigation)	17	5 to 40	-	Extra P was applied to 7 of 18 fields in the irrigation water.
Minimum petiole total P levels for August	0.21	.11 to .31	.15 to .27	Data reported for 10 of 18 fields

Note 1. *Normal range* is defined as the range withing one standard deviation from the mean. In simple terms, it is the range in which the majority fall, and excludes those at the high and low ends.

The accepted threshold minimum for petiole total P is 0.22 percent. Five of the ten fields for which data were received were above this level. These data indicate that some fields may require more P applied before or at planting. Soil residue P was not asked for in this survey so it is not possible to report total available P. There appeared to be no relationship between the minimum P level in August and the amount of P applied to the crop. For example, one field with only 90 pounds applied had a minimum August petiole P of 0.31 percent. Another field had 120 pounds applied and the P declined to 0.13 percent.

Phosphorous fertilization of potatoes in Alberta is currently under review. As yields continue to increase it is reasonable to expect that application rates of phosphorous will have to increase beyond the averages that growers are currently reporting. Manure will likely play a more significant role in P management in the future. Young potato plants require a readily available supply of phosphorus when they are small and before the main feeder roots start taking phosphorus from deeper in the hill and root zone. For this reason growers are being encouraged to consider attaching banding equipment to their planters. Phosphorous should be banded 2 inches above and 2 to 4 inches to the side of seed pieces.

Potassium

Nutrient description	*Average (mean)*	*Range of all growers*	*Normal range*[1]	*Comments*
	Pounds per acre			
Pre-planting broadcast K	68	0 to 120	40 to 95	K added to 16 of 17 fields
Note 1. ***Normal range*** is defined as the range withing one standard deviation from the mean. In simple terms, it is the range in which the majority fall, and excludes those at the high and low ends.				

Dr. Ross McKenzie, AAFRD fertility specialist, feels that if potassium is indicated on the soil test then growers should add a minimum of 100 pounds per acre.

Sulphur

Nutrient description	*Average (mean)*	*Range of all growers*	*Normal range*[1]	*Comments*
	Pounds per acre			
Sulphur added pre-plant or at hill	32	10 to 70	20 to 40	Sulphur was applied to 11 of 16 fields
Note 1. ***Normal range*** is defined as the range withing one standard deviation from the mean. In simple terms, it is the range in which the majority fall, and excludes those at the high and low ends.				

Foliar feeding

- Some N, P, K was foliar applied to 4 fields (of 15 fields reporting)
- Foliar micros were applied 8 of 18 fields

Micro nutrients

- Micronutrients were applied pre-plant to 1 of 18 fields
- Foliar micronutrients were applied 8 of 18 fields
- Micronutrients were applied with irrigation water to 2 of 18 fields

Other management inputs

Rotation

	Rotation years[1]					
	1	*2*	*3*	*4*	*5*	*New land*
Number of fields	0	1[2]	1	7	4	5
16 of 18 crops were planted in a 4 or more year rotation.						

Note 1: The number of potato crops in the number of years specified. For example, 4 years = 1 crop in 4 years.
Note 2: This was new land and the grower reported a normal rotation of three or four years.

Previous crop

	Previous crop				
	Wheat[1]	*Barley*	*Corn*	*Sugar beets*	*Alfalfa*[1]
Number of fields	10	3	3	2	1

Note 1: One field was half alfalfa and half wheat the previous year.

Fall irrigation

Of the 17 fields for which data were obtained, 14 were fall irrigated in 1997.

Seed

	Class			Cut or whole	
	Elite 3	*Elite 4*	*Foundation or certified*	*Cut*	*Whole*
Number of fields	16	1	0	14	2
The survey neglected to ask growers of they used seed treatments on cut seed. However, based on observation cut is always treated.					

Seed cutters

Those growers cutting seed reported using Better Built and Milestone cutters. Cutter widths were 24, 30, 36 and 60 inches.

Although not established in this survey, growers strive to cut seed pieces that average 2 ounces. Pieces smaller than 1.5 ounces and greater than 3 ounces should not total more than 20 percent of the cut seed lot.

Planting

Field sizes were not determined, but typically most fields are one full pivot circle (130 acres), with a few half fields of 65 acres.

Start date		*End date*		*Days to complete*	
Range from/to	*Average start date*	*Range from/to*	*Average end date*	*Range*	*Average* (includes start and end day which may be part days)
April 20 to May 4	April 27	April 22 to May 7	April 29	1 to 8	3

Planter description and speed

Pick planters were used to plant all fields except one. Two fields were planted with four-row planters and the res with six-row planters. One grower used an air planter.

Planter speed (mph)			
Slowest	*Fastest*	*Average speed*	*Normal range*
2.5	4.2	3.5	3.0 to 4.0

All planters have an optimum speed at which they preform best with any given seed lot. Planter performance must be established for each seed lot planted. The object is to plant pieces as close to the target spacing as possible with few misses or doubles. 80 percent of seed pieces should be within 2 inches of the target in-row spacing.

Target in-row spacing

	11 inches	*12 inches*	*13 inches*	*14 inches*
Number of fields	6	10	1	1 (whole seed)

Final plant stand

Growers estimated the final stands as follows:

Percent stand			
Lowest	*Highest*	*Average stand*	*Normal range*
85	98	91.5	88 to 94

Stands in about one half of the fields were estimated at 90 percent. This may indicate that the actual stand was not measured and 90 percent sounded like a nice round number. Based on casual observation of fields in 1998 the actual final stands were likely higher than reported.

Hilling frequency and timing

A wide range of commercial hillers and dammer dikers were used for hilling and reservoir tillage. Growers reported using equipment made by Dammer Diker, Kirshner, Allaway, Harriston, Grimme and Struik. One grower had manufactured his own dammer diker.

	Timing of first hilling			*Total number of times hilled or dammer diked*			*Total number of times hilled or dammer diked AFTER emergence only*			
	Before emergence	Before 4" high	After 4" high	1	2	3	0	1	2	3
Number of fields	8	9	1	3	9	4	1	8	7	2

Irrigation

Following is the reported frequency and amounts of irrigation water applied:

	Reported number of irrigations					*Estimated amount of water applied (inches)*					
	10	11	12	13	14+	10	12	14	16	18	20+
Number of fields	3	2	4	0	8	1	2	3	6	1	3

Potatoes require high uniform levels of water throughout the growing season. Typically during hot weather when the crop is at maximum demand (in July and early August) growers apply 0.6 to 1.00 inches of water two or three times a week to keep up with the needs of the crop. Contrary to historical belief, short- term moisture deficits when Russet Burbank potatoes are setting tubers in mid to late June results in significant yield reductions because tuber numbers are reduced.

Casual observation in 1997 and in 1998 indicates that fields are often too dry in early July and growers are applying too much water in early August.

Pest control

Herbicides used

Growers reported using the following herbicides

	Eptam	*Sencor*	*Gramoxone*	*Linuron*	*Prism*	*Poast Ultra*	*Fusilade II*
Number of fields in which products were used	2	11	6	4	11	8	1

Herbicidal programs

Following are *all* of the different herbicidal programs reported by growers.

Trade names are used for convenience. The use of specific trade names constitutes neither an endorsement nor a suggestion that similar products are not effective or available.

Sencor Prism	Sencor Poast Ultra	Sencor Gramoxone Fusilade II	Sencor Gramoxone Poast Ultra Prism	Sencor Gramoxone	Gramoxone Poast Ultra Prism	Prism	Eptam Sencor Poast Ultra Prism	Eptam Sencor Prism	Linuron Poast Ultra	Linuron

Blight control fungicides used

Growers reported using the following fungicides for control of early and late blight:

	Bravo 500	*Bravo/ Ridomil*	*Manzate 200*	*Ridomil MZ 72 WP*	*Polyram 16D/DF*	*Dithane DG*	*Tatto C*
Number of fields in which products were used	15	12	11	9	7	7	6

	Number of times fields sprayed with blight products						
	2	*3*	*4*	*5*	*6*	*7*	*8 or more*
Number of fields	1	0	0	2	1	7	7

Fungicidal combinations used

Following are *all* of the different fungicide combinations reported by growers:

Bravo Dithane Polyram Ridomil MZ	Bravo Dithane Polyram	Bravo Manzate Bravo/Ridomil Ridomil MZ	Bravo Bravo/Ridomil	Bravo Manzate Bravo/Ridomil	Dithane Polyram Ridomil MZ	Bravo Dithane Manzate Polyram Bravo/Ridomil Ridomil MZ Tatto
Bravo Dithane Manzate Polyram Bravo/Ridomil Ridomil MZ	Bravo Manzate Polyram Bravo/Ridomil Ridomil MZ Tatto	Bravo Dithane Manzate Polyram Ridomil MZ	Bravo Manzate Ridomil MZ	Bravo Manzate Bravo/Ridomil Tatto C	Polyram Bravo/Ridomil Ridomil MZ Tatto	

Late blight occurred in southern Alberta for the first time since 1993. It was found in 17 of an estimated 150 to 200 fields in southern Alberta. The first diagnosis was made on August 6. After that date spray intervals were reduced to about 7 days from 10 to 14 days.

For the first time ever the race of late blight fungus was determined to be US 8, an A2 mating type, that is resistant to metalaxyl (Ridomil). In 1992 and 1993, when late blight was first and last seen in southern Alberta, the late blight strains were all metalaxyl resistant. Tatto C, a new partially systemic fungicide effective against US 8, was used by a few growers. Acrobat, also a new partially systemic fungicide, was not sprayed as it was considered to be too late in the season. Prior to the registration of these new systemics, Ridomil was the only systemic fungicide available, however US 8 is resistant to the active ingredient metalaxyl. Unlike the partially systemic fungicides, which only move upward in plants, metalaxyl moves in both directions including down into roots and tubers. Therefore, growers continue to use metalaxyl as they feel it is effective against storage rots caused by Pythium leak and pink rot.

Insect control

Most planters were equipped with granular insecticide applicators (Gandy, Valmar, Beeline and Microband) for the application of insecticides used for early season Colorado beetle control or wireworm control.

	At-plant insecticide not used	*Thimet applied*	*Dyfonate[1] applied*
Number of fields	4	9	4

Note: Dyfonate for wireworm control is no longer available.

Mid-season Colorado potato beetle control

Growers apply mid-season insecticides for the control of spot outbreaks of Colorado potato beetles. Insecticides are tank mixed with blight fungicides and applied at the same time.

	Field not sprayed for CPB	*Sprayed once with Cymbush or Ripcord*	*Sprayed twice with Cymbush or Ripcord*
Number of fields	4	10	- ←

Colorado potato beetles are not a major problem in potato fields in southern Alberta. Growers reported using only two mid-season chemicals for controlling spot outbreaks of CPBs. Both are pyrethroids and there is a risk of the CPBs developing resistance to these products in a few years. Thimet (an organophosphate) will tend to eliminate strains of beetles that are developing resistance, however all growers are urged to also use organophosphates, carbamates and organochlorines in combinaiton with pyrethroids. Consult the AAFRD Crop Protection 1999 manual for selection of registered products.

Top killing of vines

Reglone application dates

Average date of first top application	*Range of all first application dates*	*Normal range*	*Number of fields Sprayed once only*	*Number of fields sprayed twice*
September 13	Sept. 2 to 26	Sept. 7 to 19	11	7

Reglone rates (L/acre)

Average rate for single application	*Range of rates for single application*	*First application rate when two applications made*		*Second application rate*	
		Average	*Range*	*Average*	*Range*
1.2	0.75 to 1.5	1.0	.75 to 1.25	0.7	0.5 to 1.0

Harvesting

All fields were harvested with 2-row harvesters and all fields were windrowed with two or four-row windrowers. One potato farm uses a three-row windrower and three-row harvester.

Trade names are used for convenience. The use of specific trade names constitutes neither an endorsement nor a suggestion that similar products are not effective or available.

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August 24, 1999

Glenn Hurst
Potato Growers of Alberta
Suite 6, 1323 44 Ave NE
CALGARY AB T2E 6L5

Dear Glenn:

Enclosed is a 1998 progress report for Site Specific Management of Potatoes, AARI project #96M979.

Thanks for the support of AARI and the organizations who contributed financially. Willing and skilled assistance from the collaborators made this project possible.

Yours truly,

R. Colin McKenzie
Soil and Water Agronomist

/mtb

Site Specific Management of Potatoes

1998 Progress Report

AARI Project 96M979

R.C. McKenzie
Alberta Agriculture, Food & Rural Development
Crop Diversification Centre South
Brooks, Alberta

August, 1999

Site Specific Management of Potatoes
1998 Progress Report — August, 1999

R.C. McKenzie[1]

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Background

The use of Global Positioning System (GPS) technology has made it possible, since 1991, to develop detailed yield maps of various crops. This technology has drawn interest from farmers in the USA as a method to increase profits by optimizing fertilizer applications. In Western Europe it has been used as a method to avoid environmental contamination from excess use of fertilizers.

Potatoes are a high value crop requiring high inputs. Excess nitrogen will delay maturity, reduce storage quality, contribute to ground water contamination and increase the cost of production, while insufficient nitrogen will reduce yield and will increase the severity of early blight. Phosphorus fertilizer applications on potatoes are higher than other crops. This represents an appreciable cost to farmers who are often using rented land. Potatoes are often grown on coarse textured soils, which have a low nutrient holding capacity and high field variability. Traditional research under small plot conditions can not describe this field variability and current management systems do not account for it. Field variability will become more important as the acreage of potatoes and the size of potato farms increase.

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[1]AAFRD, Crop Diversification Centre South, Brooks, AB T1R 1E6

An Alberta team commenced site specific research projects in 1993. Crop specialists, cooperating with farmers, started site specific management projects in several areas of Alberta in 1995. Fields were subdivided based on interpretation of aerial photographs. These subdivided units were sampled separately to determine fertilizer requirements. Global positioning technology used on harvesters, fertilizer spreaders and weed sprayers make it possible to very accurately manage different portions of a field. Site specific management can serve both as a research tool to improve current recommendations and as a management tool to increase the efficiency of inputs. It will be most useful on high value crops which have large inputs of chemicals, fertilizers and labour. The costs for an experimental project like this are high because of the detailed collection and analysis of the data. In the USA, however, commercial operators are now providing GPS equipment and preparing yield maps of cereals for about $8 to $10 (US) per acre. Interpretation of yield maps is the aspect which requires the most development as the collection of data to provide this interpretation is the expensive part of the operation.

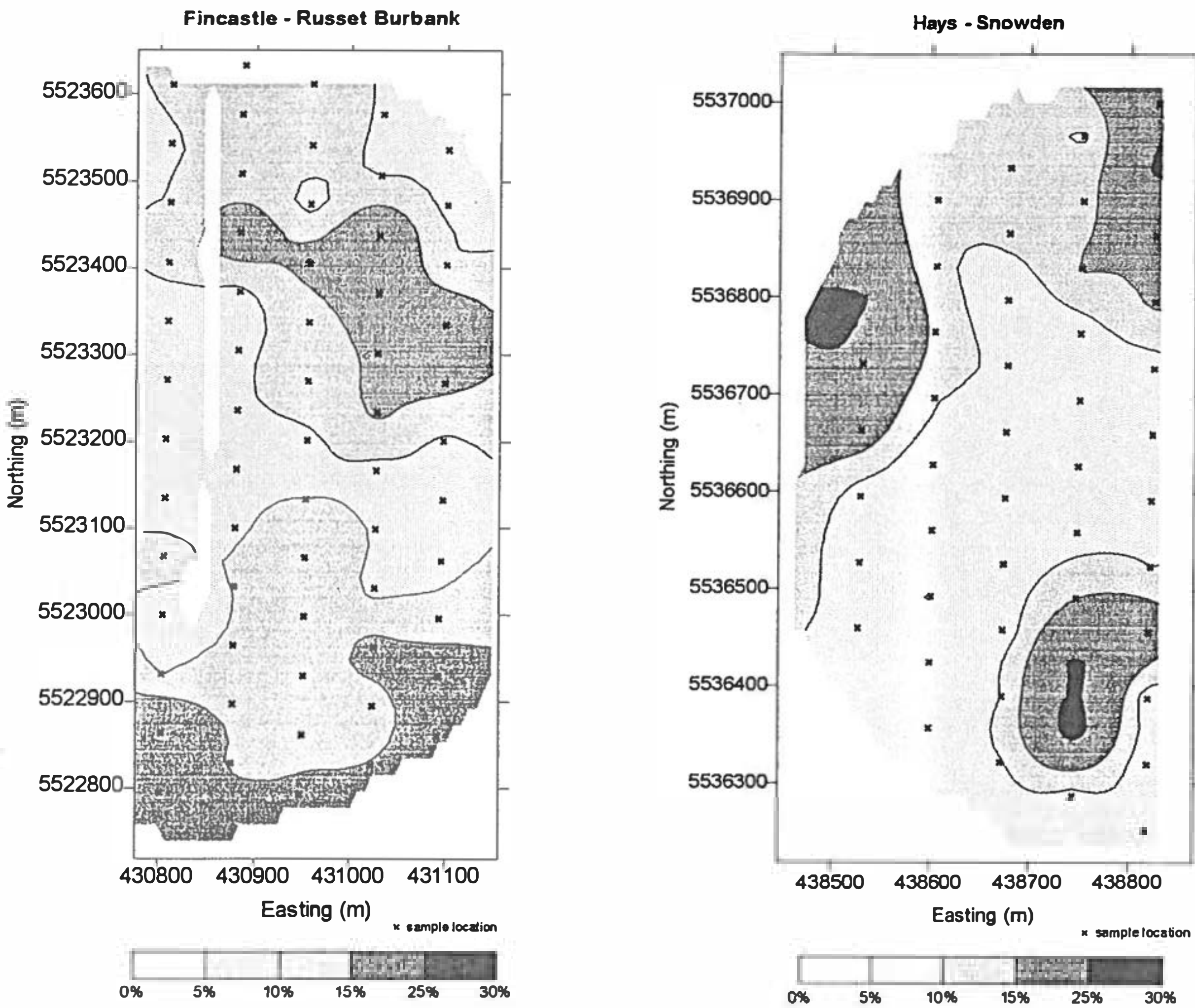
Objectives (Key Results Expected)

- To use a potato harvester equipped with a yield monitor and global positioning technology to generate maps and to measure the variability of the yield of potatoes in a field;
- To determine the effect of soil type, landscape position, nutrient level, fertility treatments, disease and weeds on the yield of potatoes;
- To determine yield and variability of crops over several years and relate this to field characteristics and to potato yield and quality;
- To evaluate the use of remote sensing and digital image analysis to detect nutrient deficiencies and diseases of potatoes;
- To measure the financial and environmental benefits of site specific management of potatoes.
- To measure the movement of nitrogen below the root zone.

Progress To Date: Results and Dicussion

Two fields of potatoes were monitored during each of 1996, 1997 and 1998. Each was about 27 ha and was half of a centre pivot irrigation system. One field 12 km south of Hays had hummocky topography and a soil texture which varied from sand to clay loam. Monitoring of Snowden potatoes, a determinate growth medium-late cultivar used for chipping, was done on the east half of the Hays field in 1996 and the west half in 1997 and in 1998 the west half of a field directly south of the previous fields. In 1998 the clay content in the 0 to 0.60 m depth varied from 5% to 30% (Figure 1).

Figure 1. Soil Texture (% Clay) October 1997 (0.0-0.6 m) of Two 1998 Potato Fields



In 1997 and 1998 Russet Burbank, a late cultivar with indeterminate growth, which is used for French fries and the fresh market, were grown about 8 km north of Fincastle. In 1997 the west half and in 1998 the east half of the field was used for potatoes. The 1996 Fincastle field was 6 km further NE and FL1625 was grown. The Fincastle sites were gently sloping fields with texture varying from loamy sand to silt loam and a clay content from 5 to 25% for the 0.0 to 0.60 m depth.

A grid was set out with GPS in October, 1996, 1997 and 1998 to provide locations for detailed sampling of the soil and the potato plants in the following year. In 1998 this grid consisted of 47 sites at the Hays field and 53 sites at the Fincastle field. In October 1996, 1997 and 1998, composite soil samples of 0 to 0.15 m, 0.15 to 0.30 m, 0.30 to 0.60 m and 0.60 to 0.90 m were taken at each grid location. Nitrogen (N), phosphorus (P), potassium (K), pH, electrical conductivity (EC) and particle size were determined on soil samples. In June of 1996, 1997 and

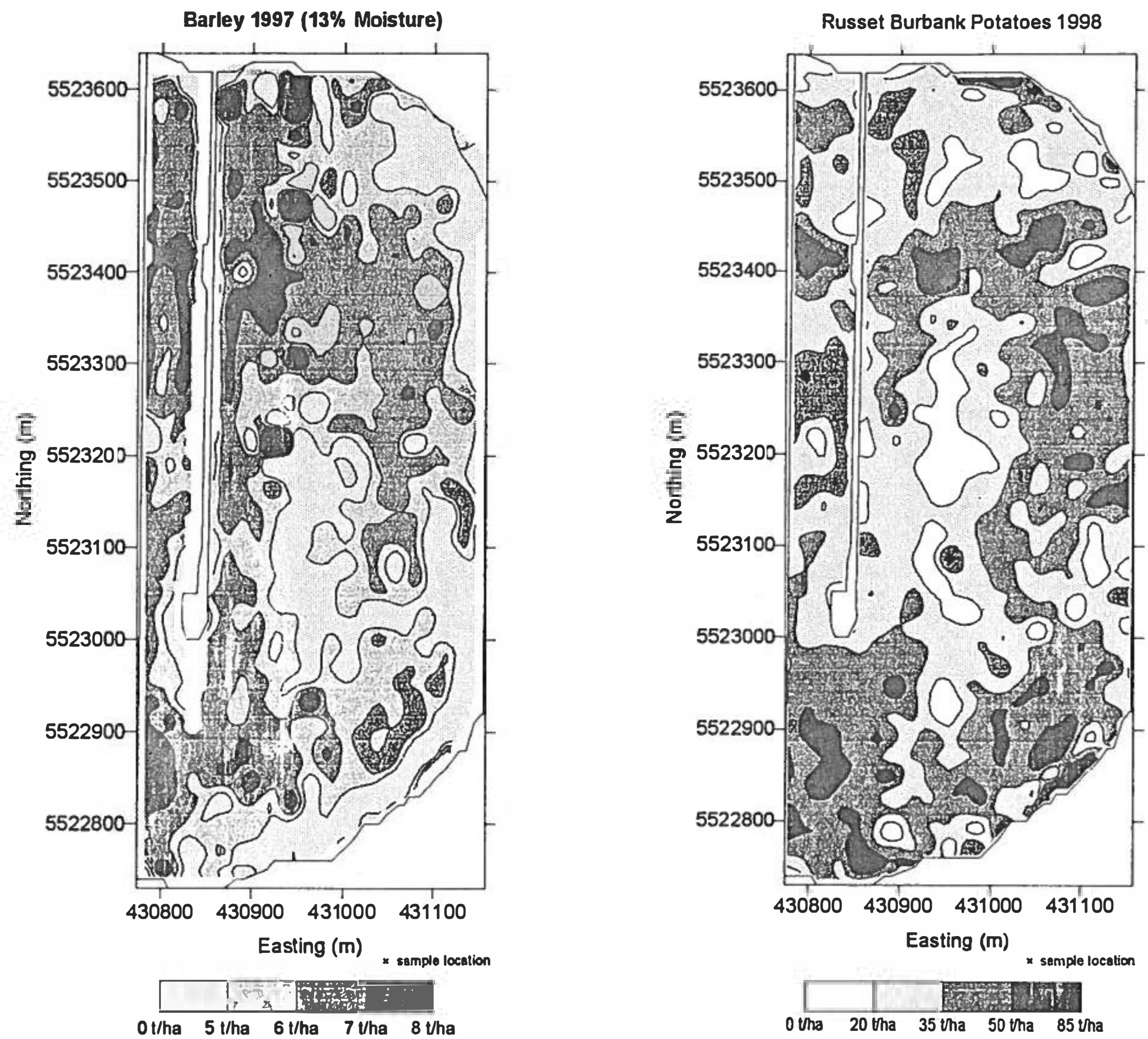
1998, neutron access tubes and a rain gauge were installed at each grid location. Soil moisture and irrigation plus precipitation readings were taken from June until harvest. During the summer of 1996, 1997 and 1998, composite petiole tissue samples were collected 3 times each year at each grid location. Nitrate-N, total N, P and K were determined on tissue samples. Fertilizer rates and additional fertilizer application by fertigation were set by the farmer and each farmer had his own soil and plant tissue testing program.

A yield monitor was used on two potato combines and yields were recorded and positioned with Novatel differential GPS in 1996 and 1998 and using *Omnistar*™ (a commercial satellite which provides a service as a base station) in 1997. Yields were successfully recorded on most of both fields. In 1996 parts of both fields were missed because the farmers were harvesting at the same time and only one yield monitor was available. In 1997 there were small blanks in the data due to errors in positioning with *Omnistar*™. In 1998 about 3 ha of the Hays field was not yield mapped. In 1997 and 1998 samples of tubers were dug by hand at each of the grid locations on both fields and yield, size and quality measurements were made on these samples.

Data was processed into contour maps using *Surfer* software package and a kriging option. Maps of soil texture, topography, soil N, P, K nutrient levels, petiole N, P, K nutrient levels, soil moisture, irrigation plus precipitation, consumptive use, tuber yield, tuber specific gravity, small tuber yield, mean tuber weight and tuber chipping or french fry scores were prepared.

Yield maps were made in 1997 on a 27 ha wheat field near Hays and a 28 ha barley field near Fincastle (Figure 2). These same fields were yield mapped for potatoes in 1998. In the 1997 Hays field there was a wide range in wheat yield from below 3 t/ha to above 9 t/ha. In the 1997 Fincastle field, barley yield ranged from below 5 t/ha to above 7 t/ha. No yield maps were made in 1998 of the fields scheduled for potatoes in 1999 because they had sugar beets which we are not presently equipped to yield monitor. The 1999 fields are the same two fields on which potato yields were first mapped in 1996.

Figure 2. Fincastle Yields in t/ha as Measured with a Yield Monitor



Nitrogen

The total soil (0 to 0.60 m) plus fertilizer nitrogen in 1998 on the Hays field was 272 lbs/ac (305 kg/ha) (Table 1) and 276 lbs/ac (310 kg/ha) on the Fincastle field. Petiole N of potatoes on the Hays field in 1998 was deficient on 96% of the samples on July 6. By July 22, 88% of the crop was deficient. By August 10, tissue N levels had improved and only 46% of the crop was deficient. The farmer added a series of four nitrogen applications (28-0-0) through the irrigation system to provide 45 lbs/ac (51 kg/ha) of N.

Petiole N was not as frequently deficient in the Fincastle field as in the Hays field. On August 11, 57% of the Fincastle petiole samples tested adequate and 21% were deficient (Table 2). The two fields had similar amounts of soil N and fertilizer nitrogen. The Hays field received slightly more nitrogen through the irrigation system than the Fincastle field but it did not receive nitrogen at seeding time. The most important difference was the Hays field received more water in July than the Fincastle field. This excess water apparently caused loss of nitrogen by leaching or denitrification.

Table 1. 1998 Soil fertility on site specific potato fields.

		Snowden	Russet Burbank
Soil N lbs/ac 0-0.60 cm	Oct./97	25	29
Fertilizer N lbs/ac	Fall/97	160	170
At seeding	Spring/98	-	18
At hilling lbs/ac	Spring/98	42	31
6 fertigations of N (lbs/ac)	July 7-Aug.13/98	45	28
	Sum N	272	276
Soil Kelowna P lbs/ac (0-0.15 cm)	Oct./97	37	60
Fertilizer P_2O_5 lbs/ac (P lbs/ac)	Fall/97	120 (52)	94 (41)
Fertilizer P_2O_5 lbs/ac at seeding (P lbs/ac)	Spring/98		(26)
	Sum P	89	127
Soil Kelowna K lbs/ac (0-0.15 m)	Oct./97	528	560
Fertilizer K_2O lbs/ac (K lbs/ac)	Fall/97	80 (66)	80 (66)
Fertilizer K_2O lbs/ac (K lbs/ac)	Spring/98	0	0
	Sum K	594	628

Table 2. Petiole analysis in 1998 from site specific potatoes.

	NO_3-N %			P %			K%		
	July 6-7	July 22-23	Aug. 10-11	July 6-7	July 22-23	Aug. 10-11	July 6-7	July 22-23	Aug. 10-11
Standards for adequate level of nutrient	0.16-0.24	0.12-0.18	0.10-0.16	0.22-0.62	0.20-0.50	0.16-0.36	7-9	5-7	3.5-5.5
Hays (Snowden)									
% High	0	0	4	17	0	0	0	67	100
% Adequate	4	12	50	77	21	54	73	33	0
% Deficient	96	88	46	6	79	46	27	0	0
Fincastle (Russet Burbank)									
% High	3	24	22	0	0	0	0	19	57
% Adequate	21	59	57	76	30	6	33	73	41
% Deficient	76	17	21	24	69	94	67	3	2

Phosphorus

Petiole P (Table 2) (Figure 3) was adequate for most of both fields on the first sampling in 1998. Soil P was adequate on most of the Fincastle field and marginal on the Hays field. It declined rapidly on the Hays field and by July 22 most of the petiole samples were deficient compared to a minimum recommended level of 0.2%. However, by August 10 only 46% of the samples were deficient compared to a minimum standard of 0.16% P. The farmer at Hays had applied 120 lbs/ac P_2O_5 fertilizer. Either the crop lost its ability to absorb P from the soil through disease or the fertilizer P did not remain in an available form to the crop. The soil pH was between 7.0 and 8.0. Calcium carbonate ($CaCO_3$) was determined on samples from 12 of the grid sites for each of the two fields (Table 3). Mean $CaCO_3$ levels were very low on the Hays field or 0.3% for 0 to .15 m depth to 1.7% for 0.30 to 0.60 m. The Fincastle field had $CaCO_3$ levels of 2.6% for 0.0 to 0.15 m to 6.4% for 0.30 to 0.60 m. The $CaCO_3$ content of the Hays field was not high enough to appreciably fix phosphorus however the higher levels on the Fincastle field could be expected to reduce the availability of phosphorus. Clay content was low averaging about 11% on both fields. The Fincastle field had higher soil P than the Hays field. Potato tissue P declined steadily and 94% of the Fincastle field was deficient by August 11. It is not clear to what extent fixation of P by clay or calcium carbonate or loss of ability of the potatoes due to disease such as Rhizotonia reduces the uptake of phosphorus in these two fields.

Table 3. Mean $CaCO_3$ levels on twelve samples from the 1998 Hays and Fincastle potato fields.

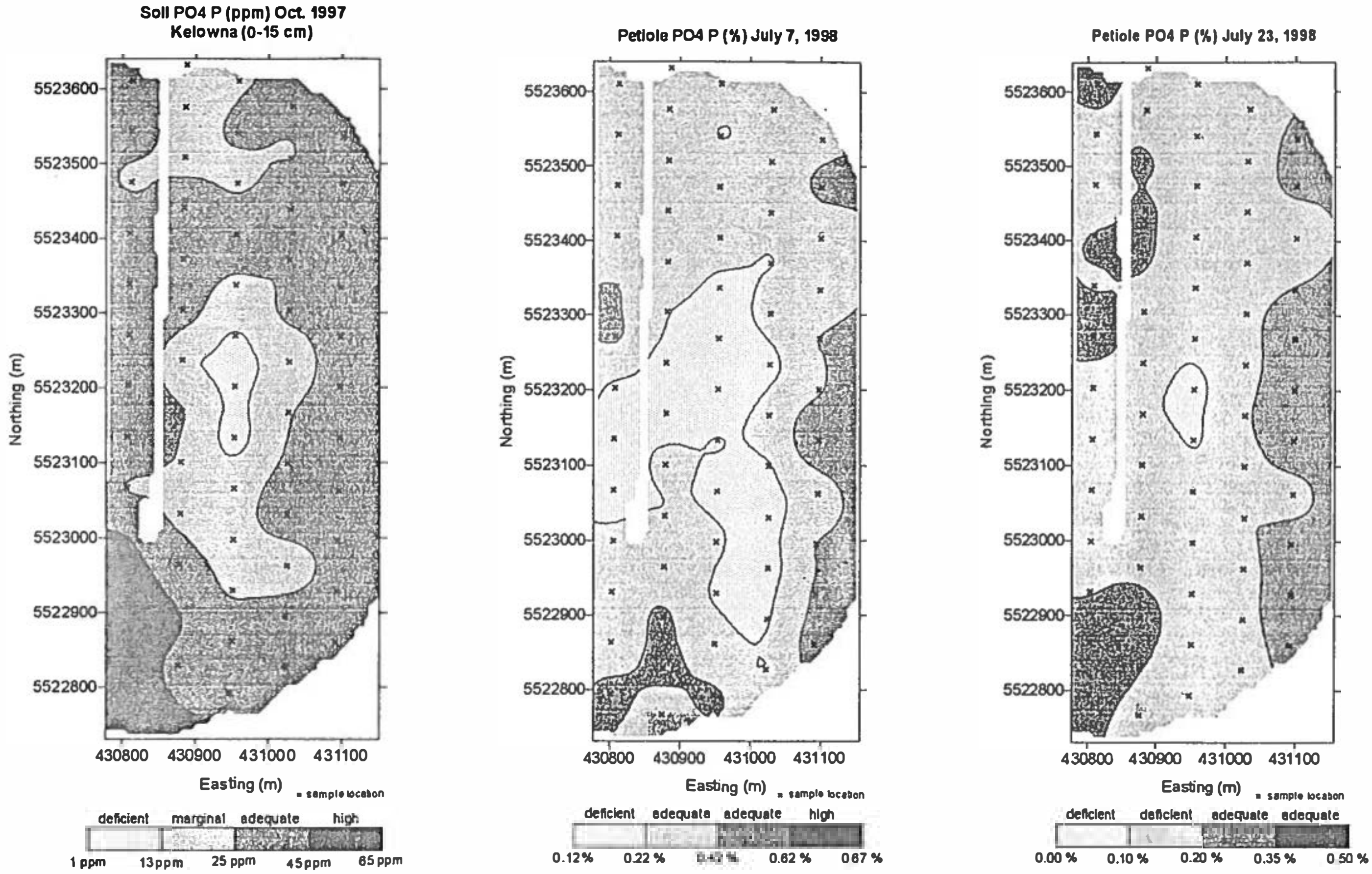
Depth m	% $CaCO_3$ Hays	% $CaCO_3$ Fincastle
0.0 - 0.15	0.3	2.3
0.15 - 0.30	0.6	3.5
0.30 -0.60	1.7	6.4

Potassium

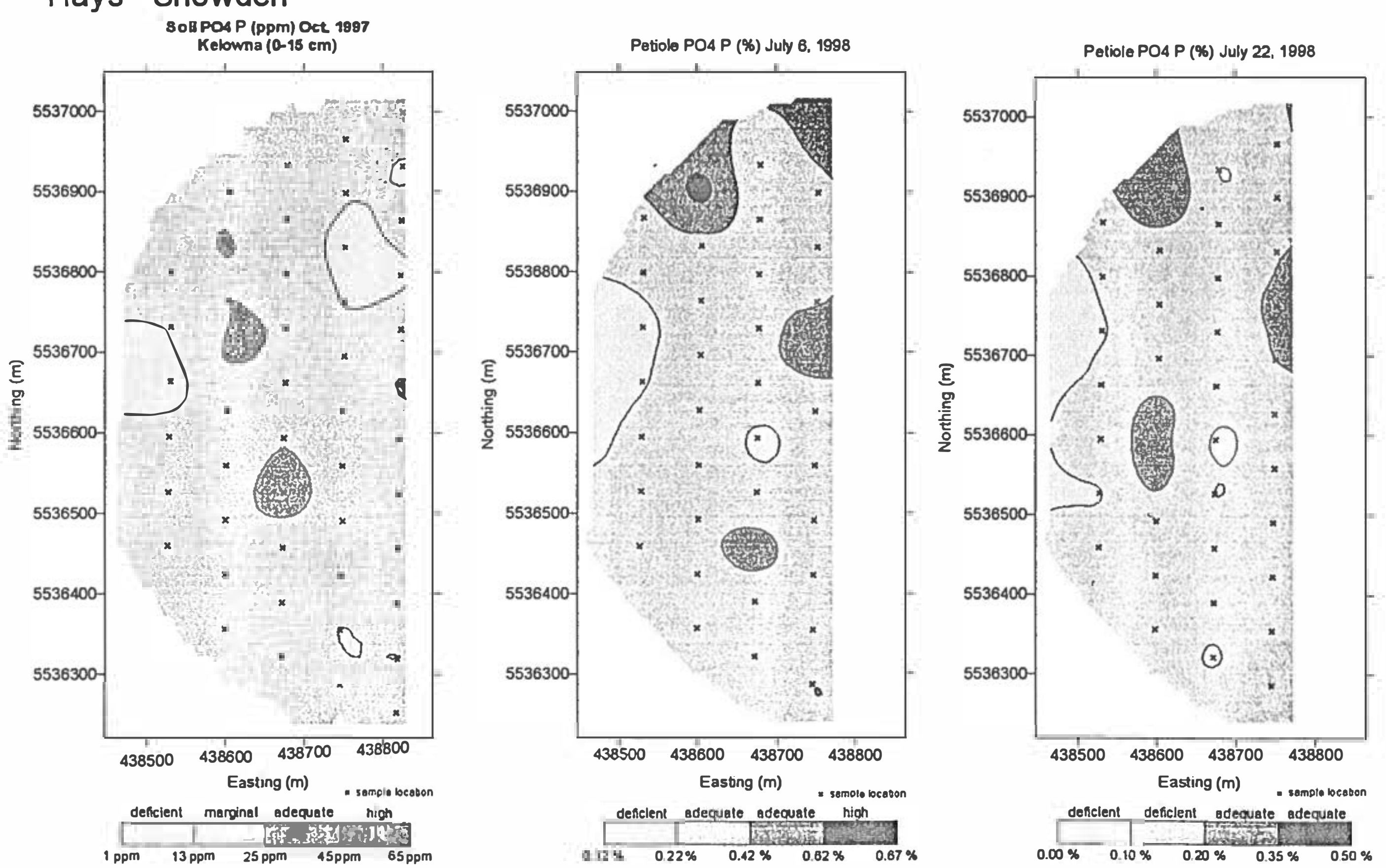
The Hays field had marginal levels of soil K (75-150 ppm) on 38% of the sample sites and the Fincastle field had marginal levels of soil K (>150 ppm) at 47% of sites. The Hays field had 27% and the Fincastle field 67% of the field with deficient levels of petiole K (<7%) in the first week of July (Figure 2). By August 10-11 the Hays field had 100% of the field and the Fincastle 57% of the field with a high level tissue potassium and only 2% of the field with deficient levels of tissue K. These results are similar to 1996 and 1997 where potassium was deficient early in the season and in excess late in the season. Standards for adequate and deficient petiole K are not well established for potatoes. These standards may also need to be adjusted for crops growing under cold conditions. This project has not tested if extra potassium will increase yield of tubers.

Figure 3. Soil and Petiole Phosphate Phosphorus of Two Fields of Potatoes

Fincastle - Russet Burbank



Hays - Snowden



Irrigation Yield and Quality

In 1996, water application on the Hays field was not uniform. The high pressure circular pivot was operated at below optimum pressure which resulted in more water at the centre and less at the outside of the field. In early 1997 the farmer had this irrigation system redesigned and converted to a low pressure pivot. Subsequent Irrigation applications were more uniform but irrigation and rainfall on the outer portions of the pivot were about 40 mm (or 10%) greater than the centre portions of the pivot in both 1997 and 1998 fields. The 1998 pivot, also a low pressure pivot, water applications were slightly higher on the outside than in the centre. Average water applications plus rainfall from June 17 to September 10 was about 410 mm which is high for a medium late determinate variety of potatoes. Therefore, any parts of the field receiving slightly less water would not usually be under water stress. In 1997 at the Hays field, the average tuber size was lower on the outer part of the field. In 1998 there were no differences in tuber size in response to water applications.

The Hays (Snowden) potatoes in 1998 yielded less in the centre of the field than the remainder of the field. This was similar to the previous crop of wheat (Figure 2). The centre part of the field had a clay content of 5-10% in both surface soil (0 - 0.60m) and subsoil (0.60 - 0.90m). The remainder of the field had higher clay contents than this in the subsurface layers.

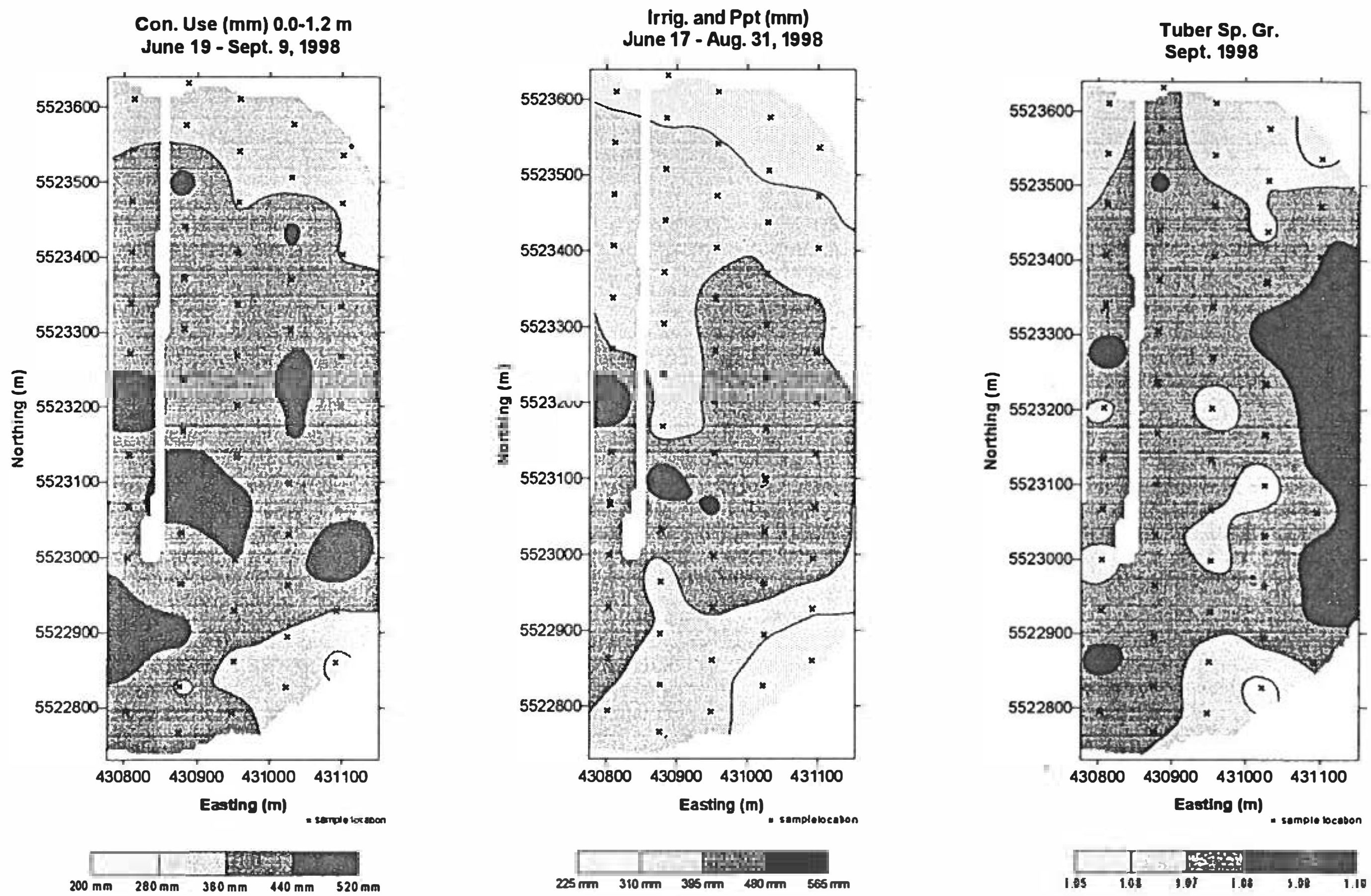
Tuber samples collected at the grid points in the Hays field were used in chipping quality tests. Contour maps were made of the chipping scores, which ranged from 54 to 64. These scores were not closely correlated to any of the measured crop or field characteristics.

The Fincastle potato fields in 1996 and 1997 were irrigated by two different corner pivots. The Fincastle field in 1997 showed uneven water applications on the main portion of the field with applications from 360 to 500 mm. The edges of this corner pivot system also received less water than the main part of the field. In 1998 this difference persisted (Figure 3) on the east half of the same field as in 1997. In 1998 the central part of the field received 350 to 450 mm while the outer parts of the field received 250 to 350 mm. The average water use in 1998 from June 17 to August 31 was about 385 mm.

The uneven water applications at Fincastle influenced the size of tubers, with the moister areas in 1997 producing a higher total yield and a greater number of small tubers than the dryer corners. In 1998 the yield was lower in the centre part of the field and the corners and highest on the east side of the field. The centre and the east side all had a low barley yield in 1997 (Figure 3). The corners received less water than the remainder of the field. The centre was lower in soil P and K than the remainder of the field. Most of the field was low (below 3 ppm) in soil N (0 to 0.60 m).

Tuber specific gravity (Figure 4) was lower (1.055 to 1.07) in the corners than the remainder of the field (1.065 to 1.085). Restricted water supply will delay maturity of an indeterminate variety like Russet Burbank and cause reduced specific gravity. The east side had a high potato yield in 1998 and a low barley yield in 1997 which may be because this part of the field has high soil phosphorus. Potatoes respond more to phosphorus than barley.

Figure 4. Fincastle Potatoes 1998: Consumptive Use, Precipitation + Irrigation and Tuber Specific Gravity



Scores of French fry texture and color were determined for the Fincastle Russet Burbank tuber samples collected on the grid. Texture scores varied from 3.0 to 4.0 on a scale of 1.0 to 4.0 with 4 being excellent. Color scores ranged from 3.0 to 6.0 on a scale of 1.0 to 7.0 where 7.0 is excellent. The texture and color score ratings did not correlate closely to crop water measurements, crop analysis, soil analysis or tuber yield.

Nitrogen Fertilizer Rates

A series of strips of different treatments of N and P fertilizer were applied in April, 1998 on both potato fields. Each strip was 6 rows wide or 5.18 m on the Hays field and 5.49 m at the Fincastle field to account for the six rows width harvested. The strips were each about 800 m long and were repeated three times on each field. The strips consisted of nitrogen (60 lbs/ac N) and phosphorus (65 lbs/ac P_2O_5) added (Table 4) in addition to the rates applied by the farmers (Table 1).

Table 4. Nutrients lbs/ac applied in 1998 on fertilizer strips in excess of farmers rate to Hays and Fincastle fields.

Treatment	N	P_2O_5
N	60	0
P	0	65
NP	60	0
Check	0	0

Table 5. Potato yields in tons/acre (tonnes/ha) and gross value in $/acre on fertilizer strips.

	Hays		Fincastle	
Treatment	Yield	◊ Gross value ($/acre)	Yield	◊ Gross value ($/acre)
N	15.6 (34.9)	1498	14.8 (33.2)	1421
P	17.2 (38.6)	1651	16.9 (37.8)	1622
NP	16.7 (37.5)	1603	16.3 (36.6)	1565
Check	16.9 (37.6)	1574	16.0 (35.9)	1536

◊Value is based on 80% marketable at $120/ton

The treatments were harvested with the farmers' potato harvesters and yields were measured with the yield monitor. There were no significant differences between fertilizer treatments. In both fields the N treatment yielded less than the check or farmer's rate (Hays 4.4% and Fincastle 7.7%). The NP treatment was similar to the farmer's rate and the P treatment yielded slightly more (Hays +2.7% and Fincastle +5.3%) than the farmer's rate.

Nutrient Accumulation and Movement

Soil analysis in 1998 showed a moderate amount of nitrate in the soil zone at the Fincastle field (up to 100 kg N/ ha in the upper 1.5 m). Nitrate in shallow lacustrine groundwater at this site occurred at up to three times the drinking-water guideline; it was derived from agricultural sources. Nitrate was not detected in the underlying till.

In 1998 nitrate in shallow groundwater at the Hays field, at concentrations below or slightly exceeding the drinking-water guideline, was also derived from agricultural sources. High nitrate in till at locations with deep water table (7 to 9 times greater than the drinking-water guideline) was possibly derived from natural geologic sources. This site received excess water on portions of the field. This produces conditions leaching of nitrates downward and for reduction of nitrate and loss of N in a gaseous form as N_2 or NO_2.

Sodium and sulphate almost always exceeded drinking-water guidelines in groundwater in both study areas. Chloride guidelines were also often exceeded and generally increased with depth to a maximum of 250 mg/L. These ions were derived from natural processes. Manganese and phosphate often exceeded drinking water guidelines, and these chemicals were probably also derived from natural sedimentary sources. Soil results showed phosphate was concentrated in the upper 30 cm of the soil zone.

Conclusions

In 1997 total N for the crop from soil reserves and fertilizer applications were high yet both fields showed deficiencies in petiole N. Further applications of N fertilizer will cause increased losses of N to groundwater. In 1997 strip trials of N fertilizer indicated one farmer's rate was appropriate for maximum yield and the other's was slightly low. In 1998 the farmers' nitrogen application rates were increased over 1997 by 20% on the Hays field and by 7% on the Fincastle field. In 1998 petiole nitrogen deficiency at the third sampling for the two fields averaged 34% which was reduced from the 81% of the samples deficient in 1997. The extra nitrogen the farmers applied in 1998 had a beneficial effect. In 1998 fertilizer N treatments above the farmers' rates reduced the tuber yield; in contrast to 1997 where it had little effect.

In 1997 soil P and petiole P were adequate on the field which had received manure. The other field had low levels of petiole P on and after July 23 despite the large amounts of phosphorus that were added as fertilizer. This may indicate that fertilizer phosphorus was no longer available or that disease restricted phosphorus uptake. In 1998 both fields had appreciable portions with deficient tissue phosphorus levels. Extra phosphorus applied, in addition to the farmer's rates, slightly increased tuber yields on both fields.

In 1998 petiole K was low on the first sampling and later became adequate or high, similar to 1997 and 1996. Low temperatures may be the cause of low tissue K in early July. Research is needed to determine if petiole K levels below the current standards indicate a deficient crop, which will respond to K fertilizers under southern Alberta conditions.

Irrigation applications were found to be uneven on both sites. The amount of water influenced the size of tubers with more and smaller tubers being found in portions of the fields that received adequate amounts of water. At the Fincastle site, the specific gravity of the Russet Burbank tubers was low on the portions of the field which received less water than the remainder of the field.

Tuber quality was measured by tuber size, specific gravity and chipping and french fry evaluations. Only tuber size and specific gravity were associated with water, soil or crop factors.

In 1997 yield maps were made of barley at Fincastle and wheat at Hays on fields which were to be seeded to potatoes the following year. The wheat and barley yields were, in most cases, closely related to the potato yields.

Groundwater analysis from water table wells at both locations showed excess N which has leached downward from surface fertilizer applications. This occurred despite tissue N often being deficient. Excess irrigation or rainfall is believed to be the cause of loss of N to groundwater. Deeper wells at Hays contained high levels of nitrate which was believed to be developed from geological sources.

Site Specific Management of Potatoes

AARI Project No. 96M979

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ABSTRACT

Potato crops have many characteristics that make them suitable for precision agriculture, such as a high value with costly inputs of pesticides, fertilizer and water. The application of fertilizer and pesticides on potatoes may cause environmental problems and the risks of these can be reduced by using precision farming techniques. This potential for use of precision agriculture technology has not been exploited to any great extent because problems exist which have not been fully resolved. Between 1996 and 1999 a project on the site specific management (or precision farming) of potatoes was undertaken. The goals of the project were to utilize yield monitoring and global positioning technology to generate maps and to measure the variability of the yield of potatoes in a field; to determine the effect of soil type, landscape position, nutrient level, fertility treatments, disease and weeds on the yield of potatoes; to determine yield and variability of crops over several years and relate this to field characteristics and to potato yield and quality; to evaluate the use of remote sensing and digital image analysis to detect nutrient deficiencies and diseases of potatoes; to measure the financial and environmental benefits of site specific management of potatoes; and to measure the movement of nitrogen below the root zone.

A yield monitor was successfully adapted to two farmers' potato harvesters and used to map tuber yields. Difficulties were encountered on parts of fields where soil lumps occurred, usually on areas with a high clay content. Yield maps were also developed from grid sampling. These grid samples were used to determine tuber yield, average tuber size and tuber quality as measured by specific gravity, chipping score and French fry score. Uniformity of irrigation affected tuber size. No relationship was found between chipping and French fry score and the measured factors of soil or water in the field. Grid sampling of the fields also showed variability in soil texture, which was correlated to various soil and plant chemical properties.

Two of six fields had sufficient variability of soil nitrogen to justify the cost of soil sampling and variable rate application. However, petiole NO_3-N in the first week of July was significantly negatively related to 0.0-0.60 m depth of soil clay and was not significantly related to soil NO_3-N. This means it would be more useful for farmers on these fields to base a site specific nitrogen application on soil clay content than on soil NO_3-N content. Soil P was significantly positively correlated to petiole P content but not clay content. Opportunities exist for precision applications of phosphorus particularly on two of the fields that had a history of receiving non-uniform applications of manure. However, phosphorus fertilizer applications based on grid sampling of soil phosphorus should provide some improvement in efficiency of uptake of phosphorus. Potassium levels in the soil from 1997 to 1999 were marginal to adequate on most grid sample sites. In 1997 and 1998 petiole K levels were deficient in the first week of July but became adequate to high in two later samplings. The reason for this is not known. It may be due to lower soil temperatures in early July restricting uptake, rather than the higher soil temperatures in the USA where the standards for petiole K were developed. There is a need to develop local standards for petiole K levels.

Precision fertilizer application is practiced on some potato farms in Canada, but the use of this technology is limited by the cost of soil sampling and analysis to accurately describe the field. If precision agriculture technology is to have widespread adoption in the potato industry, solutions to the obstacles of cost, soil lumps and other problems need to be incorporated into the technology.

FIGURES

Snowden Potatoes: Hays 1997 Sample Sites

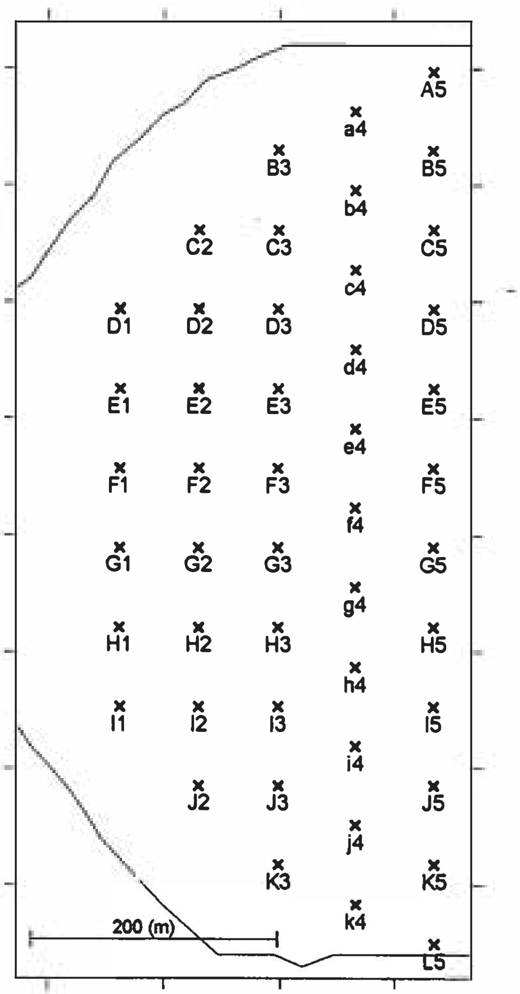


Figure 1. Sampling grid for yield, petioles, water and soil samples for Snowden potatoes grown at Hays in 1997.

INTRODUCTION

Since 1991, Global Positioning System (GPS) technology and yield monitoring equipment has made it possible to develop detailed yield maps of various crops. Farmers in the USA, Canada and Australia are interested in GPS as a means to increase profits by optimizing fertilizer applications. In western Europe, GPS has been used to avoid environmental contamination from excess application of fertilizers and manure. Other computer technology makes it possible to overlay maps of yields, soil or crops and measure relationships between them.

Since 1994, site specific management of cereal and oilseed crops in Alberta has increased steadily. Today, about 300 farmers in Alberta use yield monitors and some of these prepare yield maps of their fields. Site specific management of inputs can be done in a detailed or in a general manner by dividing the field into a few categories (Bouma et. al., 1995). Variable rate inputs can be applied with the assistance of GPS by a programmable fertilizer or herbicide applicator. Prototype irrigation systems have been developed to apply variable rates of water. (King et. al., 1995).

Potatoes are a high value crop requiring a lot of inputs, such as fertilizer, pesticides and irrigation. Potatoes are often grown on coarse textured soils that have low nutrient holding capacity and are high in field variability. Excess nitrogen can delay maturity of the crop and contribute to groundwater contamination. With the use of site specific management zones, with soil texture as a variable, the contamination of water can be reduced (Delgado and Duke, 2000; Whitley et. al., 2000). Insufficient nitrogen will reduce yield and increase the severity of early blight in potatoes. Phosphorus fertilizer applications for potatoes are higher than other crops, which represents an appreciable cost to farmers who are often growing potatoes on rented land. High phosphorus application may cause excess soil phosphorus, the major agricultural factor that contributes to water contamination. This results in the rapid growth and decay of algae in lakes, streams and rivers causing eutrophication and fish death. Recommendations for phosphorus requirements of potatoes by Tindall et. al. (1991) exceed those measured in a precision agriculture experiment by Davenport et. al. (1999). Traditional research under small plot conditions does not account for field variability and is usually conducted on uniform sites. The production of irrigated potatoes in southern Alberta has increased from about 9,000 ha in 1992 to

18,000 ha in 2000 and further increases are expected. If potatoes are grown in a one crop per four years rotation, 72,000 ha will be required or more than 13% of the irrigated land in Alberta. This expansion means fields are being used which are less than optimum for potato production.

Potato processors are concerned about uniform quality of tubers. By controlling storage conditions, processors can alter the sugar content of a storage bin of potatoes to an optimum level for processing. However, this is difficult in a storage bin of potatoes where the original quality is not uniform. For processing, the size and shape of tubers are important. As well, a high specific gravity in potatoes means there is more dry matter for making chips or French fries and the tubers will store well. However, two producers of French fries have encountered problems with some Alberta tubers having excessively high specific gravities, which interfered with processing. Other factors that are detrimental are the presence of disease or hollow heart.

Potato fields are closely monitored during the growing season. Many growers sample leaf petioles and monitor each field on a weekly or biweekly basis for nitrogen nutrition. During the growing season when required, fertilizers are added by fertigation or pesticides are applied to control diseases, insects or weeds. Most observations are based upon repeated sampling of a specific area within the field. The area sampled may only be representative of a portion of the field. Growers need to have some idea of the variability within a field when applying inputs to the field (King et. al., 1999; Verhagen, 1997).

A yield monitor for potatoes consisting of load cells mounted under the harvester belt was first built by Harvestmaster (Campbell, 1999) and tested by the USDA near Prosser, Washington in 1995 (Rawlins et. al., 1995; Schneider et. al., 1997). The harvester position in the field was continually located by means of a differential global positioning system. C. McKenzie and M. Green observed these tests and concluded it merited evaluation on Alberta fields as a means to measure tuber yield and correlate this to soil and crop conditions. Since that time, other yield monitors have been developed consisting of load cells on a weigh wagon (Godwin et. al., 1999) or with a camera and computer to identify tubers from other irregular objects (Wooten et. al., 2000).

OBJECTIVES

1. To use a potato harvester equipped with a yield monitor and global positioning technology to generate maps and to measure the variability of the yield of potatoes in a field;
2. To determine the effect of soil type, landscape position, nutrient level, fertility treatments, disease and weeds on the yield of potatoes;
3. To determine yield and variability of crops over several years and relate this to field characteristics and to potato yield and quality;
4. To evaluate the use of remote sensing and digital image analysis to detect nutrient deficiencies and diseases of potatoes;
5. To measure the financial and environmental benefits of site specific management of potatoes;
6. To measure the movement of nitrogen below the root zone.

DEVIATIONS FROM OBJECTIVES

Remote sensing data with spectral analysis was obtained in the first year (1996) of the project on one field at Hays and in the fourth year (1999) at Hays and Fincastle. In 1997 and 1998 false color infrared imagery data was obtained on two fields. This type of infrared imagery was not useful for detailed analysis. In 1998 satellite multispectral imagery was obtained from Resource 21 and it was not feasible to do detailed analysis.

Yield of potatoes and yields of the previous crops on these fields was only obtained on two fields in 1997. Some of the other crops were sugarbeets for which a yield monitor was not available. Some of the grain was harvested with an older model combine, which was not suitable for attaching a yield monitor. Some grain fields were harvested with a custom operator who was not agreed upon until commencement of harvest. This did not provide an opportunity to install a yield monitor, so these fields were not monitored.

Nitrogen movement below the root zone was difficult to distinguish from residual nitrogen, which was also present in the till parent material. Only estimates of nitrogen movement through the soil profiles could be made.

In 1999, at the Hays site, treatments of compost and manure were applied in strips, to determine whether or not they would affect the incidence of *Rhizoctonia* and scab on tuber surfaces.

Soil Salinity

Using Global Positioning techniques (Cannon et. al., 1994), soil salinity was mapped on a field with an EM38 meter (McKenzie et. al., 1989) in order to compare growth of potatoes to soil salinity (McKenzie et. al., 1997). This method would evaluate the potential of mapping a field for soil salinity and limiting planting of potatoes only on those areas with less than a critical salinity level. A salt tolerant crop could be planted on the remainder of the field. This objective was not included in the original objectives.

RESEARCH DESIGN AND METHODS

Fields Monitored

In April 1996, two cooperating farmers were selected who agreed to provide one potato field each year for four years. Each irrigated field consisted of half a center pivot or 27 to 31 ha. The farmers were using a three-year rotation. This meant in the fourth year the project would return to the field monitored in the first year. The fields for one farm were located about 12 to 13 km south of Hays, Alberta, and fields for the other farm were from 3 to 10 km north of Fincastle, Alberta.

The legal location, soil type, number of grid sampling points, type of irrigation system and variety of potatoes grown for the fields monitored are given in Table 1. A sampling grid was set up on each field (Fig. 1). In 1996, this grid was established in the spring after seeding of potatoes. In 1996, the single soil samples taken were used to determine soil texture and water holding capacity. In the next three years, the grid was established in the fall of the preceding year with a set of composite soil samples from about 12 cores taken before fertilizer was applied. These samples (Table 2) were used to determine texture, water holding capacity and soil fertility. The grid sampling points were located with differential GPS.

The choice of potato cultivars and field practises were left up to the individual farmer cooperators. Field practises and cultivars can be considered as typical for irrigated potato

production in southern Alberta. The cultivars Snowden and Frito Lay 1625 are both chipping types while the Russet Burbank are fryers (Table 2). They are all considered as "late" varieties. Farmer experiences are that Russet Burbank have demonstrated better response to higher nitrogen fertilizer applications thus, they are fertilized more heavily. Frito Lay 1625 are also noted for their extensive rooting (vertical and horizontal) so they may be able to better exploit soil fertility. Farmers used their normal methods of seeding, cultivation, irrigation, pest control and harvest of their potato fields. The farmers' fertilizer applications are given in Table 3. Soil nitrogen, phosphorus, potassium values in 1996 were obtained from the farmers' records and in 1997, 1998 and 1999 were obtained from the grid samples (Table 4) and from the farmers' or fertilizer company's records. Soil phosphorus was determined by the Kelowna method (Van Lorop, 1988) and soil potassium was determined by the ammonium acetate methods in 1999. In 1997 and 1998, soil potassium was determined by the Kelowna method (Van Lorop, 1988), which gives lower values than the ammonium acetate method.

Table 1. Legal location and legal description of potato fields monitored and date first irrigated.

Year/Site	Legal Land Location	Soil Type	First Irrigated	Pivot Irrigated
1996 Hays	E½ NE 9 12 14 W of 4	from 0-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994
Fincastle	E½ NW 7 11 14 W of 4	Chin light loam Fluvial lacustrine	1956	1984
1997 Hays	W½ NE 9 12 14 W of 4	from 0-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994*
Fincastle	W½ NW 27 10 15 W of 4	Cavendish loamy sand and dune sand	1956	1987
1998 Hays	W½ SE 9 12 14 W of 4	from 10-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994*
Fincastle	E½ NW 27 10 15 W of 4 E½ SW 34 10 15 W of 4	Cavendish loamy sand and dune sand	1956	1987
1999 Hays	E½ NE 9 12 14 W of 4	from 10-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994*
Fincastle	E½ NW 7 11 14 W of 4	Chin light loam Fluvial lacustrine	1956	1984
Vauxhall	S½ SW 5 13 6 W of 4 E½ 5 13 6 W of 4	Clay loam to loam overlying Clay loam to clay till at about 1 m	1921	1995

*** pivot converted from high pressure to low pressure in 1997**

Table 2. Sampling sites, irrigation systems, field size and variety of potatoes grown.				
Year/Site	**# of grid sampling sites**	**Type of pivot Irrigation system**	**Field area (ha)**	**Cultivar of Potatoes**
1996				
Hays	40	High pressure	28	Snowden
Fincastle	8	High pressure corner	30	Frito Lay 1625
1997				
Hays	47	Low pressure	29	Snowden
Fincastle	53	High pressure corner	31	Russet Burbank
1998				
Hays	48	Low pressure	29	Snowden and others
Fincastle	63	High pressure corner	30	Russet Burbank
1999				
Hays	53	Low pressure	28	Snowden
Fincastle	51	High pressure corner	31	Frito-Lay 1625
Vauxhall	33	2 low pressure	115	Russet Burbank

Soil Moisture and Water Tables

Alberta Agriculture Food and Rural Development (AAFRD) Irrigation Branch staff from Taber and Brooks monitored soil water at each of the grid sampling points with a neutron probe. Soil moisture was determined to a depth of 1.0 m. Available moisture limits were calculated from particle size data according to Oostervelt and Chang (1980). A rain gauge was installed at each sampling point and rainfall and irrigation measurements were made approximately biweekly.

In 1997 and 1998 the groundwater was measured with 3 to 6 piezometer nests in each field (Rodvang, 1998 and 1999). The goal was to characterize groundwater flow and chemistry on the sites and determine whether agricultural nitrate occurred in the groundwater. Soil samples were collected during drilling and groundwater samples were collected during the season.

Fertilizer and Soils

Soil available nitrogen (N), phosphorus (P), and potassium (K) and soil pH maps were made for the 1997, 1998 and 1999 fields based on data collected the previous October from the sampling grid (Table 4). Soil texture maps were made from all fields based on grid samples (Fig. 2), which were used to develop relationships between texture and nutrient availability. In 1999, at Fincastle and Hays, soil calcium carbonate levels were determined and used to prepare maps at both sites.

Fertilizer Treatments

In 1997, 1998 and 1999, strip fertility experiments were set out. In 1997, the treatments (Table 5) applied were centered around the N2 treatment (farmer rate) (Table 3). Each strip was 8 rows or 6.7 m wide on the Snowden field and 8 rows or 7.3 m wide on the Russet Burbank field. In 1998, the fertilizer strips were in addition to the farmers' fertilizer rates (Table 6). Each strip was 6 rows wide or 5.03 m at Hays and 5.49 m at Fincastle. This represented one pass of the potato harvester. Yields were acquired and positioned on the fertilizer strips in 1997 and 1998 with GPS and a yield monitor on the farmers' potato harvesters.

In 1999, fertilizer plots were set out at Hays. Each plot was 12 rows or 10.1 m wide by 400 m long and was replicated twice. Compost manure and fertilizer treatments (Table 7) were broadcast on the plots in October of 1998. The plots were not fertilized by the farmer, except for 41 kg/ha N at seeding and a fertigation application of 50 kg/ha N during the growing season. The potatoes were hilled and seeded by the farmer in April of 1999. Snowden potatoes were grown and the field was fertigated (Table 3) and irrigated similar to the remainder of the field. Counts of visibly diseased plants on 600 m rows in each treatment were made in August of 1999.

Table 3. Farmers' soil fertility (N, P and K) before fertilization and N, P and K fertilizers applied and depth of soil samples (kg/ha).

		Hays (kg/ha)	**Fincastle (kg/ha)**
1996	Soil N Fall 95^{0}	(29) 0.0-0.30 m	(73) 0.0-0.60 m
	Fertilizer N prior to seeding	120	59
	Banded N at hilling	34	0
	Fertigated N	58	11
	Total N	**241**	**144**
	Soil P	(35) 0.0-0.30 m	(67) 0.0-0.30 m
	Fert P	48	32
	Total P	**83**	**99**
	Total K not available		
1997	Soil N 0.0-0.60 m	37	67 (52)
	Fert N Fall 96	90	0
	Banded N at hilling	39	179
	Fertigated N	88	41
	Total N	**254**	**287**

Table 3. Farmers' soil fertility (N, P and K) before fertilization and N, P and K fertilizers applied and depth of soil samples (kg/ha).			
		Hays (kg/ha)	**Fincastle (kg/ha)**
	Soil P 0.0-0.15 m 0.0-0.30 m	24	196
	Fert P Fall 96	59	0
	Fert P Spring 97	0	7
	6 fertigations	22	
	Total P 0.0-0.15 m	**195**	**203**
	Soil K 0.0-0.30 m	685	1066 (1935)
	Fert K Fall 96	56	0
	Fert K Spring 97	0	46
	Total K	**741**	**1112**
1998	Soil N 0.0-0.60 m	28	32
	Fertilizer N Fall 97	179	190
	N at seeding	0	20
	N at hilling	47	35
	6 fertigations	50	31
	Total N	**304**	**308**
	Soil P 0.0-0.15 m	41	67
	Fertilizer P Fall 97	58	46
	Fertilizer P at seeding		29
	Total P	**99**	**142**
	Soil Kelowna K 0.0-0.15 m	591	627
	Fertilizer K Fall 97	74	74
	Total K	**665**	**701**
1999	Soil N 0.0-0.60 m	38	90
	Fertilizer N Fall 98	157	112
	Fertilizer N at hilling	41	20
	Fertigations of N	50	30
	Total N	**286**	**252**
	Soil P 0.0-0.15 m 0.0-0.30 m	47 71	93 127
	Fert P Fall 98	59	39
	Fert P Spring	0	29
	Total 0.0-0.15 Soil P	**106**	**161**
	Soil K 0.0-0.30 m	757	733
	Fertilizer K Fall 98	56	56
	Fertilizer K Spring	0	0
	Total K	**813**	**789**

[0] ( ) soil nutrient values supplied by the farmer from his soil sampling

Table 4. Soil analysis done for the site specific potato project.

Year	Sand (%)	Silt (%)	Clay (%)	NO_3 – N (ppm)	NH4-N (ppm)	Miller Axley PO_4-P(ppm)	Kelowna PO_4-P (ppm)	Ammon Acetate K (ppm)	Kelowna K (ppm)	pH	2:1 extract E.C. (dS/m)	Zn (ppm)	Cu (ppm)	Mn (ppm)	Fe (ppm)	Na (ppm)	CaO_3 (ppm)	S (ppm)
1996 sampled May 26 0.0-0.90 m	✓	✓	✓	-	-	-	-	-	-	-	-	-				-	-	-
1997 sampled Oct.96 0.0-0.90m	✓	✓	✓	✓	1/6 of profiles	✓	0.0-0.15 m 0.15-0.30 m		0.0-0.15 m 0.15-0.30 m	✓	✓	1/6 of 0.0-0.15 m samples					Hays	
1998 sampled Oct. 97 0.0-0.90m	✓	✓	✓	✓	✓	✓	0.0-0.15 m 0.15-0.30 m		0.0-0.15 m 0.15-0.30 m	✓	✓	0/0-0.15 m						
1999 sampled Oct. 98 0.0-0.90 m	✓	✓	✓	✓	✓	✓	0.0-0.15 m 0.15-0.30 m	✓	0.0-0.15 m 0.15-0.30 m	✓	✓	0.0-0.15 m				✓	0.0-.15 0.15-0.30	✓

✓ all samples analyzed

Samples were dug from each treatment and treatment yields were determined using a yield monitor and GPS on the farmer's harvester. Disease counts of the amount (%) of tuber surfaces infected with scab and *Rhizoctonia* were determined on 160 tubers from each treatment. Occurrence of disease was not significantly different between treatments so this data is not reported.

Table 5. Nutrients (N, P and K) in kg/ha applied on fertilizer strips in 1997.

	Hays			Fincastle		
Treatment	**N**	**P**	**K**	**N**	**P**	**K**
N1	30	59	50	53	6	41
N2	92	59	50	176	6	41
N3	182	59	50	311	6	41

Table 6. Nutrients (kg/ha) applied in 1998 on fertilizer strips in excess of farmers rate to Hays and Fincastle fields.

Treatment	N	P
N	67	0
P	0	32
NP	67	32
Check	0	0

Table 7. Fertilizer treatments at Hays in 1999.

		Nutrients kg/ha		
Treatment	**T/ha**	**N**	**P**	**K**
High compost	18.1	199	84	174
Low compost	9.8	107	45	94
High manure	26.8	158	82	216
Low manure	12.8	75	39	103
High phosphorus		90	58	0
Low phosphorus		90	20	0

Tissue Samples

Each field was tissue sampled three times at each of the grid points (early July, late July and the second or third week of August). Tissue samples consisted of 45 to 70 petioles taken from the fourth leaf of plants within 5 m of the grid sampling points. All the tissue samples were analyzed to determine NO_3 N, total N, P, Ca and moisture. In 1996 and 1997, 24% of the samples, and in 1998 and 1999, all the samples, were analyzed to determine K, S, Zn, B, Mn, Fe, Mg, Al, Cu, Na (Table 8). These tissue levels were compared to sufficiency limits (Table 9) based on limits used by various Alberta and USA soils laboratories.

Pest Monitoring

Diseases were monitored by walking the fields. Some areas of the Hays fields received excess water and developed water-induced rot of tubers. These areas were not harvested. In 1999 fertilizer, compost and manure treatments were set out as strips on the Hays field. Disease counts were made on two rows from the three 50 meter long strips from each of the two replicates of the treatments. The 1999 Vauxhall and Fincastle fields had very little disease on all fertilizer treatments so no disease counts were made in these fields.

In 1996 to 1998 weeds in all fields were widely dispersed and not clustered so they were not mapped with GPS or remote sensing techniques. In 1999 dense areas of Canada Thistle (*Cirsium arvense*) occurred on the Hays field. The perimeters of some of these GPS areas were mapped with differential GPS, by walking with a backpack unit obtaining correction data from a base station at the edge of the field. These areas were then located on the CASI images of the field.

Remote Sensing

In July 1996, Itres, a commercial remote sensing firm, collected airborne compact spectographic imager (CASI) data on the Hays potato field. Alberta Environment took color infrared photos at a scale of 1:5,000 and 1:10,000 on July 14, 1997, at Hays and Fincastle; July 23, 1998 at Hays and Fincastle and July 23, 1999 at Hays, Fincastle and 1:15,000 photos at Vauxhall. On July 28, 1999, CASI data were taken of the Hays, Fincastle and Vauxhall potato fields by Itres. GPS positions of ground control points were taken and used to prepare georeferenced images.

Tuber Samples

In 1997, 1998 and 1999, two samples were hand dug near each grid point prior to harvest. Each hand sample consisted of four uniformly spaced plants in 1.22 m of row. The farmer at Fincastle used 0.91 m row spacing between rows and the farmer at Hays used 0.84 m spacing between rows. In addition, in 1999, four samples were hand dug from each replicate of each fertilizer treatment.

The potato samples were washed, graded into size categories and weighed to determine yield. Scab and *Rhizoctonia* scores were made on 20 tubers from each sample from Hays in 1998 and both Hays and Fincastle in 1999. Samples were chipped and chipping quality color scores were done on the Hays tuber samples in 1997, 1998 and 1999. Samples were French fried and French fry quality, color and texture scores were done on the Fincastle tuber samples in 1997, 1998 and 1999.

Global Positioning Systems and Yield Monitoring

Global positioning techniques were used to locate points on the grid for sampling tubers (Table 10). At harvest, the potato fields were mapped using a NovAtel GPS and a Harvestmaster yield monitor mounted on the farmer's potato harvester (Campbell, 1999). The NovAtel RT-20 DGPS delivered accuracies of 0.20 m horizontal and 0.30 m vertical. A topographic map was prepared at the same time as the yield map. In 1997, wheat and barley fields were yield mapped using an Ag Leader yield monitor coupled to an Omnistar receiver, with real-time differential corrections from a geostationary satellite service. This system provided accuracies of 0.5 to 1.0 m horizontal and 1.0 to 2.0 m vertical. The Omnistar information was not suitable to use to prepare topographic maps because of the lack of accuracy in the vertical axis.

Soil Salinity

The site at Vauxhall was chosen in 1999 because it contained a range of soil salinity. Potatoes are considered to be moderately sensitive to salinity. In April, prior to seeding the potatoes, the soil salinity in the field was mapped by towing an EM38 salinity meter behind an all-terrain vehicle and positioning it with GPS technology (Cannon et. al., 1994). On July 28 and September 1, 1999, Itres flew over the field and collected CASI data. In late September, 58 points were selected to represent different levels of soil salinity. At each of these sample points, salinity was determined with an EM38 according to McKenzie et. al. (1989). Tuber samples consisting of two 1.22 m lengths of row each with four uniformly spaced plants, were dug at these sampling points. A regression analysis was developed between tuber yields, tuber specific gravity and soil salinity. The CASI imagery was compared to the salinity map.

Table 8. Petiole analysis volume and parameters.

		Sampling date			Analysis													
Year	Location	1st	2nd	3rd	Moisture	N	Ca	P	NO_3 N	K	S	Zn	B	Fe	Mg	Al	Ca	Na
1996	Hays	July 3	July 30	Aug. 20	✓	✓	✓	✓	✓		∉	∉	∉	∉	∉	∉	∉	∉
	Fincastle	July 4	July 30	Aug. 20	✓	✓	✓	✓	✓		∉	∉	∉	∉	∉	∉	∉	∉
1997	Hays	July 3	July 23	Aug. 12	✓	✓	✓	✓	✓	✓	∉	∉	∉	∉	∉	∉	∉	∉
	Fincastle	July 7	July 24	Aug. 13	✓	✓	✓	✓	✓	✓	∉	∉	∉	∉	∉	∉	∉	∉
1998	Hays	July 6	July 22	Aug. 10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Fincastle	July 7	July 23	Aug. 11	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1999	Hays	July 7	July 30	Aug. 17	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Fincastle	July 9	July 28	Aug. 13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Vauxhall	July 6	July 27	Aug. 11	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✓ all samples analyzed

∉ 1/5 of samples were analyzed

Table 9. Potato petiole nutrient sufficiency levels from three soil/plant analysis labs and levels found in this project.				
	Stage/or time after emergence	**NO_3-N (%)**	**P (%)**	**K (%)**
Lab A				
	Vegetative	1.2-1.5	03.0-04.0	7.0-8.0
	Tuber initiation	1.2-1.5	0.25-0.35	7.0-8.0
	Tuber bulking	1.2-1.5	0.25-0.30	6.5-7.5
	Tuber half grown	1.0-1.5	0.20-0.25	6.0-7.0
	Tuber maturing	0.5-1.0	0.15-0.20	3.0-5.0
Lab B				
	+3 weeks	2.5-3.0	0.24-0.44	11.8-13.8
	+9 weeks	1.8-2.3	0.20-0.40	9.8-11.8
	+15 weeks	1.2-1.7	0.16-0.36	7.8-9.8
	Pre-vine kill	0.5-1.0	0.14-0.34	5.8-7.8
Lab C				
	Early season	0.8-1.2	0.12-0.2	9-11
	Mid season	0.6-0.9	0.08-0.16	7-9
	Late season	0.3-0.5	0.05-0.1	4-6
Hays and Fincastle for FL 1625, Russet Burbank or Snowden				
	early July (3^{rd}-7^{th})	1.4-2.2	0.22-0.62	7-9
	late July (23^{rd}-30^{th})	1.2-1.8	0.20-0.50	5-7
	mid August (12^{th}-17^{th})	1.0-1.6	0.16-0.36	3.5-5.5

Table 10. GPS Applications 1996-1999.			
Year/Crop	**Site**	**GPS differential source**	**Monitor**
1996			
Russet Burbank Potatoes	Fincastle	Novatel RT-20 + local base corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
1997			
Russet Burbank Potatoes	Fincastle	Omnistar + geostationary corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
Wheat	Hays	Omnistar + geostationary corrections	Ag Leader
Barley	Fincastle	Omnistar + geostationary corrections	Ag Leader
1998			
Russet Burbank Potatoes	Fincastle	Novatel RT-20 + local base corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
1999			
FL1625 Potatoes	Fincastle	Novatel RT-20 + local base corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
Russet Burbank Potatoes (salinity only)	Vauxhall	Novatel RT-20 + local base corrections	EM38 salinity meter

RESULTS AND DISCUSSION

Soil Moisture, Water Tables and Yields

In 1996, at Hays, potatoes were grown on the east half of a high-pressure pivot (Fig. 3b), which was operated at less than the optimum pressure. This resulted in an uneven distribution of water with excess water applied near the centre and insufficient water applied on the outer parts of the circle. On the same pivot, in the following year, 1997 (Fig. 3a), potatoes were grown on the western half. Meanwhile, the farmer had redesigned his system, converting the high pressure pivot to a low pressure pivot. This new pivot had uneven calibration causing a high application of water on the outer part of the circle and less in the centre. The contrasting distribution patterns from the two years are shown in Fig. 3.

Prior to redesign of the pivot system, excess irrigation near the centre of the pivot caused accumulation of water below the root zone in Hays (1996) (Fig. 4b) while the surface layers (Fig. 4b) had deficient available water, especially in the outer parts of the pivot (30% to 55% of field capacity). These conditions create the possibility for leaching of nutrients below the root zone, waterlogging and increased disease in low areas of the fields. The excess irrigation occurred because the pivot was operating near the center at less than the designed pressure.

In three years, 1997-1999 and six fields, uniformity of irrigation application was a significant factor, influencing yield in four of the six fields. In three fields, Hays 1998 (Fig. 5a), Hays 1999 and Fincastle 1999 (Fig. 5b), total yield significantly increased with increasing irrigation.

Mean tuber weights were increased with increasing irrigation at Hays 1998 (Fig. 6a) and slightly, but not significantly, decreased with increasing irrigation at Hays in 1997 (Fig. 6b).

Irrigation management is one of the critical factors influencing both yield and tuber size. Areas of the field, which received more than average irrigation plus precipitation had increased tuber numbers, reduced mean tuber weights and greater numbers of small tubers, as compared with areas which received less than average irrigation plus precipitation.

At Fincastle in 1996 and in 1999 and on the two halves of a field in 1997 and 1998, corner pivots were used. These pivots did not provide as much water to the corners as the rest of the field. When the corner arm was extended and operating, the remainder of the pivot appeared to have reduced output.

Piezometer measurements of groundwater depth movement and soil NO_3-N content at the Hays site in 1997 (Fig. 7) and Fincastle 1997 (Fig. 8) and 1998 are reported by Rodvang (1998 and 1999). Hays had less than half the NO_3 N than Fincastle. The Hays site was irrigated more than the Fincastle site. Nitrate levels were low at depth but this may be due to reducing conditions, causing denitrification. Once all nitrate is reduced, denitrifying bacteria tend to reduce sulphate to H_2S. The odor of H_2S was present at two of the well sites at Hays in 1997 indicating some sulphate was being reduced (Rodvang, 1998). At some of the wells, the texture was coarse permitting downward movement of water. At Hays, the flow of groundwater occurred from the irrigated field outward to the unirrigated rangeland. Irrigation has caused water table mounding below the sites. Water tables rose during the summer at Hays and reached a peak of 1.2 m below the ground at one site in 1997 and 1.65 m in 1998.

At Fincastle, the irrigation applications generally were less than at Hays. The water table followed the surface topography. In 1997 water table depths ranged from 1.7 to 3.5 m. In 1998 at Fincastle, water table depths varied from 1.5 to 2.5 m below ground level and were over 5 m deep at one of the six sites. Water levels rose during the summer in both years and declined after late August. Vertical hydraulic gradients indicated slight downward flow at most piezometer nests.

In 1997, nitrate was present in soil water at the piezometer sites at levels from 1 to 20 mg/kg at Fincastle. Nitrate levels at Hays were lower, from 1 to 6 mg/kg. Site 6 (R6 in Fig. 7) was located on native range adjacent to the potato field and had almost no nitrate to a depth of 1.5 m. The difference between the nutrient level at this site and the other 5 sites shows the effect of irrigated agriculture for 19 years.

Soil water phosphorus (P) was from 4 to 10 mg/kg at the cultivated Hays replicates (Fig. 9). This was compareble to the Fincastle site, where P ranged from 20 to 40 mg/kg in the 0-0.15 m layer (Fig. 10). The higher levels of P at Fincastle than at Hays was because Fincastle received hog manure applications for a number of years. It is interesting that the P had not move below 0.60 m at the time of sampling.

Soil Fertility

Nitrogen

Nitrogen (N) is the fertilizer used in largest quantities by potato growers and application of 160 to 240 kg of N/ha cost from $100-$150/ha. Site specific applications of N offers possibilities for reduction of costs. Soil nutrient variability was more evident at Fincastle than at Hays. Soil nitrogen was variable on the previous fall samples for the 1997 Fincastle field and to a lesser extent on the 1997 Hays field. The 1997 Fincastle field, for the 0.0-0.60 m depth, had 40% of the sample sites considered to be very deficient, 51% deficient to marginal and 10% adequate to high (Table 11). The farmer applied 179 kg/ha N at hilling and another 41 kg/ha N by fertigation during the growing season. These applications would be anticipated to be in excess of what could be used by the crop in areas of the field that already had 73 and 173 kg/ha soil N and would be expected to reduce potato tuber specific gravity. However, there was no relationship between soil N and specific gravity at the grid sites on the field. The 1997 Fincastle site had 89% of the 0.0-0.60 m soil samples with less than 15% clay, which means excess N could easily move downward. In 1997, Hays had 73% of the sample sites with 31 kg/ha N for 0.0-0.60 m and 26% of the sites with 63 kg/ha N so the whole field was low in nitrogen.

In 1998 at Fincastle in the 0.0-0.60 m layer, 92% of the soil sample sites had less than 5 ppm N (very deficient) with an average of 14 kg/ha N. The remaining 8% (deficient to marginal) had an average of 65 kg/ha N. In 1998 at Hays, 68% of the soil sample sites had less than 5 ppm N and the remaining 32% of the sample sites had between 5 and 7.5 ppm N. The variability at these two fields in 1998 was not sufficient to justify the costs of site specific fertilization of nitrogen.

All the soil sample sites for 0.0-0.60 m at Hays in 1999 were less than 5 ppm N (Table 11). In 1999 at Fincastle the 0.0-0.60 m layer, 90% of the sample sites were very deficient (<5 ppm N),

6% were deficient to marginal (5-15 ppm N) and 4% were high (>20 ppm N). This site would offer possibilities for precision application of N with detailed mapping of soil N. This site had 27% of the 0.60-0.90 m samples with greater than average (165 kg/ha) soil N. The nitrogen at depth is evidence of leaching of nitrogen during previous cropping.

Soil N data collected from grid sampling for two fields for three years indicates only two of the six fields had sufficient variability in soil nitrogen to justify variable rate fertilization. Soil N for 6 fields (Fig. 11b) was not significantly related to petiole NO_3-N on July 3-7. This also indicates that when these fields were grouped together, variable rate application based on soil NO_3-N the previous fall does not offer possibilities for improved nitrogen management. Fincastle in 1997, and perhaps in 1999, had sufficient variability to justify the cost of sampling and analysis to determine soil nitrogen and then to apply variable rates of nitrogen fertilizer. The spatial soil fertility data must be collected before a decision can be made on the feasibility of variable rate fertilization.

Phosphorus

At Fincastle in 1997, soil phosphorus (P) for 0.0-0.15 m was high by Alberta Standards and exceeded 100 kg/ha P for 96% of the grid sample sites and exceeded 168 kg/ha P (20 ppm) for 58% of the sample sites (Table 12). This same field had 88% of the 0.0-0.30 m samples exceeding 200 kg/ha P and 46% of the samples exceeding 320 kg/ha P. The father of the current owners raised hogs from 1964 to about 1975 directly south of the 1997 site and used the 1997 field for spreading hog manure. It is not known how much hog manure was applied or what level the soil phosphorus reached but the subsequent 22 years cropping with little or no phosphorus fertilizer added has not yet reduced the soil P to levels which are environmentally safe. The adjacent field at Fincastle used in 1998 had only 6% of the samples for 0.0-0.15 m with soil P greater than 100 kg/ha.

In October 1998 before fertilizer was applied, the 1999 Fincastle site had high soil P in the 0.0-0.15 m layer (average 117 kg/ha) on the southern 67% of the field and adequate or marginal (average 50 kg/ha P) on the remainder of the field (Fig. 12a). The farmer had spread liquid hog manure on a portion of the field in the fall of 1997. This farmer applied 39 kg/ha P to the entire

field in October 1998 and 29 kg/ha P in the spring of 1999. If phosphorus fertilizer costs $1.25/ kg P, then $1765 could have been saved from not applying P to the part of the field that received hog manure. The farmer's soil sample analysis results were not available from the fertilizer dealer for the fall of 1998 on the 1999 Fincastle field. It is not known if the fertilizer rates were estimated or were based on samples taken on the north end of the field where manure was not applied.

In 1999 at Hays (Table 12) in the 0.0-0.15 m layer, soil P was deficient to marginal on 62% of the field and adequate on 38% of the field (Miller-Axely method of analysis). The Hays fields did not have a history of receiving manure so they were generally lower in soil P than the Fincastle fields, which had received manure.

Potassium

Soil potassium (K) levels in samples from the Fincastle fields (Table 13) were usually adequate and, in a few cases, high. The 1997 field also had 13% of its grid sample sites with high levels of potassium (greater than 300 ppm in the 0.0-0.15 m depth). This appears to be a relic from the hog manure applications made between 1965 and 1974. Tissue potassium was adequate or high on the part of the field that received hog manure. If potassium fertilizer costs $0.55/kg K then $784 could have been saved in 1997 by not applying K to the field. The 1999 Fincastle field also had some sample sites with high levels of K. The sites in 1999 were not related to the portion of the field that received one application of hog manure in 1997. Fincastle sites have received manure applications and have been irrigated since 1956. This is longer than the Hays sites, which have been irrigated since 1978 and have not received manure applications.

The Hays sites in 1997 and 1998 (Table 13) were marginal to adequate in soil K. In 1999, the Hays sites were marginal to high but there was no easily identifiable pattern and the high areas were parts of the outer edge of the field. It does not seem economical to apply site specific applications of K to the Hays fields.

Table 11. Soil nitrogen levels in ppm N (0.0-0.60 m depth) in October of the previous year for grid sample sites grouped by % according to Alberta Agriculture Standards.

Location	Year	Very deficient	Deficient	Marginal	Adequate	High
ppm		<5	5-7.5	7.5-15	15-20	>20
Hays	97	73	19	8	0	0
	98	68	32	0	0	0
	99	100	0	0	0	0
Fincastle	97	40	25	26	6	4
	98	92	6	2	0	0
	99	90	2	4	0	4

Table 12. Soil phosphorus levels in ppm P (0.0-0.15 m depth) in October of the previous year for grid sample sites grouped by % according to Alberta Agriculture standards.

Location	Year	Deficient	Marginal	Adequate	High	Very high
ppm		<13	13-25	25-45	45-75	>75
Hays	97✦	34	66	0	0	0
	98✦	8	60	31	0	0
	√	12	79	8	0	0
	99✦	2	60	38	0	0
	√	6	74	21	0	0
Fincastle	97✦	0	0	4	38	58
	98✦	20	35	39	6	0
	√	6	30	57	8	0
	99✦	6	16	12	64	0
	√	2	24	22	53	0

✦ Miller Axley method
√ Kelowna method

Table 13. Soil potassium levels in ppm K (0.0-0.15 m depth) in October of the previous year for grid sample sites grouped by % according to Alberta Agriculture standards.

Location	Year	Deficient	Marginal	Adequate -	Adequate +	High
ppm		0-75	75-150	150-225	225-300	>300
Hays	97†◊	0	67	23	9	2
	98√	0	38	52	10	0
	99◊	0	26	39	14	21
Fincastle	97†◊	0	0	38	49	13
	98√	4	40	36	15	6
	99◊	0	4	71	16	10

† 0.0-0.30 m depth
√ Kelowna method
◊ Ammonium acetate method

Table 14. Petiole analysis of N, P and K for 1996-99 for 3 dates for potatoes at Hays and Fincastle showing % of samples at adequate level.

	NO_3-N %			P %			K%		
Table 14 a. 1996	**July 3-4**	**July 30**	**Aug. 20♦**	**July 3-4**	**July 30**	**Aug. 20♦**			
Adequate level	1.6-2.4	1.2-1.8	0.08-1.4	0.22-0.62	0.20-0.50	0.10-0.30			
Hays % High **% Adequate** **% Deficient**	2 88 10	0 26 74	0 0 100	0 100 0	0 20 80	0 0 100			
Adequate level	1.6-2.4	1.2-1.8	0.10-0.16	0.22-0.62	0.20-0.50	0.16-0.36			
Fincastle % High **% Adequate** **% Deficient**	0 88 12	0 0 100	0 0 100	0 100 0	0 63 37	0 88 12			
Table 14 b. 1997	**July 3-7**	**July 23-24**	**Aug. 12-13**	**July 3-7**	**July 23-24**	**Aug. 12-13**	**July 3-7**	**July 23-24**	**Aug. 12-13**
Adequate level	0.16-.24	0.12-0.18	0.10-0.16	0.22-0.62	0.20-0.50	0.16--0.36	7-9	5-7	3.5-5.5
Hays % High **% Adequate** **% Deficient**	0 45 55	0 0 100	0 0 100	0 94 6	0 2 98	0 0 100	0 0 100	40 60 0	67 33 0
Fincastle % High **% Adequate** **% Deficient**	0 12 88	8 17 75	6 32 62	13 87 0	55 39 6	11 79 9	0 6 94	94 6 0	100 0 0
Table 14 c. 1998	**July 6-7**	**July 22-23**	**Aug. 10-11**	**July 6-7**	**July 22-23**	**Aug. 10-11**	**July 6-7**	**July 22-23**	**Aug. 10-11**
Adequate level	0.16-0.24	0.12-0.18	0.10-0.16	0.22-0.62	0.20-0.50	0.16-0.36	7-9	5-7	3.5-5.5
Hays % High **% Adequate** **% Deficient**	0 4 96	0 12 88	4 50 46	17 77 6	0 21 79	0 54 46	0 73 27	67 33 0	100 0 0
Fincastle % High **% Adequate** **% Deficient**	3 21 76	24 59 17	22 57 21	0 76 24	0 30 69	0 6 94	0 33 67	19 73 8	57 41 2
Table 14 d. 1999	**July 7**	**July 30**	**Aug. 17**	**July 7**	**July 30**	**Aug. 17**	**July 7**	**July 30**	**Aug. 17**
Adequate level	0.16-0.24	0.10-0.18♦	0.08-0.14♦	0.22-0.62	0.18-0.45♦	0.14-0.34♦	7-9	5-7	3.4-5.4♦
Hays % High **% Adequate** **% Deficient**	9 46 44	6 28 66	2 32 66	0 85 15	0 22 88	0 43 57	80 20 0	0 96 4	0 100 0
	July 9	**July 28**	**Aug. 13**	**July 9**	**July 28**	**Aug. 13**	**July 9**	**July 28**	**Aug. 13**
Adequate level	1.6-2.4	1.2-1.8	1.0-1.6	0.22-0.62	0.20-0.50	0.16-0.36	7-9	5-7	3.5-5.5
Fincastle % High **% Adequate** **% Deficient**	0 14 86	0 20 80	6 29 65	51 45 4	22 65 14	55 41 4	76 24 0	98 2 0	2 92 6

♦Standards were adjusted downward because of the late sampling date and Snowden, a mid-season variety, was nearing maturity.

Petiole Analysis

Potato producers routinely take petiole samples from late June through mid to late August. The samples are tested for nitrate nitrogen (NO_3-N) to help producers maintain consistent nitrogen health or to make corrections for insufficient N by fertigating the entire field. Historically, potato producers did not test for phosphorous or potassium status nor did they make adjustments for insufficient P and K. In the last 3 or 4 years, many have also been analyzing for P, K in addition to NO_3-N.

Nitrate Nitrogen

In 1996, petiole NO_3–N (Table 14) was adequate at most of the sites at the time of the first sampling but, despite fertigation with additional N, it decreased and became deficient at the time of the second and third sampling.

In 1997, petiole N at Hays (Table 14b) was adequate on 45% and deficient on 55% of the sites at the time of the first sampling and deficient on 100% of the sites at the time of the second or third samplings. Soil nitrate N was deficient on 92% of the sites (Table 11) the previous October and 77% of the field had less than 15% clay in the 0.0-0.60 m. The field received from 0.37-0.45 m of rainfall and irrigation from June 23 to September 9 (Fig. 3a). The coarse textured soils permitted leaching of nitrogen below the root zone, which meant there was excess moisture.

In 1997, the Fincastle site was deficient in petiole N (Table 14) on 88% of the field in early July to 62% by August 12. Fincastle received about the same amount of irrigation and rainfall as Hays but over a period one week longer than the Hays site (June 24 to September 18). The Russet Burbank potatoes at Fincastle used more water in the latter part of the season than the earlier maturing Snowden potatoes at Hays.

In 1998, petiole analysis on both Hays and Fincastle indicated that the percent of samples that were deficient decreased from highs of 96 and 76 early in July to 46 and 21 by August 10 or 11 (Table 14c). Total soil nitrogen plus fertilizer nitrogen (Table 3) was higher in 1998 than in 1997 and 1996. This may be the reason that the tissue nitrogen did not decline like it did in 1996 and

1997. In 1999 at the time of the third petiole sampling (Table 14d), both Hays and Fincastle had about 66% of the samples deficient in petiole N.

Petiole analysis for nitrogen in the first week of July was significantly correlated with soil N the previous October in three of the six fields monitored, such as Hays in 1999 (Fig. 11a). This was before uniform applications of nitrogen fertilizer. However, petiole nitrate for all fields was not significantly correlated to soil nitrogen (Fig. 11b) and had an r of 0.95. Petiole nitrate was significantly positively correlated to soil clay per cent (Fig. 11c) with an r of 0.45. This means it would be more useful to base a variable nitrogen fertilizer application on soil clay content than on soil nitrogen. The fields chosen for this project had most of the samples with a clay content between 6% and 32% (Fig. 2). This is a lower range clay content than is typical for agricultural soils but it is typical for potato soils. The variability of texture of the soils used in this project may be higher than is typical of soils used for potato production.

Petiole nitrate N was significantly negatively correlated to tuber yield in early July (r = 0.25) (Fig. 11d) and in late July there was no significant relationship between petiole nitrate N and yield (Fig. 11e). In August (Fig. 11f) petiole nitrate N was significantly positively correlated (r = 0.155) to yield. This suggests nitrogen supply may be excessive early in the growing season and deficient later in the season. The areas with higher clay content could be expected to retain nitrogen late in the season, while those areas lower in clay content are subject to loss of nitrogen by leaching. These same areas with a higher clay content, and therefore a higher exchange capacity could be expected to have less soluble nitrogen early in the season, thus lower petiole N content than areas with a lower clay content.

Phosphorus

Tissue P at Hays in 1996 and 1997 (Fig. 13) was adequate in the first week of July and declined rapidly to become 100% deficient in the August samples (Tables 14a and 14b). This same decline did not occur at the Fincastle site, which had a higher level of available soil P (36% of soil sample sites tested marginal or higher) in 1997 as compared to Hays, which had 8% of soil P marginal or higher (Table 12).

In 1998, both fields were mostly marginal in soil P (Table 12) but received high applications of fertilizer P (119 kg/ha Hays and 153 kg/ha at Fincastle, Table 3). Despite these high applications of fertilizer, available tissue P declined by Aug. 10-11 to become 46% deficient at Hays and 94% deficient at Fincastle (Table 14c).

In 1999, in early July, the tissue P levels in the Hays field were mostly marginal (85 %) with some areas (15%) high (Table 14d). The Fincastle field was 51% high and 45% marginal and 4% low. Petiole P levels were high or adequate in the part of the field that had received hog manure. In the remainder of the field, petiole P levels were adequate on July 9 and declined to become deficient or adequate on July 28 and August 13.

Petiole phosphorus on six fields for July 3-7 was highly significantly positively correlated to soil P (Fig. 14a) (r = 0.57**). On the same six fields, petiole phosphorus content was highly significantly negatively correlated to soil clay content (Fig. 14b) (r = 0.32**). This occurs because soil P is tied up in unavailable forms on clay. However, there was no significant correlation between soil P and clay content. In contrast to soil nitrogen, soil phosphorus content can be used as a basis for variable rate application of phosphorus fertilizers. Petiole P was highly significantly positively correlated to yield at all three sampling times (Fig.14c, 14d and 14e). This indicates petiole P was low for optimum yields on these fields.

Potassium

Tissue K analysis was not done in 1996. In 1997, at both Hays and Fincastle, almost all sites were deficient in the first week of July (Table 14). By July 23 and 24 tissue levels increased and by August 12-13 the Hays field had 67% high levels of K and the Fincastle field had 100% high levels of K (Table 14 and Fig. 15). A similar pattern occurred in 1998. In 1997 mean tissue K at Hays was 6.2% July 3, 6.9% July 23 and 6.0% August 12. In 1997 at Fincastle, mean tissue K was 6.5% July 7, 7.5% July 24 and 6.4% August 13. However, in 1999 both Hays and Fincastle showed most of the field with excess levels of tissue K on July 7 and 9 (Fig. 16a) and this decreased to 0% with excess at Hays and 2% with excess at Fincastle by the 13th of August (Fig.16b).

It is not known why these tissue levels in 1997 and 1998 changed so much, in contrast to the standards, which indicate tissue K levels normally decline during the season. Potassium uptake is reduced by low soil temperature. The standards have been developed in parts of the USA where soil temperatures would usually be higher than in southern Alberta. In southern Alberta, June nights are often quite cool.

Tissue K levels at both sites for three years were not significantly related to yield. Apparently these K levels were not appreciably deficient. In another experiment, in 2000 and 2001, field tests with phosphorus fertilizer and compost at a total of 5 locations showed declining tissue potassium levels throughout the season. This problem of petiole K levels deficiencies needs more study in western Canada where soil K levels are usually high but some of the growing season temperatures are lower than required for maximum growth of potatoes.

Fertilizer Treatments

The N_3 treatment (Table 15) at Hays in 1997 gave the highest yield and the potato crop was worth $116/ha more than the N_2 treatment but required $60/ha more nitrogen fertilizer (N fertilizer cost = $0.66/kg) than the N_2 treatment. This increase in yield and value does not account for changes in quality such as low specific gravity, which may occur on the high N treatment. At Fincastle, the N_2 treatment, which was the farmer's rate, showed the highest yield. This N2 treatment also showed losses in nitrogen below the root zone (Rodvang, 1998). In 1998 the nutrients applied (Table 6) were in addition to the farmer's rate (Table 3).

Table 15. 1997 potato yields (t/ha) and gross value on fertilizer strips.

Treatment	Hays		Fincastle	
	Yield	Gross value ($/ha)▲	Yield	Gross value ($/ha)▲
N_1	39.2	4140	39.4	4161
N_2	42.5	4488	42.7	4509
N_3	43.6	4604	42.0	4435

▲ Value is based on 80% marketable at $132/tonne.

At both sites in 1998 (Table 16), the N treatment yielded less than the check or farmer's rate (-4.4% Hays and –7.7% Fincastle). At both sites the NP treatment yielded similar to the check (-0.3% Hays and +1.1% Fincastle). The P treatment at both sites yielded more than the check

(+2.7% Hays and +5.3% Fincastle). These results indicate the farmers are at an optimum rate with respect to nitrogen. Phosphorus rates on these two fields may be low. Both of these fields had high phosphorus fertilizer applications (Table 3) and petiole P levels declined during the season (Table 12).

Table 16. 1998 potato yields (t/ha) and gross value on fertilizer strips.

Treatment	Hays		Fincastle	
	Yield	Gross value ($/ha)▲	Yield	Gross value ($/ha)▲
N	34.9	3685	33.2	3506
P	38.6	4076	37.8	3992
NP	37.5	3961	36.6	3865
Check	37.6	3970	35.9	3791

▲Value is based on 80% marketable at $132/tonne.

In 1999, six treatments were set out at Hays (Table 7) consisting of two rates of compost, manure and phosphorus fertilizer. Disease counts on the foliage of the plants (Table 17) indicated that the low phosphorus treatment had a greater amount of foliar disease than all other treatments. The three high rate treatments also had a lower incidence of foliar disease than their corresponding low rate treatments, indicating an overall benefit of high rates of P, whatever the form, in terms of foliar disease. Because this field has been used a number of times for growing potatoes in the last 10 years, the level of foliar diseases was quite high. *Rhizoctonia* and scab counts were also made on the tuber surfaces. Variability on tuber disease counts was high and disease occurrence on tubers was low so no conclusions can be made regarding the influence of these treatments on tuber disease.

The 1999 Hays field has a history of developing low P levels in petioles in late July and August despite high rates of P fertilizer being applied. The treatments had no significant effect on tuber yields (Table 17) although compost and manure treatments yielded slightly more than the P treatments. Tuber numbers were also recorded for each treatment.

Table 17. Effect of P, compost and manure on tuber yield and size and disease incidence of potatoes – Hays, 1999.

				% surface infected on 160 tubers		% plants affected
Treatments	**Total tuber Wt (t/ha)**	**Medium Tubers (t/ha)**	**Tubers▲ /1.2 m**	***Rhizoctonia***	**Scab**	**Disease▲ on 600 m row**
Low P	34.6	30.2	65	0.68	0.75	9.0
High P	36.5	32.5	70	0.32	0.88	7.1
Low compost	40.0	33.3	95	0.82	1.20	6.6
High compost	38.7	35.2	82	0.36	0.57	5.9
Low manure	37.2	34.0	81	0.68	0.57	7.6
High manure	39.8	36.2	75	0.86	0.73	6.1

▲significant at 5% level

Pest Monitoring

Weeds

In most fields, the weeds did not occur in large numbers in any one area so they were not suitable for site specific management. In 1999 on the Hays field, there were patches from 10 m to 50 m in diameter, which were heavily infested with Canada Thistle. In late August prior to harvest, the perimeters of some of these patches were mapped with GPS. It was not possible to identify these patches on remote sensed imagery taken on July 28. If accurately identified, these patches of Canada Thistle could be controlled with spot applications of chemicals such as Lontrel (clopyralid) or Roundup (glyphosate). These chemicals are toxic to potatoes so this is an extreme treatment and the herbicides need to be applied precisely. The potential exists for developing an irrigation system, which will provide site specific applications of herbicides, as well as water (Eberlein, 1999).

Disease

Diseases were monitored each year on all fields. Disease incidence was low and diseased plants were scattered. No attempt was made to map disease. Late blight did occur in varying degrees on the fields prior to harvest and it would have been possible to map this disease but it is difficult to distinguish from vine senescence. Disease surveys were done in the middle of August when the incidence of late blight was low.

Insects

Colorado potato beetles were the only insect pest present at sufficient levels to require insecticide application by the farmers. Colorado potato beetles are native to southern Alberta so the problem of resistance to insecticides is not as important as in areas where it only occurs on potatoes. It is not necessary to retain non resistant populations for reproduction in portions of the fields as described by Weisz et. al.(1996). Flescher et. al.(1999) describes how Colorado potato beetle are most dense near the edge of fields thus making them suitable for site specific management. However, due to farmer vigilance and spray programs, the Colorado potato beetles never became a serious problem in any areas of the fields tested, so were not suitable for site specific management.

Remote Sensing

Potato fields are closely monitored during the growing season for the onset of nutrient deficiencies, disease and pests. With respect to nutrients, typically test areas are established in a field and 40 to 50 petioles from representative plants are collected at each sampling date for determination of primarily N but also P and K content (Schaupmeyer, 1992). This method of petiole sampling provides only limited information regarding spatial variability across the whole field and does not provide information suitable for use with variable rate equipment. Remote sensing data offers one source of spatial information suitable for use in site-specific management systems. Digital imaging systems provide the potential to delineate management zones within a field based upon soil characteristics and the detection of crop stresses both in the short and long term (Brisco et al., 1998, Moran et al., 1997). A number of algorithms have been proposed to measure chlorophyll or N content of plants using remote sensing (Table 18). The close correlation between leaf chlorophyll and N availability suggests that chlorophyll content can be use to characterize N status and vice versa (Filella and Peñuelas, 1994). The majority of the algorithms or indices are based upon reflectance in the green (530-600 nm), red (670-680 nm) or so-called 'red-edge' (690-710 nm) normalized to reflectance in the near-infrared (750-900 nm) range of the electromagnetic spectrum. Reflectance at wavelengths above 735 nm is relatively insensitive to chlorophyll or N levels while reflectance at 550 and 690-710 nm is most sensitive. Sensitivity to N stress at 670-680 nm is variable due to the signal being saturated and reflectance reaching a minimum at relatively low chlorophyll levels (Gitelson et al., 1999). The objective within this study was to test, using airborne remote sensing imagery, the suitability of the reported algorithms to estimate petiole-N content in potatoes and examine the spatial information regarding N status across the field.

Table 18. Published algorithms for chlorophyll/N estimation using remote sensing data.			
Index	**Formula**	**Citation**	**CASI bands**
Simple ratio			
SR_{800_670}	(R_{800nm}/R_{670nm})		17, 25
SR_{695_430}	$(R_{695nm}R_{630nm})$	Carter 1994	1, 18
SR_{605_760}	(R_{605nm}/R_{760nm})	Carter 1994	12, 23
SR_{695_760}	(R_{695nm}/R_{760nm})	Carter 1994	18, 23
SR_{695_670}	(R_{695nm}/R_{670nm})	Carter 1994	17, 18
SR_{750_705}	(R_{750nm}/R_{705nm})	Gitelson and Merzlyak 1996, Sims and Gamon 2002	19, 22
SR_{750_550}	(R_{750nm}/R_{550nm})	Gitelson and Merzlyak 1996, Lichtenthaler et al. 1996	9, 22
SR_{667_717}	(R_{667nm}/R_{717nm})	Leblon et al. 2001	17, 20
SR_{550_850}	(R_{550nm}/R_{850nm})	Schepers et al. 1996	9, 28
SR_{710_850}	(R_{710nm}/R_{850nm})	Schepers et al. 1996	19, 28
SR_{800_680}	(R_{800nm}/R_{680nm})	Sims and Gamon 2002	17, 25
SR_{735_700}	(R_{735nm}/R_{700nm})	Gitelson and Merzlyak. 1999	19, 21
Pigment specific simple ratio (PSSR)	(R_{810nm}/R_{676nm})	Blackburn 1998	17, 26
Normalized difference index			
Normalized green difference vegetation index (NGVDI)	$(R_{750nm} - R_{550nm})/(R_{750nm} + R_{550nm})$	Gitelson et al. 1996	9, 22
Photochemical reflectance index (PRI)	$(R_{531nm} - R_{570nm})/(R_{531nm} + R_{570nm})$	Gamon et al. 1992	8, 10
Pigment specific normalized difference (PSND)	$(R_{810nm} - R_{676nm})/(R_{810nm} + R_{676nm})$	Blackburn 1998	17, 26
Normalized difference index (NDI_{750_700})	$(R_{750nm} - R_{700nm})/(R_{750nm} + R_{700nm})$	Gitelson and Merzylak 1994, Sims and Gamon 2002	19, 22
Normalized difference index (NDI_{800_680})	$(R_{800nm} - R_{680nm})/(R_{800nm} + R_{680nm})$	Sims and Gamon 2002	17, 25
Normalized pigments chlorophyll ratio index (NPCI)	$(R_{680nm} - R_{430nm})/(R_{680nm} + R_{430nm})$	Peñuelas et al. 1994	1, 17
Structure-insensitive pigment index (SIPI)	$(R_{800nm} - R_{445nm})/(R_{800nm} + R_{680nm})$	Peñuelas et al. 1995	2, 17, 25
Others			
Modified simple ratio (mSR_{750_445})	$(R_{750nm} - R_{445nm})/(R_{705nm} - R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Modified normalized ratio (mNR_{750_445})	$(R_{750nm} - R_{705nm})/(R_{750nm} + R_{705nm} - 2*R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Optimized soil adjusted vegetation index (OSAVI)	$(1 + 0.16)*(R_{800nm} - R_{670nm})/(R_{800nm} + R_{670nm} + 0.16)$	Rondeaux et al. 199	17, 25
Modified chlorophyll absorption in reflectance index (MCARI)	$[(R_{700nm} - R_{670nm}) - (0.2*(R_{700nm} - R_{550nm}))*(R_{700nm}/R_{670nm})]$	Daughtry et al. 2000	9, 17, 19
Transformed chlorophyll absorption in reflectance index (TCARI)	$3*[(R_{700nm}-R_{670nm})-(0.2*(R_{700nm}-R_{550nm}))*(R_{700nm}/R_{670nm})]$	Haboudane et al. 2002	9, 17, 19
Plant senescence reflectance index (PSRI)	$(R_{680nm} - R_{500nm})/(R_{750nm})$	Merzlyak et al. 1999	6, 17, 22
Carotenoids	$[4.145*(S_{760nm}/S_{500nm})*(R_{500nm}/R_{760nm})]-1.171$	Chapelle et al. 1992	5, 23
Chlorophyll b	$2.94*[((S_{675nm}/R_{650nm}*S_{700nm})*(R_{650nm}*R_{700nm}/R_{675nm}))]+0.378$	Chapelle et al. 1992	15, 17, 18
Chlorophyll a	$22.735[=(S_{675nm}/S700_{nm})*(R_{700nm}/R_{675nm})] - 10.407$	Chapelle et al. 1992	17, 18

Nitrogen

On July 28, 1999, Itres acquired digital images over the Hays and Fincastle test fields. The image data were acquired over the spectral range 420-965 nm using a Compact Airborne Spectrographic Imager (CASI) at 2 and 3 m resolution. The spectral bands in which data were acquired varied with the resolution from 36 to 48 nm respectively. The image data were radiometrically corrected and geocoded by Itres.

The data were imported into the ENVI™ image analysis software package (Research Systems Inc. Colorado, USA) and converted from spectral radiance units ($\mu W\ cm^{-2}\ sr^{-1}\ nm^{-1}$) to surface reflectance (%) using the FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) atmospheric correction model (Anon., 2001). The input parameters used in the model are shown in Table 19.

Table 19. Input parameters for the FLAASH atmospheric correction model.

Parameter	Input
Latitude/Longitude	49.9867N, 111.8523W
Sensor altitude	2.286 km
Ground elevation	0.786 km
Atmospheric model	Sub-Artic Summer
Aerosol model	Rural
Visibility	40 km

Images of the various chlorophyll/N indices outlined in Table 18 were created using the band math function in the image analysis software. The spatial patterns of the indices across the sites were visually examined and compared to those in the kriged maps derived from the ground based petiole nitrate N samples. The grid sampling points were overlaid on the imagery and the reflectance values under a 3 x 3-pixel window centered over each grid point were extracted for each band and each chlorophyll/N index. The relationship between the various chlorophyll/N indices and the petiole nitrate N values was assessed using correlation and regression analyses.

True colour images derived from the 2 m resolution airborne imagery for both the Fincastle and Hays sites are shown in Fig. 17. Both the 2 and 3 m resolution images were processed but due to the similarity in the information content only the 2 m data will be discussed. The images show differential "greeness" across the fields, particularly in the Hays field. The spatial patterns tend

to correspond to soil texture, particularly in the northern end of the field at Hays and likely results from poorer growth on the coarse textured soils. Consistent with the observation that many of the proposed indices involve reflectance in similar wavebands, the spatial patterns in the images derived for the various indices were similar (Table 18). Only the images showing the spatial variability in the index SR_{550_850} derived from reflectance at 550 and 850 nm are shown (Fig. 18 and 19). Visual comparison of the petiole-N maps derived in Surfer™ using the grid point petiole nitrate N data and the index SR_{550_850} shows similarities in the patterns across both fields. Generally, areas of low petiole nitrate N exhibited high values for the SR_{550_850} index.

Fincastle Site

Correlation analysis showed a strong relationship between most of the chlorophyll/N indices and petiole nitrate N for the Fincastle site (Table 20). The strongest relationships were evident with simple ratios involving either reflectance in the green band (550 nm) or the red-edge (700-710 nm) and the near infrared reflectance (750-850 nm). These observations can be attributed to the greater range of chlorophyll/N content to which reflectance at 550 and 700-710 nm responds. The absorption feature at 660-680 nm saturates at relatively low chlorophyll content and thus relative to 550 or 700-710 nm is insensitive to variation in chlorophyll/N.

Hays Site

At the Hays site, visually there were some similarities between the spatial patterns within the image of the SR_{550_850} index and the kriged map of the ground based sampling. The extent of the N deficient areas in the remote sensing image appeared less than in the kriged map. The imagery may provide a more accurate representation of the spatial variability given that each pixel in the remote sensing image represents information from an area of 2 x 2 m on the ground while the ground data is an interpolation from grid points at greater than 100 m apart. Quantitative analysis showed only a limited number of indices were significantly related to petiole nitrate N. The strength of the relationship was poor compared to that at the Fincastle site. The lack of a strong relationship may reflect uncertainty in the georeferencing of the airborne imagery and the sampling sites and the heterogeneity of the crop reflectance in the areas selected for sampling (Deguise et al., 1998).

Table 20. Relationship between the various proposed indices and petiole nitrate N samples.		
Index	**Fincastle**	**Hays**
Simple ratio		
SR800_680	0.751	NS
SR695_430	-0.734	-0.356
SR605_760	-0.781	NS
SR695_760	-0.748	NS
SR695_670	0.449	-0.318
SR750_705	0.820	NS
SR750_550	0.821	NS
SR677_717	-0.639	NS
SR550_850	-0.832	NS
SR710_850	-0.832	NS
SR735_700	0.821	NS
PSSR	0.764	NS
Normalized difference index		
NGVDI	0.809	NS
PRI	0.770	NS
PSND	0.706	NS
NDI750_700	0.809	NS
NDI750_705	0.696	NS
NDI800_680	0.707	NS
SIPI	-0.660	NS
Other		
mSR750_705	0.821	0.326
mNR750_705	0.813	0.308
OSAVI	0.722	NS
MCARI	0.445	-0.298
TCARI	-0.800	-0.317
PSRI	-0.597	
Carotenoids	0.746	NS
Chlorophyll a	-0.448	0.313
Chlorophyll b	-0.674	NS
PSRI	-0.597	NS
NPCI	-0.702	NS
# of Observations	**N=51**	**N=54**

Summary

The results of the study indicated that potato petiole nitrate N could be estimated from remote sensing imagery at one test site but not the other. At the Fincastle site, visually the spatial patterns in the remote sensing derived maps for N levels and those derived from ground based plant sampling were similar. Errors in the overlay of petiole sampling points on the remote

sensing imagery may account for the lack of a significant quantitative relationship at the Hays site. Further studies are being conducted to determine the ability to estimate plant N content using remote sensing techniques.

Soil Salinity

A soil salinity map was made of the additional Vauxhall potato field in 1999 (Fig. 20). This permitted identifying those areas of the field where problem levels of salinity occurred. Tuber samples in these areas were compared to measurements of electrical conductivity (E.C.) calculated from EM38 readings and a tolerance of potatoes to salinity was developed for this field (Fig. 21a). A 50% yield reduction of potatoes occurred at an E.C. of about 6 dS/m. This method is suitable for precision applications to potato production. A salinity tolerance limit and a salinity map means it is then possible to identify those areas where it is not feasible to grow potatoes. Specific gravity of tubers was found to be higher in saline soils than non-saline soils (Fig. 21b).

CONCLUSIONS

A yield monitor was successfully adapted to two farmers' potato harvesters. Maps of tuber yields were developed based on data collected from the harvester. Difficulties were encountered on parts of fields where soil lumps occurred. These lumps usually occurred on areas with a high clay content and resulted in false high yield readings from the mass-based yield sensor. This will be a major restriction to yield mapping of potatoes unless technology can be developed to separate tubers from soil lumps on the harvester belt.

Yield maps were also developed from grid sampling. These grid samples were used to determine tuber yield, average tuber size and tuber quality as measured by specific gravity, chipping score and French fry score. Uniformity of tuber quality is a major concern of processors. Uniformity of irrigation affected tuber size. No relationship was found between chipping and French fry score and the measured factors of soil or water in the field.

Grid sampling was used to develop numerous maps of irrigation and precipitation, consumptive water use, soil texture and nutrient contents, plant petiole (tissue) nutrient contents and the tuber characteristics just described.

Grid sampling of the fields showed variability in soil texture. Most of the fields contained about 6 to 30% clay with a few sites with as much as 40% clay. The texture was correlated to various soil and plant chemical properties.

When yield mapping with differential GPS using a base station in the corner of the field, accurate topographic maps could be developed. When differential corrections were obtained from a geostationary satellite service, the vertical accuracy was no longer suitable for confident topographical mapping.

Soil levels and fertilizer applications of nitrogen by the farmers were in most cases equal to what a crop of potatoes yielding 50 t/ha would be anticipated to take up. No allowance was made for release of nitrogen from soil organic matter. Tissue nitrate levels were frequently deficient according to standards used by Alberta potato growers. Two of six fields had sufficient variability of soil nitrogen to justify the cost of soil sampling and variable rate application. However, petiole NO_3-N in the first week of July was significantly negatively related to clay content (0.0-0.60 m) and was not significantly related to soil NO_3-N. This means it would be more useful for farmers on these fields to base a site specific nitrogen application on soil clay content than on soil NO_3-N content.

Soil P was significantly positively correlated to petiole P content. Soil P was not significantly correlated to clay content or other easily-measured soil characteristics. Opportunities exist for precision applications of phosphorus particularly on two of the fields that had a history of receiving non-uniform applications of manure. Thus, in the absence of any easily-measured factors that are correlated to P, a strategy of phosphorus fertilizer applications based on grid

sampling of soil phosphorus should provide some improvement in efficiency of uptake of phosphorus.

Potassium levels in the soil from 1997 to 1999 were marginal to adequate on most grid sample sites. In 1997 and 1998 petiole K levels were deficient in the first week of July but became adequate to high in two later samplings. The reason for this is not known. It may be due to lower soil temperatures in early July restricting uptake, rather than the higher soil temperatures in the USA where the standards were developed. There is a need for research that will develop local standards for petiole K levels.

Diseases and insect pests were examined but their occurrence was very infrequent and highly variable, thus not predictable or manageable with site specific technologies. Weeds were carefully managed by farmers thus fields were too weed-free to allow for examination of the usefulness of site specific management for weed control. The sites used in the trials, like most potato fields, were extremely flat, which eliminated the opportunity for relating landscape position to potato yield.

Economic analysis indicated that grid sampling and site specific applications of P and K, on a field that received uneven manure applications, would have realized significant savings.

Remote sensing imagery was successful correlated to plant petiole NO3-N at one test site but not the other. Errors in the overlay of petiole sampling points on the remote sensing imagery may account for the lack of a significant quantitative relationship at the Hays site.

Piezometers were used to measure groundwater depth movement and soil NO_3-N content at the Hays (1997) and Fincastle (1997, 1998) sites. Overall, nitrate levels were low at depth but this may have been due to reducing conditions, causing denitrification. At the Hays site, flow of groundwater occurred from the irrigated field outward to an unirrigated rangeland. Irrigation has caused water table mounding below the sites and water tables rose during the summer at the Hays site.

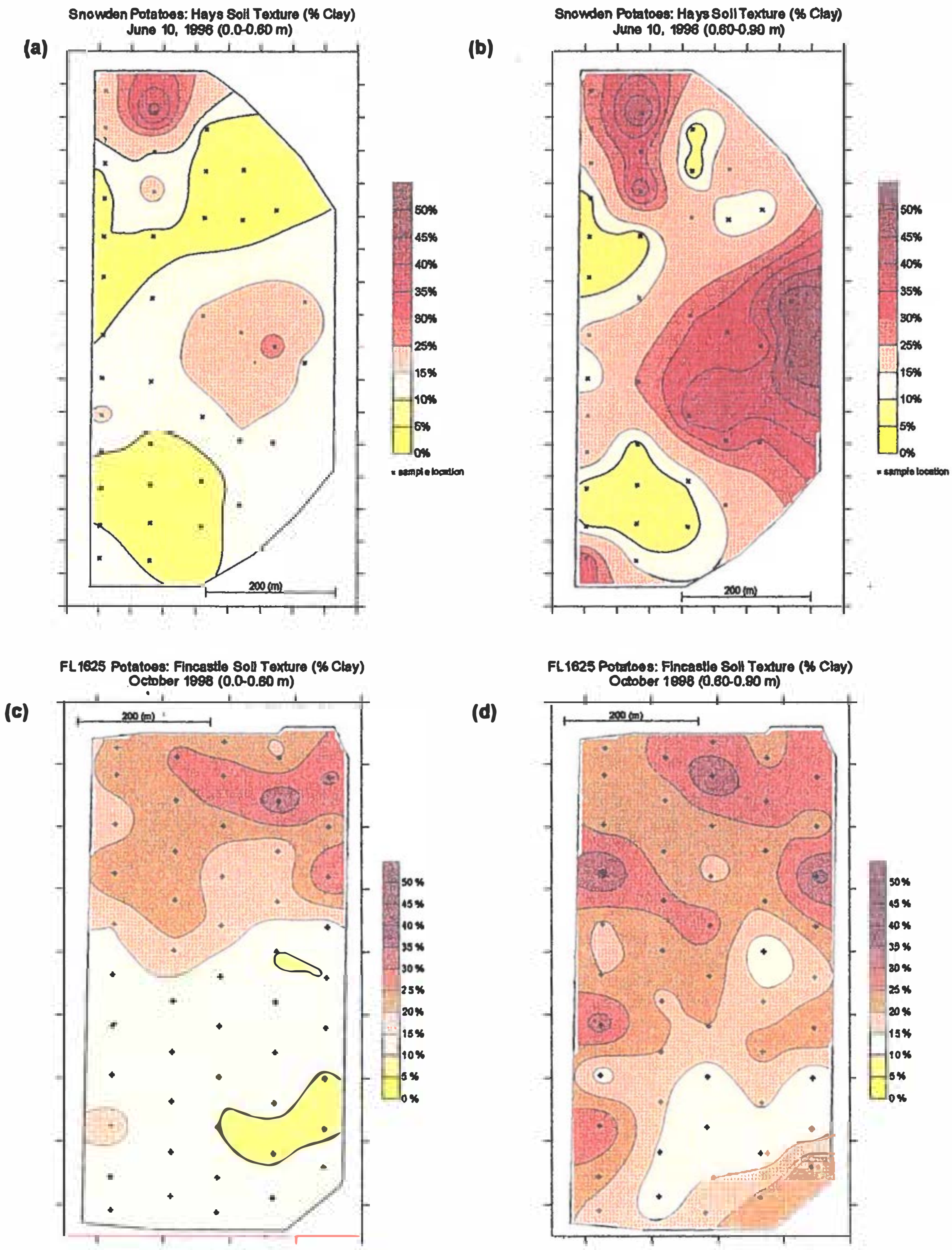


Figure 2. Soil texture maps of Hays 1996 (a and b) and Fincastle 1999 (c and d) fields for two soil depths 0.0-0.60 m and 0.60-0.90 m.

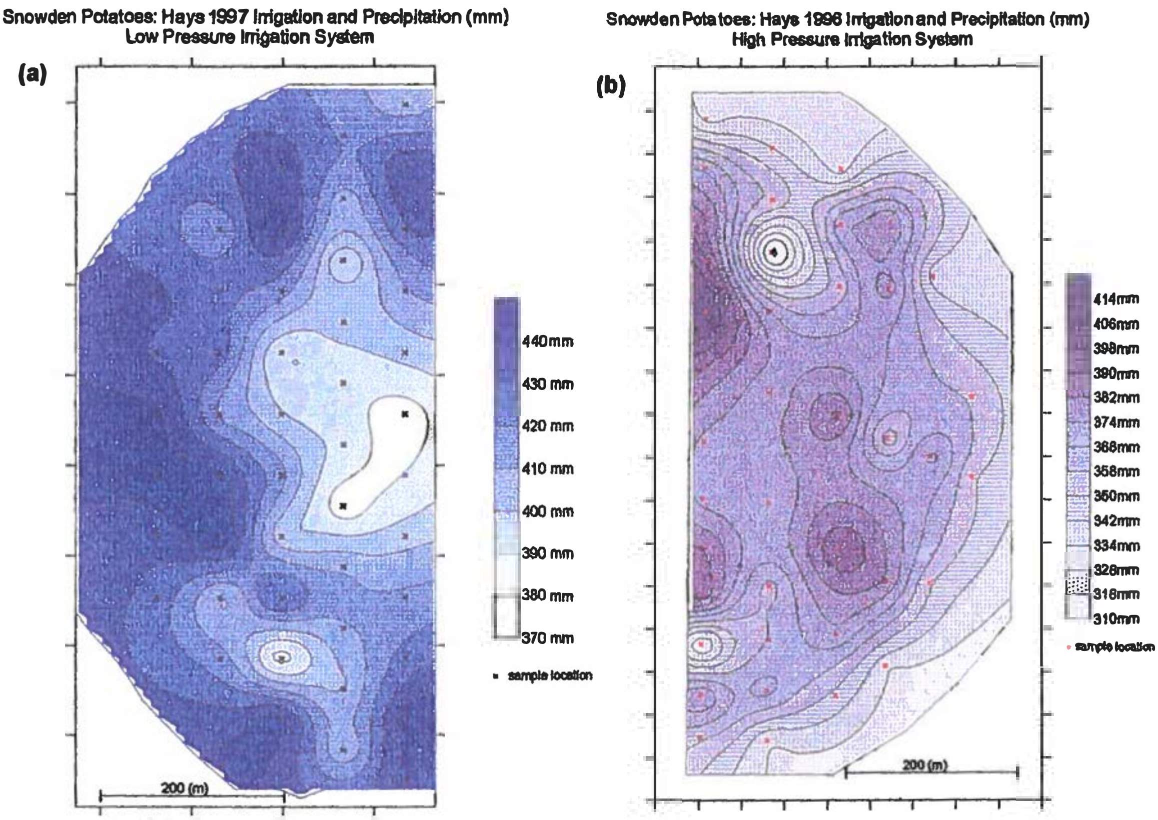


Figure 3. Change of sprinkler design causing contrasting distribution of irrigation and preciptation at Hays in 1997 west (a) and 1996 east (b).

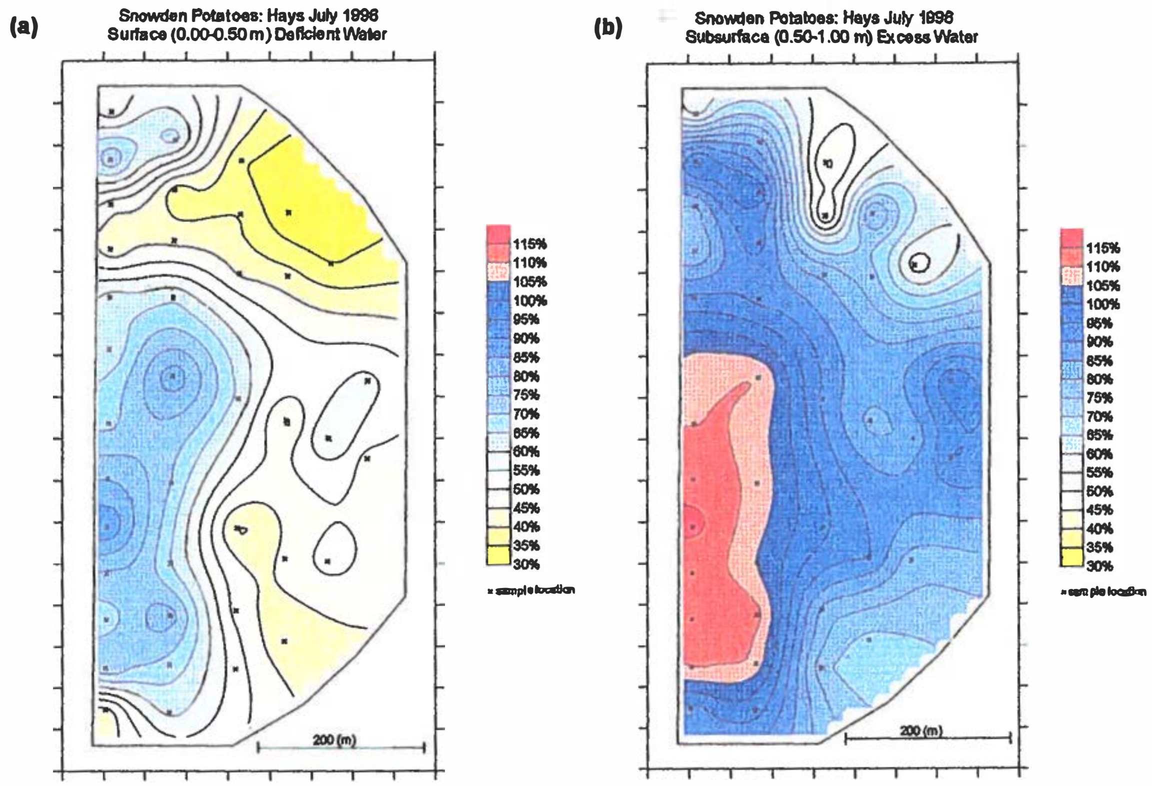
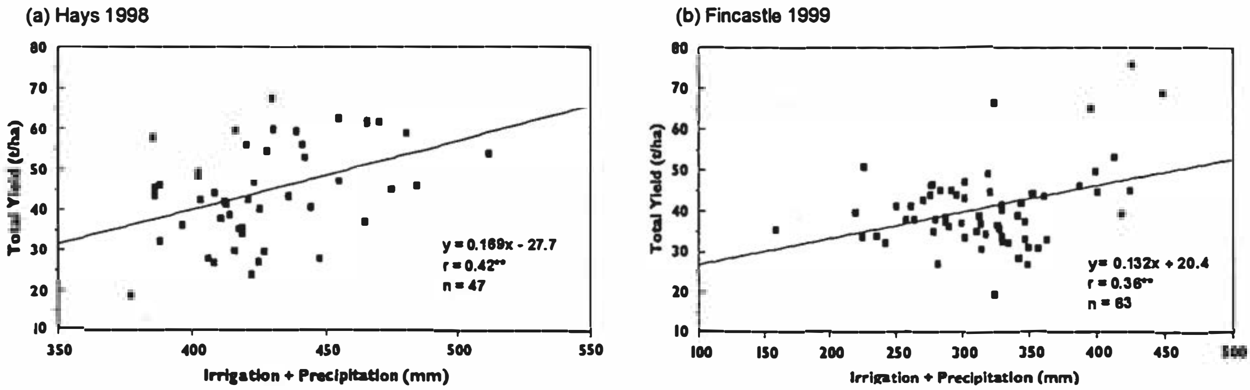
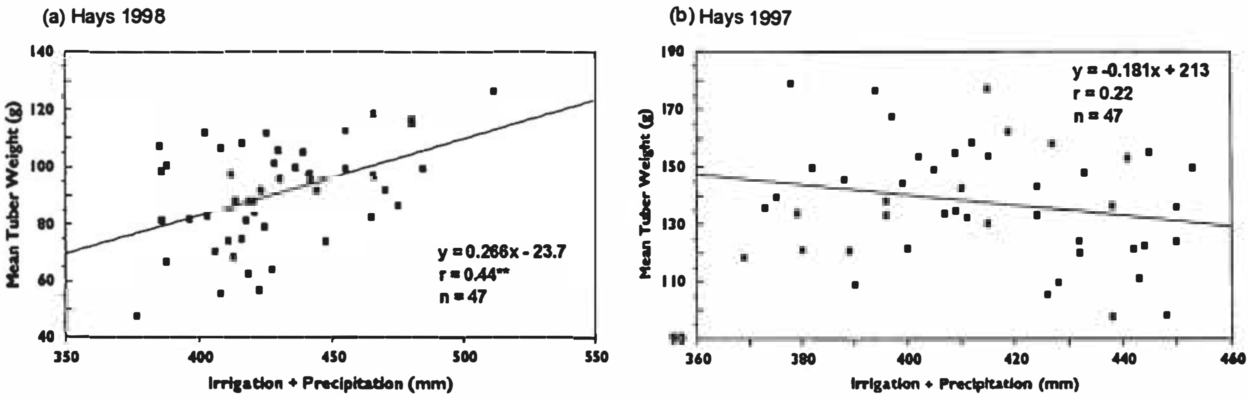


Figure 4. Percent of available moisture (100% = field capacity) in 1996 at Hays for (a) 0.0-0.50 m and (b) 0.50-1.00 m.



** = r significant at the 0.01 level

Figure 5. Correlation between total potato yield and total added water (irrigation + precipitation) at (a)Hays 1998 and (b)Fincastle 1999.



** = r significant at the 0.01 level

Figure 6. Correlation between mean tuber weight and total added water (irrigation + precipitation) at (a)Hays 1998 and (b)Hays 1997.

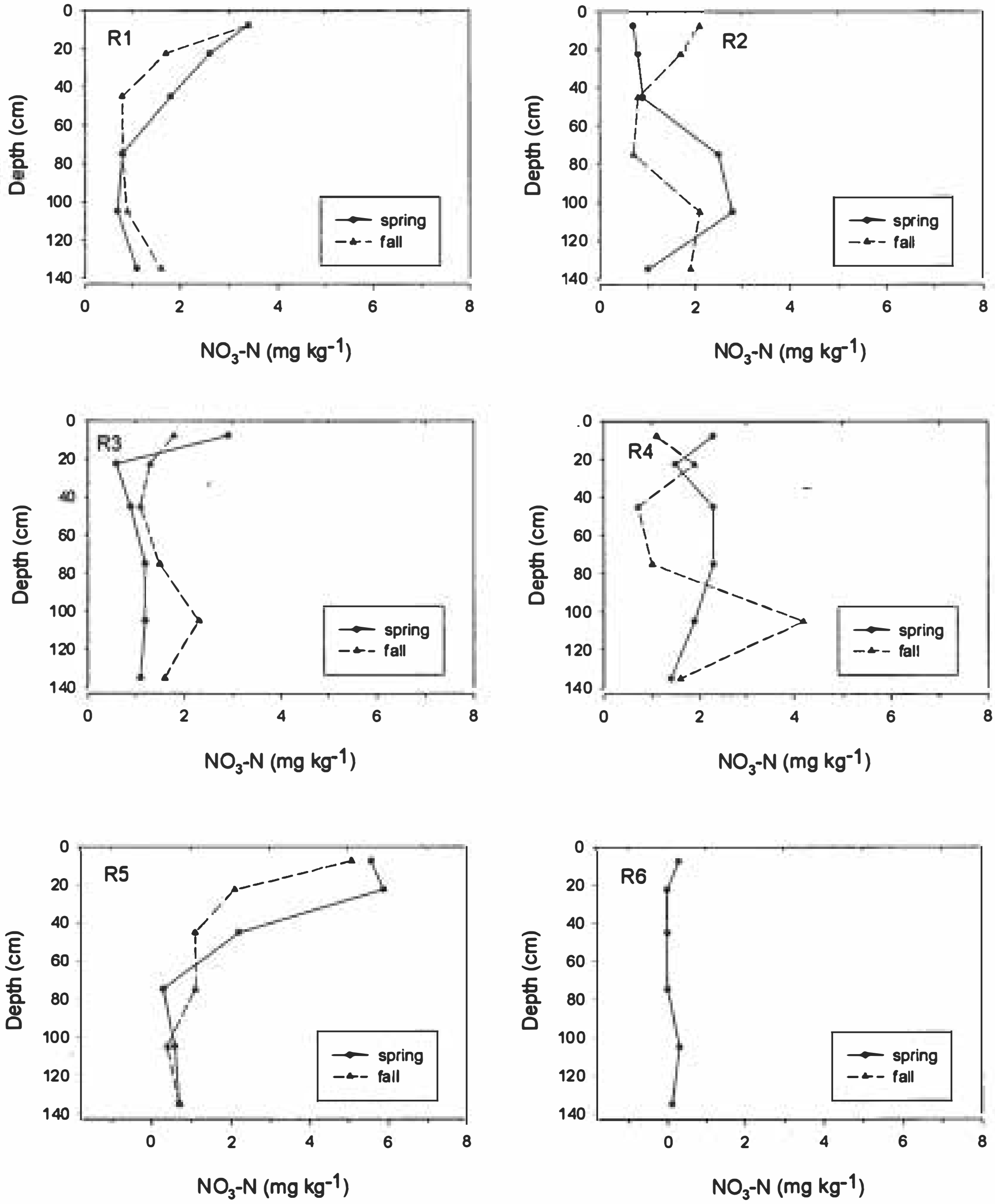


Figure 7. Soil NO_3-N at piezometer sites from 1997 at Hays.

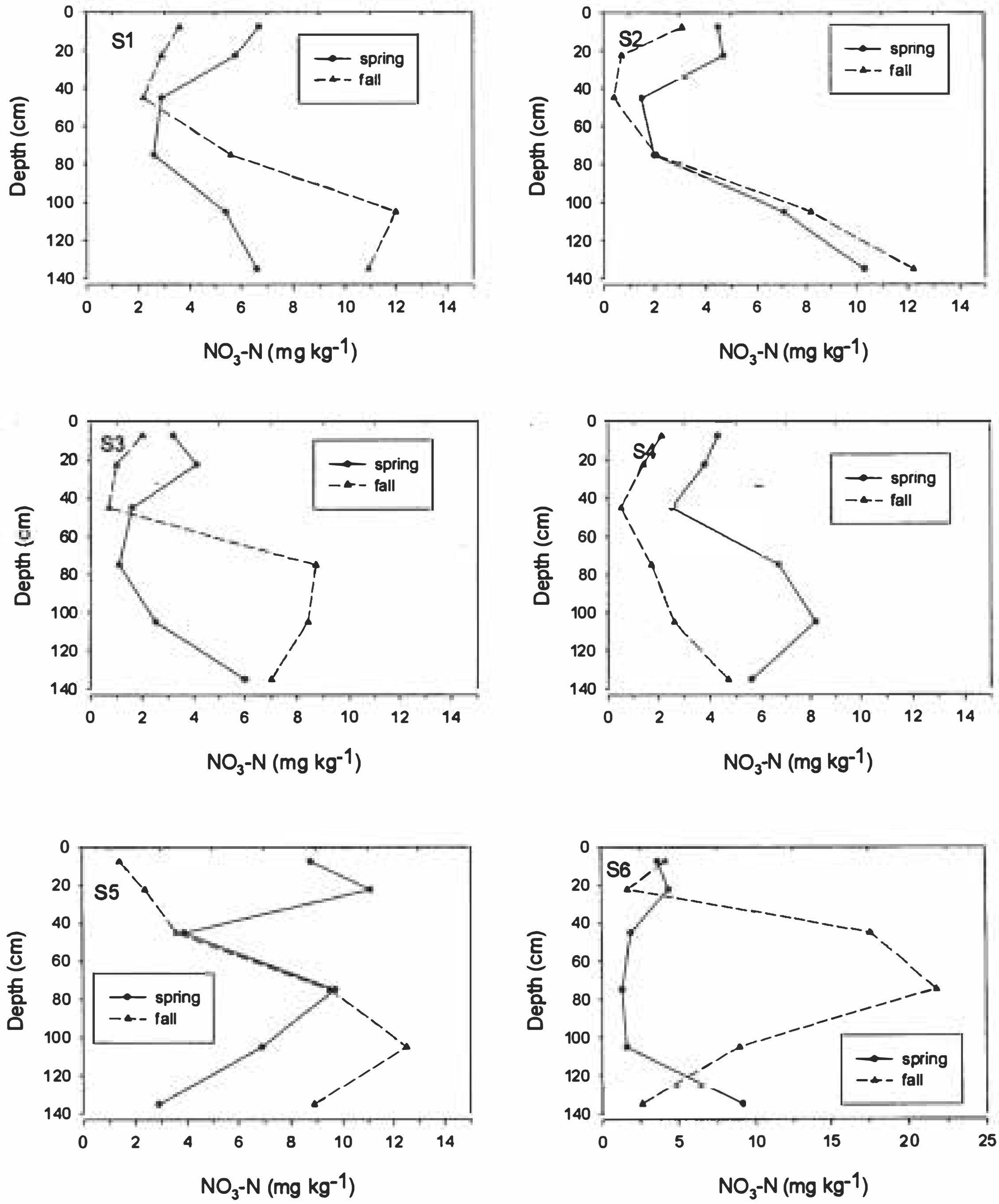


Figure 8. Soil NO_3-N levels at piezometer sites from 1997 at Fincastle.

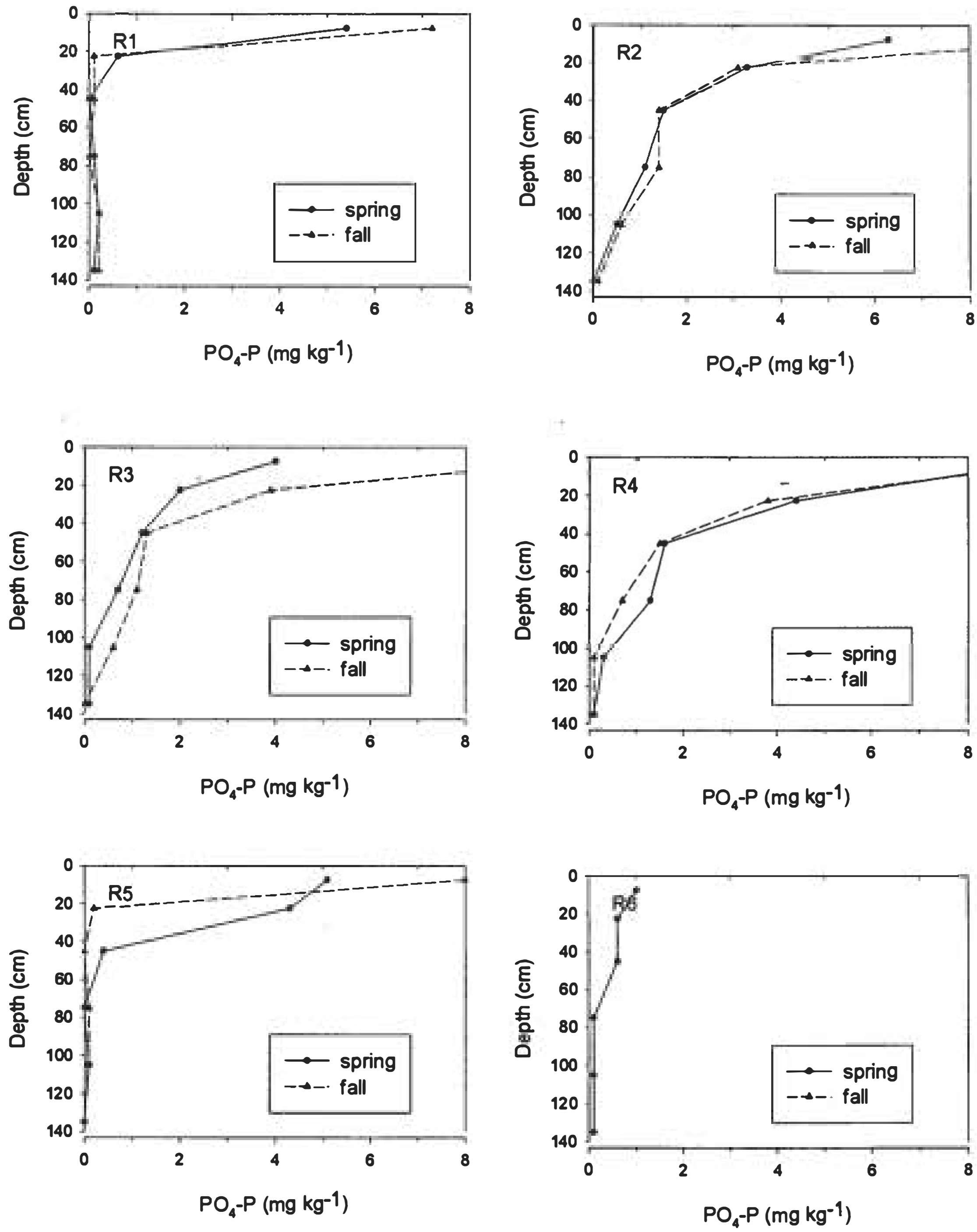


Figure 9. Soil PO_4-P at piezometer sites from 1997 at Hays.

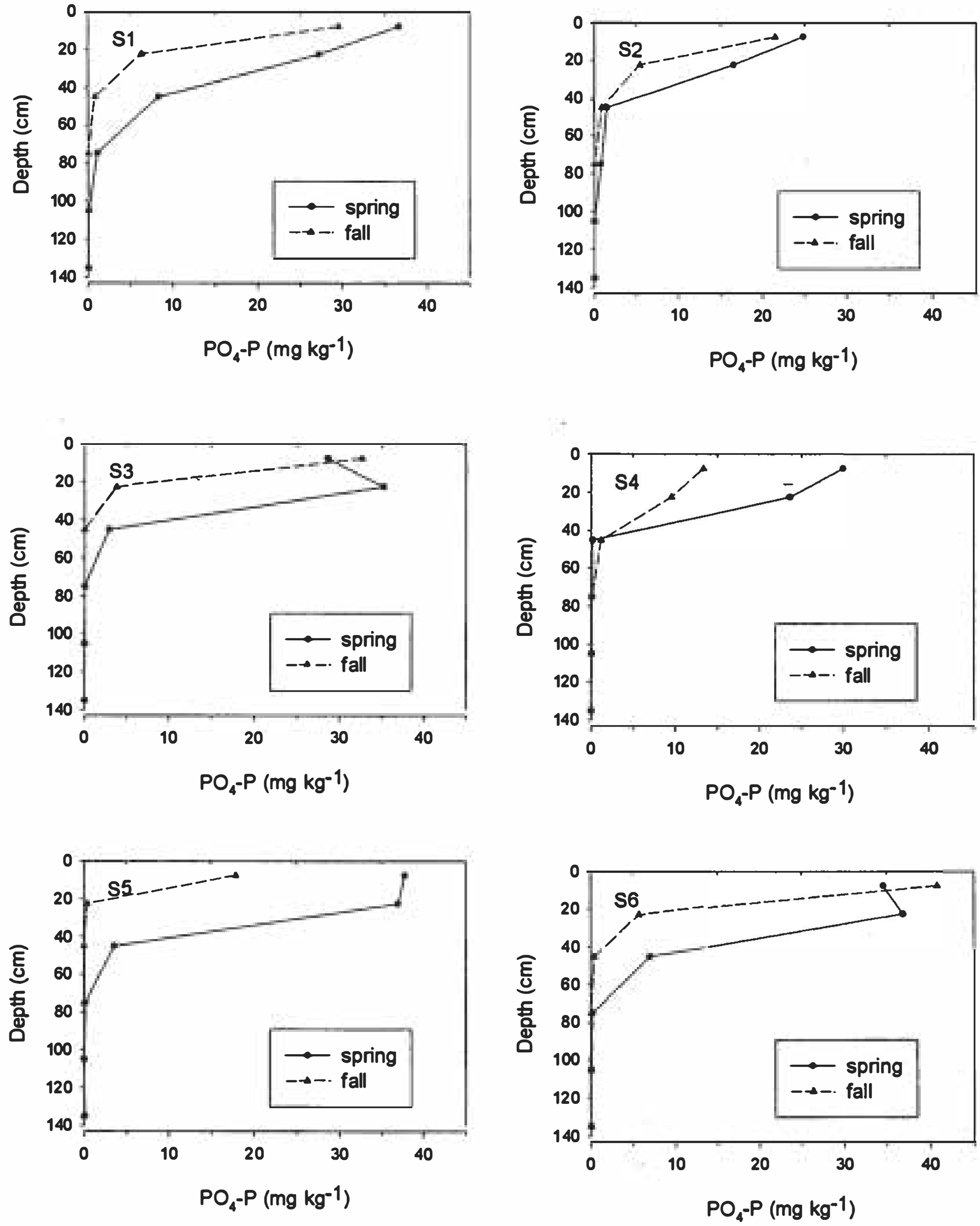
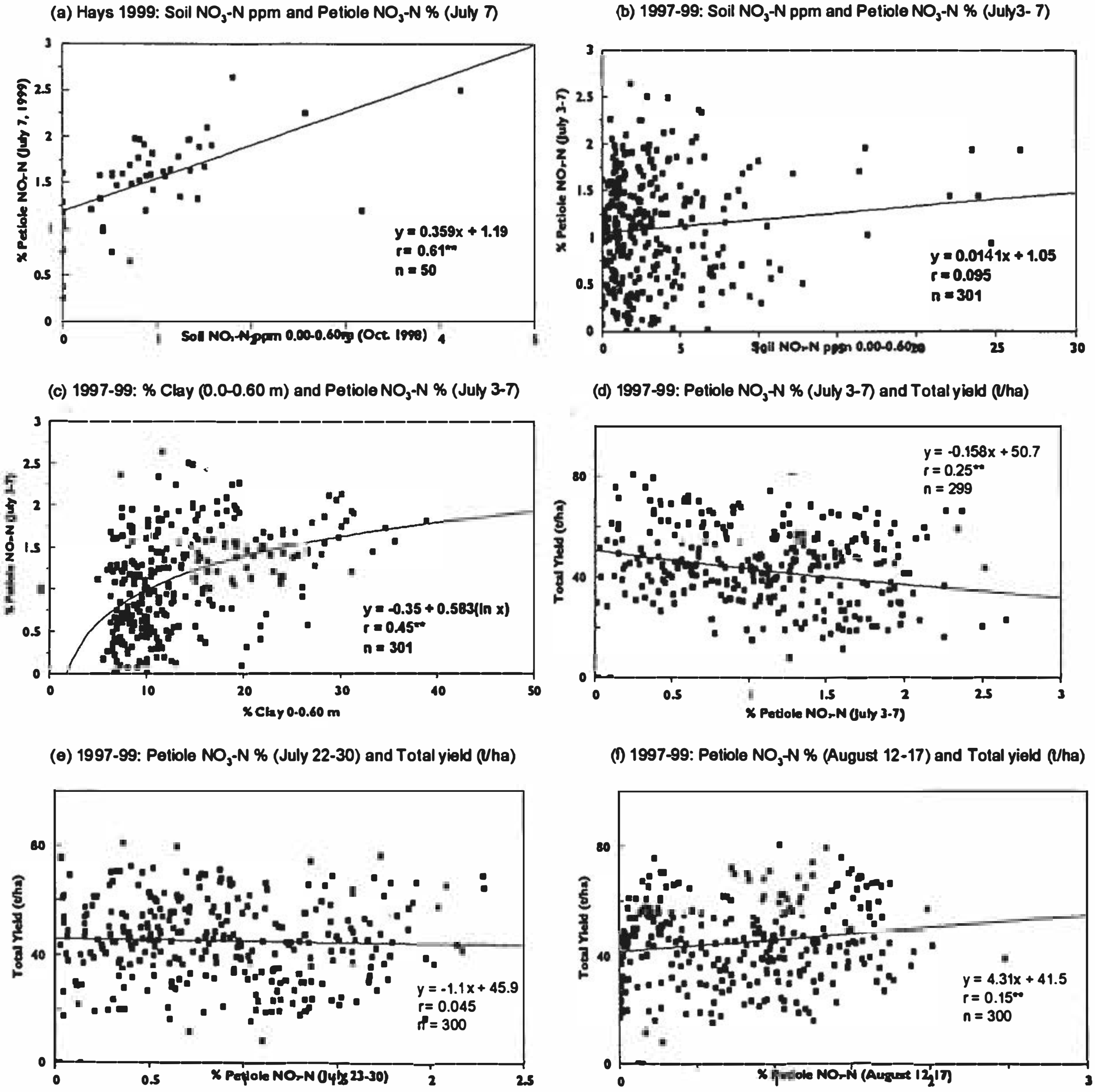


Figure 10. Soil PO_4-P at piezometer sites from 1997 at Fincastle.



* = r significant at the 0.05 level, ** = r significant at the 0.01 level

Figure 11. Correlation between potato petiole NO_3-N and (a) soil NO_3-N for Hays 1999 and (b) soil NO_3-N, (c) soil clay and (d, e and f) total yield for Fincastle and Hays potatoes 1997-1999.

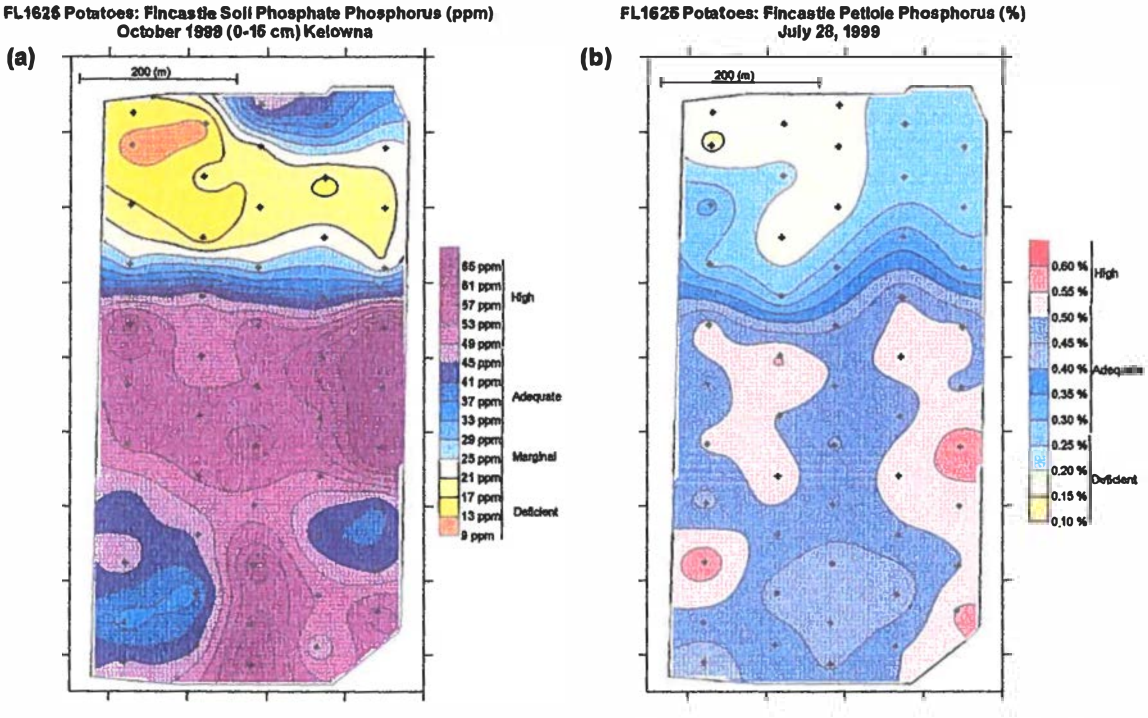


Figure 12. Fincastle (a) soil PO_4-P (October 1998, 0.00-0.15 m) and (b) petiole P (July 28, 1999) for a field which was partially fertilized with hog manure October 1997.

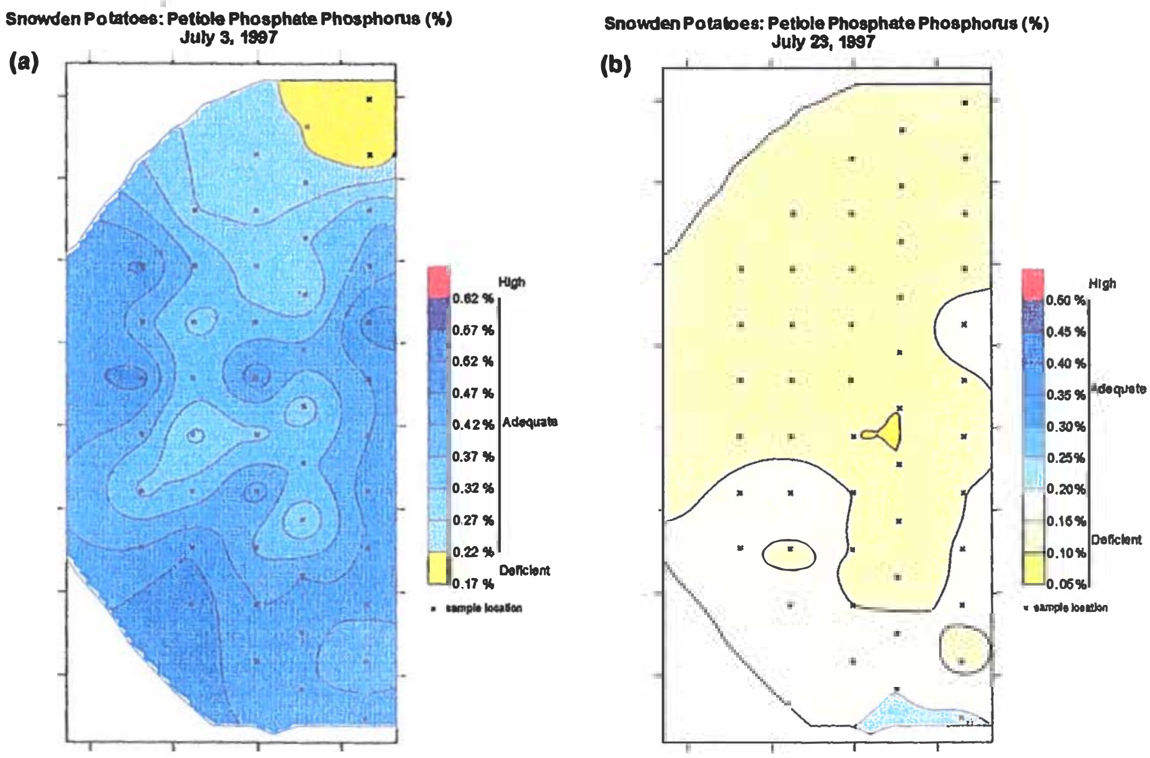


Figure 13. Petiole P levels at Hays (July 1998) showing rapid decline of petiole P from (a) July 3 to (b) July 23, 1997.

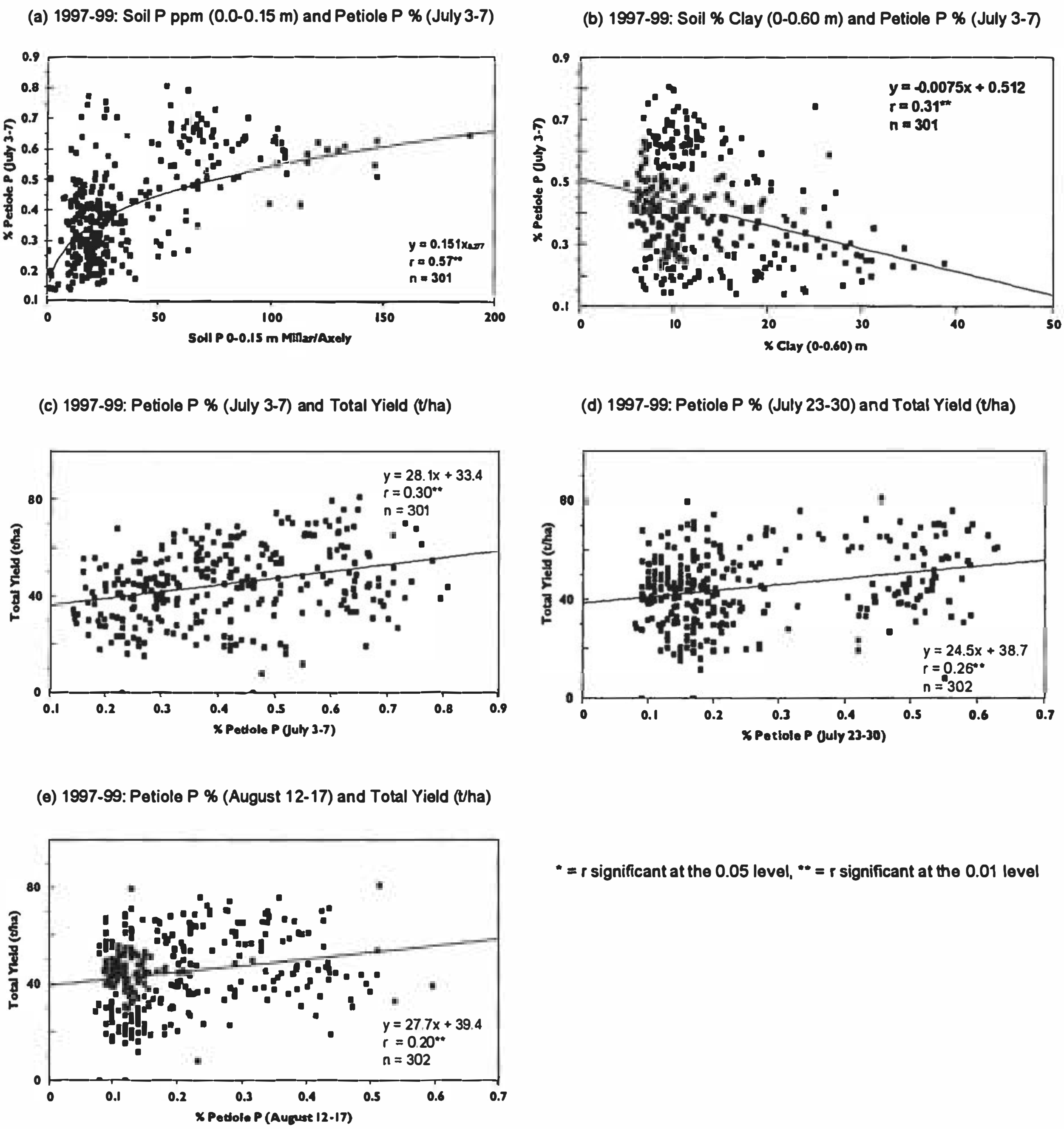


Figure 14. Correlation between potato petiole P and (a) soil PO_4-P, (b) soil clay and (c, d and e) total yield for 3 sampling dates at Hays and Fincastle for 1997-1999.

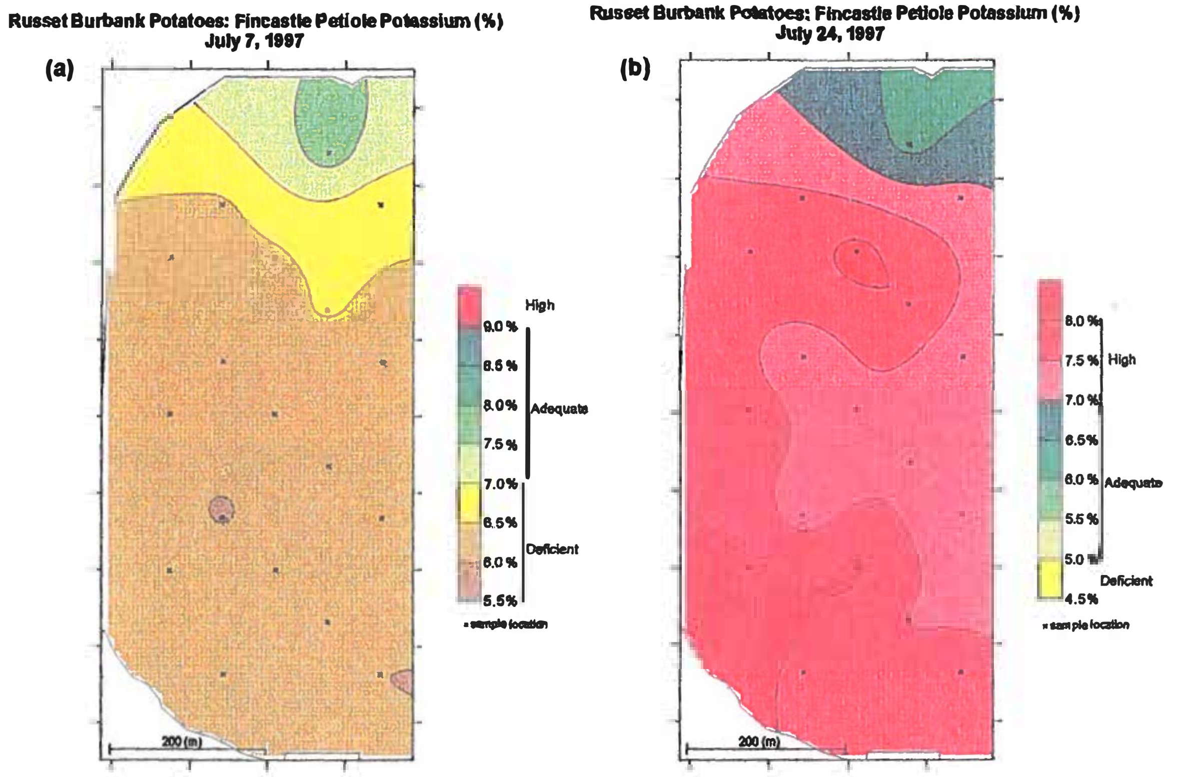


Figure 15. Petiole potassium showing an increase of percent K from (a) July 7, 1997 to (b) July 24, 1997 at Fincastle.

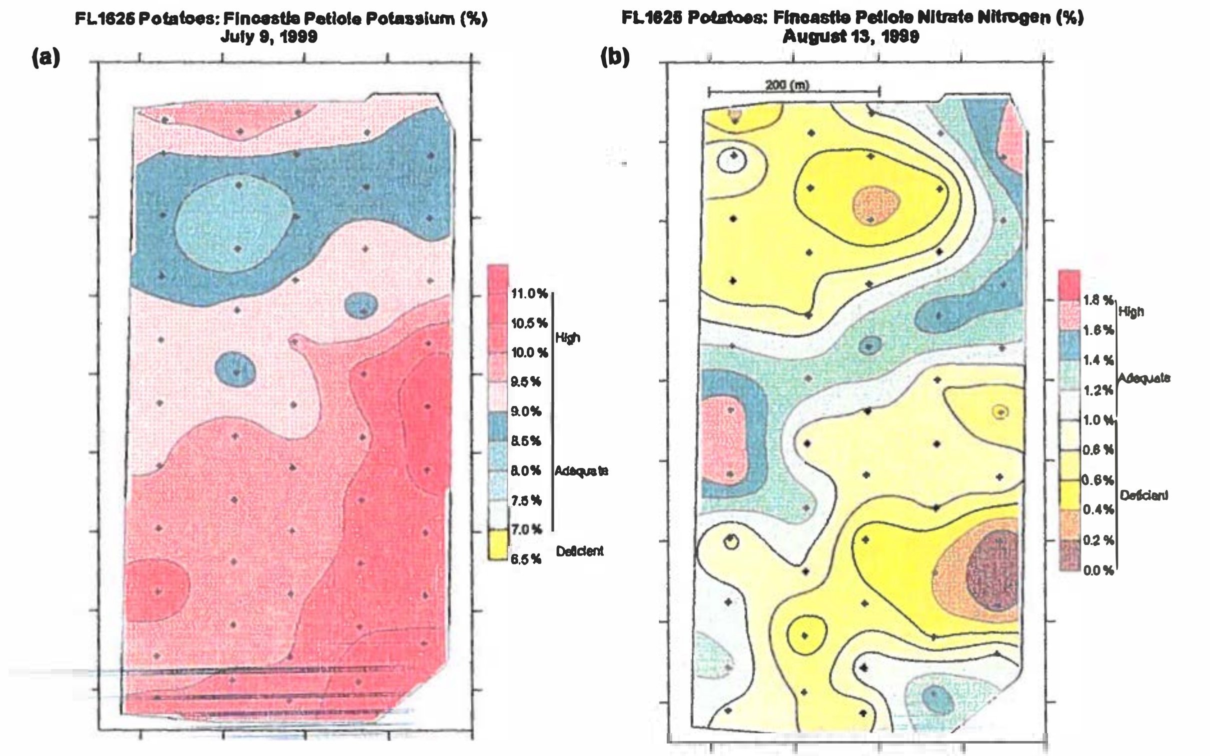


Figure 16. Petiole potassium showing a slight decrease of percent K from (a) July 9, 1999 to (b) August 13, 1999 at Fincastle.

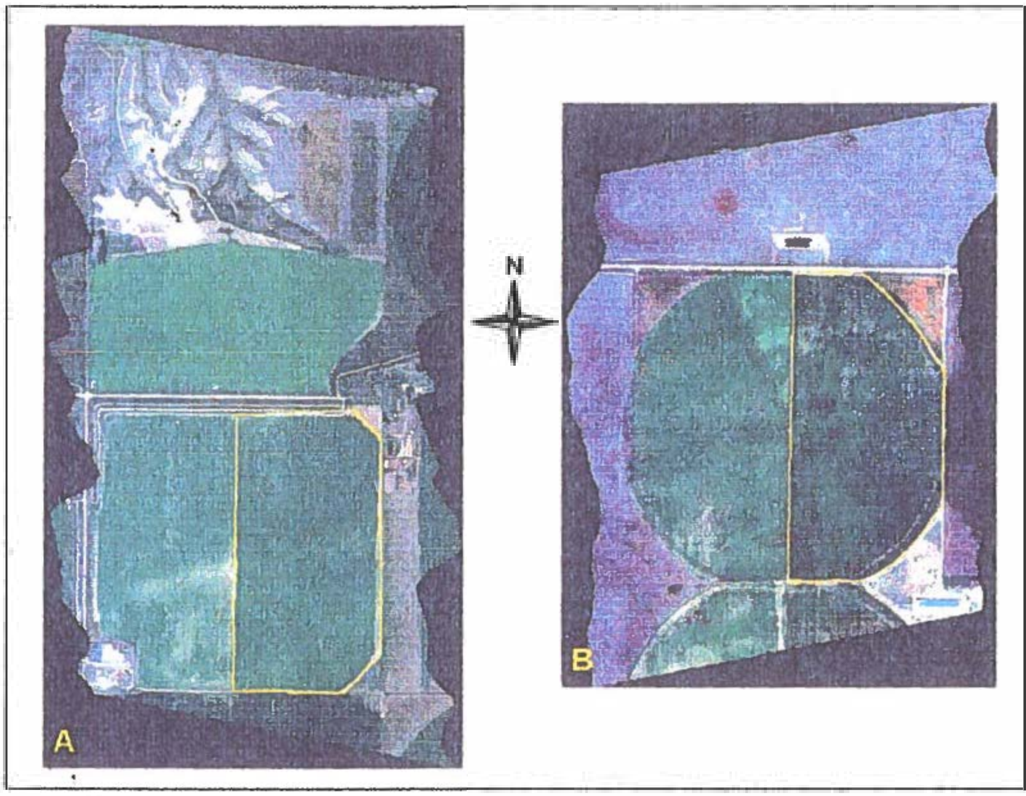


Figure 17. True colour composite images acquired July 28, 1999 at the (a) Fincastle and (b) Hays sites.

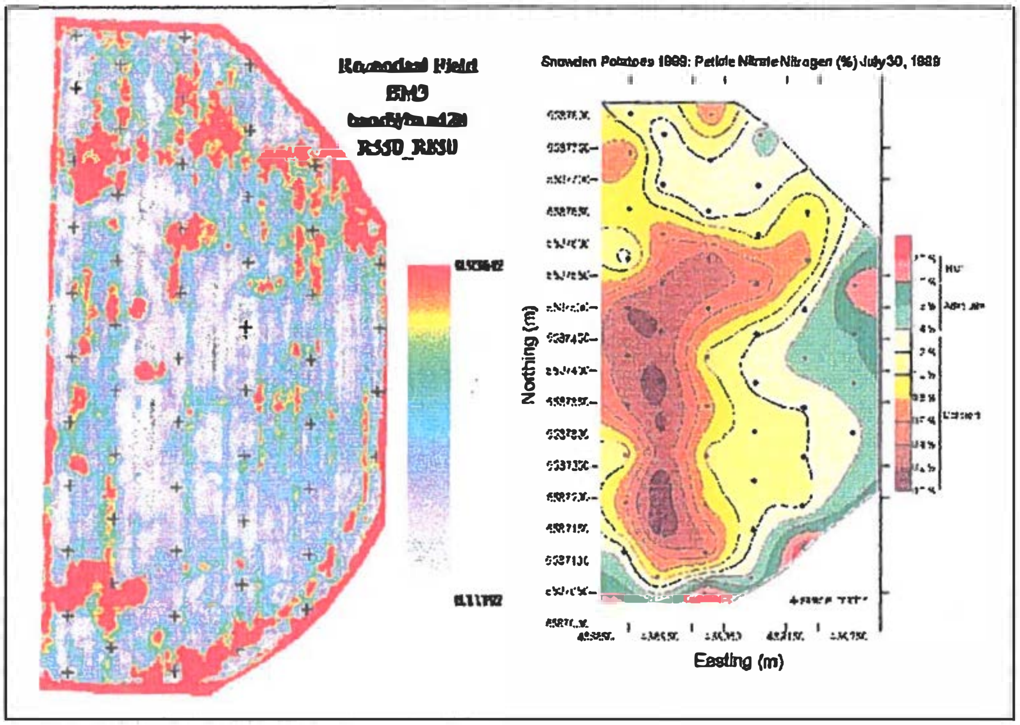


Figure 18. Fincastle site SR_{550_850} index image and petiole N map (July 28, 1999) derived from ground-based sampling.

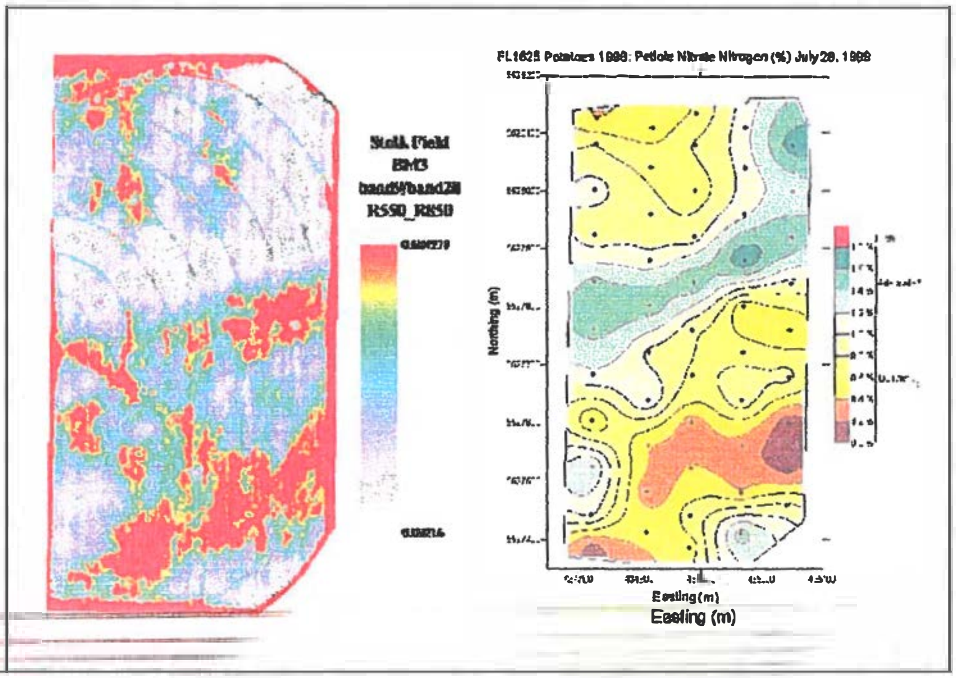


Figure 19. Hays site SR_{550_850} index image and petiole N map (July 30, 1999) derived from ground-based sampling.

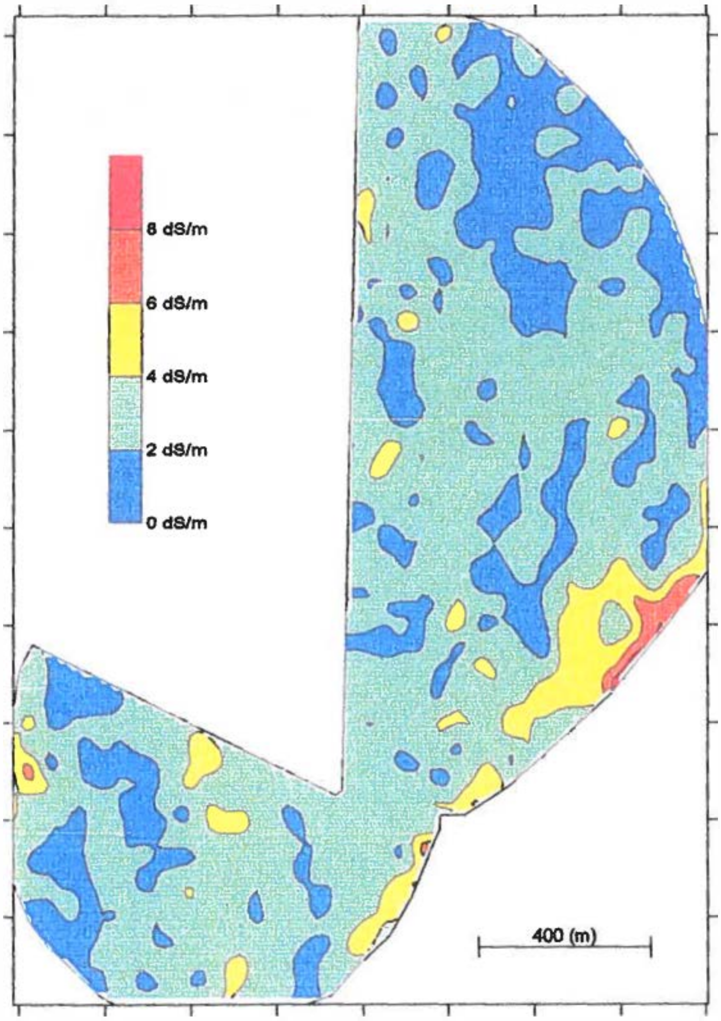
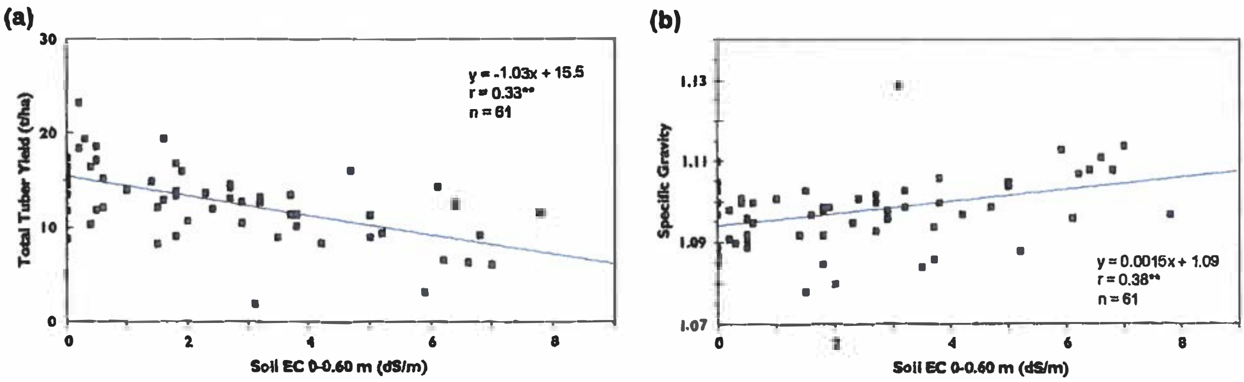


Figure 20. Soil salinity map (E.C. dS/m) for Vauxhall potatoes, April 1999.



** = r significant at the 0.01 level

Figure 21. The effect of soil salinity on (a) tuber yield and (b) tuber specific gravity for Vauxhall potatoes 1999.

IMPLICATIONS OF THE STUDY WITH REGARD TO THE IMPROVEMENT OF ALBERTA'S AGRICULTURAL AND FOOD INDUSTRY AND ADVANCEMENT OF AGRICULTURAL KNOWLEDGE

This project showed the difficulties using current yield monitoring equipment on many commercial fields. When soil variability is present, there are areas, which contain a high percentage of clay and form lumps on the harvester. The yield monitor weighs the material on the harvester belt and does not distinguish between potatoes and other material. Yield monitors usually work satisfactorily on fields, which do not contain medium or fine textured areas. Upper limits of currently used potato petiole nutrient sufficiency standards for phosphorus were found to be high. Subsequent experiments with rates of phosphorus on potatoes have confirmed this.

Petiole nutrient contents of potassium were shown to be unreliable as an indication of potassium deficiency. Research needs to be done to determine what are critical levels for yield or quality and what factors influence the potassium of petioles when grown under conditions with cold night temperatures like those of southern Alberta.

Field variability and lack of uniformity of output of irrigation water were found to be factors, which influence the growth and quality of potatoes. Farmers would do well to measure the output and uniformity of their irrigation systems.

Soil salinity was shown to be a measurable characteristic, which can be used to select portions of potential fields, which are not suitable for growing potatoes.

Site specific monitoring and yield mapping of a potato field, which is sampled by grid is a useful research technique to identify factors, which may be influencing yield and quality of potatoes.

ACKNOWLEDGEMENTS

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J. Rodvang monitored ground water at a series of piezometer nests in 1997 and 1998 and prepared the related portion of this document, including the text and Figures 7-10.

A. Smith of Agriculture and Agri-Food Canada, Lethbridge interpreted the 1999 CASI data and prepared the related portion of this document, including the text, Tables.18-20 and Figure 17-19. A. Smith's full report also appears as an appendix in this document.

L. Hingley, technologist for the Soil and Water Agronomy Program, conducted yield monitoring, sample collection and data organization and he prepared the figures and appendices for this document.

The Precision Agriculture Project with Potatoes was operated by an Alberta Agriculture, Food and Rural Development (AAFRD) team. Soil moisture budgets were determined by R. Hohm and T. Harms. D. McKenzie, R. Skretting, B. winter, T. Dell, A. Harms, H. Harms and L. Wenger collected and processed samples. J. Panford organized measurement of tuber chipping and French fry scores. M. Eliason and D. McKay assisted with setting up yield monitoring equipment. C. Murray proofread the manuscript. Word processing of the manuscript was done by S. Day and M. Bunney.

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APPENDICES

Appendices I to VIII list the raw data collected from the grid sample sites, including soil characteristics, plant tissue nutrients, rain gauge readings and hand-dug tuber sample attributes. Appendix IX provides the data from the 1999 Vauxhall soil salinity site. Appendix X is the remote sensing document provided by A. Smith.

FSTC-M009

Color Measurement of Potato Skin

Food Science and Technology Center, CDC – South
Written By: Marivic Hansen
November 24, 2003

Background

The method was developed in-house, based on the information that was learned by M. Hansen at the HunterLab Seminar in Reston, Virginia,2003

Scope

Range:

Lightness: 0-100
Chroma: 0-80
Hue: 0-360° angle

Accuracy: Determine with HunterLab Green Tile

	Actual	Average ± standard deviation (n=38)
Lightness	50.93	50.87 ± 0.05
Chroma	29.70	29.71 ± 0.11
Hue	153.37	153.32 ± 0.07

Duplicate Precision: Relative standard deviation of duplicate Green Tile readings made on the same day, N =38

Lightness: Average relative standard deviation = 0.04% (std deviation = 0.03)
Chroma: Average relative standard deviation = 0.13% (std deviation = 0.13)
Hue: Average relative standard deviation = 0.02% (std deviation = 0.02)

Day-to-day Precision: Relative standard deviation of Green Tile readings over 38 separate days.

Lightness:0.9%
Chroma: 0.38%
Hue: 0.05%

Purpose

The original project requiring this method was concerned with the physiological changes in tubers during long-term storage. Pigment composition of tubers degrades during storage. Moisture loss, texture, firmness, disease, and other factors also affect quality and consumer acceptance of stored tubers.

This method monitors the skin color of potato tubers by generating a color profile of the tuber surface. Color measurement is a critical objective quality parameter that can be used for many applications such as the analyses of physiological changes, quality changes as a result of storage conditions over period of time, the maturity of potato variety, tuber size, disease and other factors.

Procedure

A. Equipment

HunterLab ColorQuest 45°/0

B. Sample Analysis

1. Allow an hour or two for the potatoes to adjust to room temperature.
2. Randomly choose 20 small tubers for each sample.
3. Peel the outer surface of the tubers at approximately 1mm thickness.
4. Place peels in the sample dish with the skin facing downward.
5. Arrange peels so that no light can pass through the sample dish. This may require filling the sample dish ¾ full.
6. Center the sample dish over the reflectance port.
7. Place the white tile on top of the sample dish and read the sample by pressing the Read Sample on the Toolbar.
8. Fill in the sample identification table and click on OK.
9. Empty sample dish onto paper towel and mix peels thoroughly.
10. Clean sample dish in between samples.
11. Repeat steps 4-8 two more times, for a total of three measurements.
12. Proceed to the next sample.
13. After all the samples have been analyzed, save the L, a ,and b values in Excel spreadsheet.
    a. Highlight the data.
    b. From the Edit menu, copy and paste to an Excel spreadsheet.
14. From the Master Color Data active view, convert CIELab color scale to CIELCh.
    a. Double click on Active View and configure the display data.
        i. Color Scale: CIELCh
        ii. Illuminant : D65
        iii. Observer : 10°
        iv. Click on OK.
    b. Highlight C and h° data.
    c. From the Edit menu, copy, paste, and save to the same Excel spreadsheet in B.13b.

C. Instruments Parameters

1. Turn on the power by plugging the power supply box into a wall receptacle. Allow the lamp to warm up for about an hour.
2. Turn on the computer and monitor.
3. Enter any password to log on the computer.
4. Double click on HunterLab Universal Software icon.
   a. Choose Master Color Data as the display to configure.
   b. Configure the software to read the specified color scale, illuminant, and an observer.
      i. Color Scale: CIELab
      ii. Illuminant: D65
      iii. Observer: 10°
   c. Click on OK.

** NOTE: To ensure colorimetric integrity, never touch the surface of the tiles during calibration or operation. Use a small amount of isopropanol solution on Kimwipes tissue to clean the tiles when become soiled. Place the tiles in the box provided at the end of operation.

D. Sample Calculations

This method measures the skin color of a tuber surface under proper illumination and viewing conditions. The CIE system of lightness, chroma, and hue is used for the description of the color. Chroma and hue angle equations are derived from CIE L, a, and b values, so therefore:

1. C (chroma) = $(a^2 + b^2)^{1/2}$
2. h° (hue angle) = arc tan b/a

The C and h° values are calculated by the ColorQuest software in B15. Take the average values of the readings (L,C and h) for each sample.

E. Calibration

Perform calibration at the beginning of each day.

1. Double click on the CAL/Standardize button on the toolbar and follow the prompts for the standardization sequence.
2. Place the black tile in the reflectance port and click OK.
3. Place the white standard tile in the reflectance port and click OK.
4. The computer will inform you when the instrument is fully standardized.

F. Quality Control

1. Use the Green Tile as a reference sample. The first sample read and the last sample read each day should be the Green Tile.
    a. Double click on Active View and configure the data display.
        i. Color scale: XYZ
        ii. Illuminant: D65
        iii. Observer: 10°
        iv. Click on OK.
    b. Place the Green Tile on the port
    c. Press Read Sample button on the toolbar. Leave the Green Tile on the port when asked for the white tile. Click on OK.
    d. Leave the Green Tile on the port when asked for the black tile. Click on OK.
    e. Fill in the identification table and click on OK.
    f. Record the X, Y, Z values in the instrument log book.

2. Accuracy Check must meet the FSTC specifications:
    a. $X = 13.60 \pm 0.06$
    b. $Y = 19.16 \pm 0.08$
    c. $Z = 14.23 \pm 0.06$

3. Reproducibility Check: Calculate the difference between the two measurements taken at the beginning and end of the day. For each parameter (X, Y, Z), the difference between the two measurements must not exceed 0.05.

G. Sample Disposal

After analyses are finished, the tubers can be stored in the walk-in cooler in Room 165 for two weeks.

H. Data Reporting

Report the average of L,C and h° raw sample data and QC data in a spreadsheet.

APPROVAL Writer: [signature] Nov. 24/03

Manager: [signature] Nov 24/03

AGRICULTURE, FOOD AND
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Vern Warkentin
Executive Director
Potato Growers of Alberta
6008 – 46 Ave
Taber, AB T1G 2B1

January 15, 2003

Dear Vern,

Please find enclosed a copy of the final report on the "Site Specific Management of Potatoes" project, which the PGA generously sponsored. Colin was working on it through his illness and had left instructions for me to complete it. It was a four-year (1996-1999) project that produced a great deal of detailed data. Colin's intent was to distill that down, as best as possible. I hope you will find this report useful and informative.

Thank you for your financial support of the project.

Best Regards,

Shelley R. Woods

Shelley Woods
Soil and Water Research Scientist
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Site Specific Management of Potatoes

AARI Project No. 96M979

R.C. McKenzie, S.A. Woods, C.A. Schaupmeyer, M. Green, T.W. Goddard and D.C. Penney

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January 2003

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ABSTRACT

Potato crops have many characteristics that make them suitable for precision agriculture, such as a high value with costly inputs of pesticides, fertilizer and water. The application of fertilizer and pesticides on potatoes may cause environmental problems and the risks of these can be reduced by using precision farming techniques. This potential for use of precision agriculture technology has not been exploited to any great extent because problems exist which have not been fully resolved. Between 1996 and 1999 a project on the site specific management (or precision farming) of potatoes was undertaken. The goals of the project were to utilize yield monitoring and global positioning technology to generate maps and to measure the variability of the yield of potatoes in a field; to determine the effect of soil type, landscape position, nutrient level, fertility treatments, disease and weeds on the yield of potatoes; to determine yield and variability of crops over several years and relate this to field characteristics and to potato yield and quality; to evaluate the use of remote sensing and digital image analysis to detect nutrient deficiencies and diseases of potatoes; to measure the financial and environmental benefits of site specific management of potatoes; and to measure the movement of nitrogen below the root zone.

A yield monitor was successfully adapted to two farmers' potato harvesters and used to map tuber yields. Difficulties were encountered on parts of fields where soil lumps occurred, usually on areas with a high clay content. Yield maps were also developed from grid sampling. These grid samples were used to determine tuber yield, average tuber size and tuber quality as measured by specific gravity, chipping score and French fry score. Uniformity of irrigation affected tuber size. No relationship was found between chipping and French fry score and the measured factors of soil or water in the field. Grid sampling of the fields also showed variability in soil texture, which was correlated to various soil and plant chemical properties.

Two of six fields had sufficient variability of soil nitrogen to justify the cost of soil sampling and variable rate application. However, petiole NO_3-N in the first week of July was significantly negatively related to 0.0-0.60 m depth of soil clay and was not significantly related to soil NO_3-N. This means it would be more useful for farmers on these fields to base a site specific nitrogen application on soil clay content than on soil NO_3-N content. Soil P was significantly positively correlated to petiole P content but not clay content. Opportunities exist for precision applications of phosphorus particularly on two of the fields that had a history of receiving non-uniform applications of manure. However, phosphorus fertilizer applications based on grid sampling of soil phosphorus should provide some improvement in efficiency of uptake of phosphorus. Potassium levels in the soil from 1997 to 1999 were marginal to adequate on most grid sample sites. In 1997 and 1998 petiole K levels were deficient in the first week of July but became adequate to high in two later samplings. The reason for this is not known. It may be due to lower soil temperatures in early July restricting uptake, rather than the higher soil temperatures in the USA where the standards for petiole K were developed. There is a need to develop local standards for petiole K levels.

Precision fertilizer application is practiced on some potato farms in Canada, but the use of this technology is limited by the cost of soil sampling and analysis to accurately describe the field. If precision agriculture technology is to have widespread adoption in the potato industry, solutions to the obstacles of cost, soil lumps and other problems need to be incorporated into the technology.

INTRODUCTION

Since 1991, Global Positioning System (GPS) technology and yield monitoring equipment has made it possible to develop detailed yield maps of various crops. Farmers in the USA, Canada and Australia are interested in GPS as a means to increase profits by optimizing fertilizer applications. In western Europe, GPS has been used to avoid environmental contamination from excess application of fertilizers and manure. Other computer technology makes it possible to overlay maps of yields, soil or crops and measure relationships between them.

Since 1994, site specific management of cereal and oilseed crops in Alberta has increased steadily. Today, about 300 farmers in Alberta use yield monitors and some of these prepare yield maps of their fields. Site specific management of inputs can be done in a detailed or in a general manner by dividing the field into a few categories (Bouma et. al., 1995). Variable rate inputs can be applied with the assistance of GPS by a programmable fertilizer or herbicide applicator. Prototype irrigation systems have been developed to apply variable rates of water. (King et. al., 1995).

Potatoes are a high value crop requiring a lot of inputs, such as fertilizer, pesticides and irrigation. Potatoes are often grown on coarse textured soils that have low nutrient holding capacity and are high in field variability. Excess nitrogen can delay maturity of the crop and contribute to groundwater contamination. With the use of site specific management zones, with soil texture as a variable, the contamination of water can be reduced (Delgado and Duke, 2000; Whitley et. al., 2000). Insufficient nitrogen will reduce yield and increase the severity of early blight in potatoes. Phosphorus fertilizer applications for potatoes are higher than other crops, which represents an appreciable cost to farmers who are often growing potatoes on rented land. High phosphorus application may cause excess soil phosphorus, the major agricultural factor that contributes to water contamination. This results in the rapid growth and decay of algae in lakes, streams and rivers causing eutrophication and fish death. Recommendations for phosphorus requirements of potatoes by Tindall et. al. (1991) exceed those measured in a precision agriculture experiment by Davenport et. al. (1999). Traditional research under small plot conditions does not account for field variability and is usually conducted on uniform sites. The production of irrigated potatoes in southern Alberta has increased from about 9,000 ha in 1992 to

18,000 ha in 2000 and further increases are expected. If potatoes are grown in a one crop per four years rotation, 72,000 ha will be required or more than 13% of the irrigated land in Alberta. This expansion means fields are being used which are less than optimum for potato production.

Potato processors are concerned about uniform quality of tubers. By controlling storage conditions, processors can alter the sugar content of a storage bin of potatoes to an optimum level for processing. However, this is difficult in a storage bin of potatoes where the original quality is not uniform. For processing, the size and shape of tubers are important. As well, a high specific gravity in potatoes means there is more dry matter for making chips or French fries and the tubers will store well. However, two producers of French fries have encountered problems with some Alberta tubers having excessively high specific gravities, which interfered with processing. Other factors that are detrimental are the presence of disease or hollow heart.

Potato fields are closely monitored during the growing season. Many growers sample leaf petioles and monitor each field on a weekly or biweekly basis for nitrogen nutrition. During the growing season when required, fertilizers are added by fertigation or pesticides are applied to control diseases, insects or weeds. Most observations are based upon repeated sampling of a specific area within the field. The area sampled may only be representative of a portion of the field. Growers need to have some idea of the variability within a field when applying inputs to the field (King et. al., 1999; Verhagen, 1997).

A yield monitor for potatoes consisting of load cells mounted under the harvester belt was first built by Harvestmaster (Campbell, 1999) and tested by the USDA near Prosser, Washington in 1995 (Rawlins et. al., 1995; Schneider et. al., 1997). The harvester position in the field was continually located by means of a differential global positioning system. C. McKenzie and M. Green observed these tests and concluded it merited evaluation on Alberta fields as a means to measure tuber yield and correlate this to soil and crop conditions. Since that time, other yield monitors have been developed consisting of load cells on a weigh wagon (Godwin et. al., 1999) or with a camera and computer to identify tubers from other irregular objects (Wooten et. al., 2000).

OBJECTIVES

1. To use a potato harvester equipped with a yield monitor and global positioning technology to generate maps and to measure the variability of the yield of potatoes in a field;
2. To determine the effect of soil type, landscape position, nutrient level, fertility treatments, disease and weeds on the yield of potatoes;
3. To determine yield and variability of crops over several years and relate this to field characteristics and to potato yield and quality;
4. To evaluate the use of remote sensing and digital image analysis to detect nutrient deficiencies and diseases of potatoes;
5. To measure the financial and environmental benefits of site specific management of potatoes;
6. To measure the movement of nitrogen below the root zone.

DEVIATIONS FROM OBJECTIVES

Remote sensing data with spectral analysis was obtained in the first year (1996) of the project on one field at Hays and in the fourth year (1999) at Hays and Fincastle. In 1997 and 1998 false color infrared imagery data was obtained on two fields. This type of infrared imagery was not useful for detailed analysis. In 1998 satellite multispectral imagery was obtained from Resource 21 and it was not feasible to do detailed analysis.

Yield of potatoes and yields of the previous crops on these fields was only obtained on two fields in 1997. Some of the other crops were sugarbeets for which a yield monitor was not available. Some of the grain was harvested with an older model combine, which was not suitable for attaching a yield monitor. Some grain fields were harvested with a custom operator who was not agreed upon until commencement of harvest. This did not provide an opportunity to install a yield monitor, so these fields were not monitored.

Nitrogen movement below the root zone was difficult to distinguish from residual nitrogen, which was also present in the till parent material. Only estimates of nitrogen movement through the soil profiles could be made.

In 1999, at the Hays site, treatments of compost and manure were applied in strips, to determine whether or not they would affect the incidence of *Rhizoctonia* and scab on tuber surfaces.

Soil Salinity

Using Global Positioning techniques (Cannon et. al., 1994), soil salinity was mapped on a field with an EM38 meter (McKenzie et. al., 1989) in order to compare growth of potatoes to soil salinity (McKenzie et. al., 1997). This method would evaluate the potential of mapping a field for soil salinity and limiting planting of potatoes only on those areas with less than a critical salinity level. A salt tolerant crop could be planted on the remainder of the field. This objective was not included in the original objectives.

RESEARCH DESIGN AND METHODS

Fields Monitored

In April 1996, two cooperating farmers were selected who agreed to provide one potato field each year for four years. Each irrigated field consisted of half a center pivot or 27 to 31 ha. The farmers were using a three-year rotation. This meant in the fourth year the project would return to the field monitored in the first year. The fields for one farm were located about 12 to 13 km south of Hays, Alberta, and fields for the other farm were from 3 to 10 km north of Fincastle, Alberta.

The legal location, soil type, number of grid sampling points, type of irrigation system and variety of potatoes grown for the fields monitored are given in Table 1. A sampling grid was set up on each field (Fig. 1). In 1996, this grid was established in the spring after seeding of potatoes. In 1996, the single soil samples taken were used to determine soil texture and water holding capacity. In the next three years, the grid was established in the fall of the preceding year with a set of composite soil samples from about 12 cores taken before fertilizer was applied. These samples (Table 2) were used to determine texture, water holding capacity and soil fertility. The grid sampling points were located with differential GPS.

The choice of potato cultivars and field practises were left up to the individual farmer cooperators. Field practises and cultivars can be considered as typical for irrigated potato

production in southern Alberta. The cultivars Snowden and Frito Lay 1625 are both chipping types while the Russet Burbank are fryers (Table 2). They are all considered as "late" varieties. Farmer experiences are that Russet Burbank have demonstrated better response to higher nitrogen fertilizer applications thus, they are fertilized more heavily. Frito Lay 1625 are also noted for their extensive rooting (vertical and horizontal) so they may be able to better exploit soil fertility. Farmers used their normal methods of seeding, cultivation, irrigation, pest control and harvest of their potato fields. The farmers' fertilizer applications are given in Table 3. Soil nitrogen, phosphorus, potassium values in 1996 were obtained from the farmers' records and in 1997, 1998 and 1999 were obtained from the grid samples (Table 4) and from the farmers' or fertilizer company's records. Soil phosphorus was determined by the Kelowna method (Van Lorop, 1988) and soil potassium was determined by the ammonium acetate methods in 1999. In 1997 and 1998, soil potassium was determined by the Kelowna method (Van Lorop, 1988), which gives lower values than the ammonium acetate method.

Table 1. Legal location and legal description of potato fields monitored and date first irrigated.

Year/Site	Legal Land Location	Soil Type	First Irrigated	Pivot Irrigated
1996 Hays	E½ NE 9 12 14 W of 4	from 0-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994
Fincastle	E½ NW 7 11 14 W of 4	Chin light loam Fluvial lacustrine	1956	1984
1997 Hays	W½ NE 9 12 14 W of 4	from 0-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994*
Fincastle	W½ NW 27 10 15 W of 4	Cavendish loamy sand and dune sand	1956	1987
1998 Hays	W½ SE 9 12 14 W of 4	from 10-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994*
Fincastle	E½ NW 27 10 15 W of 4 E½ SW 34 10 15 W of 4	Cavendish loamy sand and dune sand	1956	1987
1999 Hays	E½ NE 9 12 14 W of 4	from 10-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994*
Fincastle	E½ NW 7 11 14 W of 4	Chin light loam Fluvial lacustrine	1956	1984
Vauxhall	S½ SW 5 13 6 W of 4 E½ 5 13 6 W of 4	Clay loam to loam overlying Clay loam to clay till at about 1 m	1921	1995

* pivot converted from high pressure to low pressure in 1997

Table 2. Sampling sites, irrigation systems, field size and variety of potatoes grown.				
Year/Site	**# of grid sampling sites**	**Type of pivot Irrigation system**	**Field area (ha)**	**Cultivar of Potatoes**
1996				
Hays	40	High pressure	28	Snowden
Fincastle	8	High pressure corner	30	Frito Lay 1625
1997				
Hays	47	Low pressure	29	Snowden
Fincastle	53	High pressure corner	31	Russet Burbank
1998				
Hays	48	Low pressure	29	Snowden and others
Fincastle	63	High pressure corner	30	Russet Burbank
1999				
Hays	53	Low pressure	28	Snowden
Fincastle	51	High pressure corner	31	Frito-Lay 1625
Vauxhall	33	2 low pressure	115	Russet Burbank

Soil Moisture and Water Tables

Alberta Agriculture Food and Rural Development (AAFRD) Irrigation Branch staff from Taber and Brooks monitored soil water at each of the grid sampling points with a neutron probe. Soil moisture was determined to a depth of 1.0 m. Available moisture limits were calculated from particle size data according to Oostervelt and Chang (1980). A rain gauge was installed at each sampling point and rainfall and irrigation measurements were made approximately biweekly.

In 1997 and 1998 the groundwater was measured with 3 to 6 piezometer nests in each field (Rodvang, 1998 and 1999). The goal was to characterize groundwater flow and chemistry on the sites and determine whether agricultural nitrate occurred in the groundwater. Soil samples were collected during drilling and groundwater samples were collected during the season.

Fertilizer and Soils

Soil available nitrogen (N), phosphorus (P), and potassium (K) and soil pH maps were made for the 1997, 1998 and 1999 fields based on data collected the previous October from the sampling grid (Table 4). Soil texture maps were made from all fields based on grid samples (Fig. 2), which were used to develop relationships between texture and nutrient availability. In 1999, at Fincastle and Hays, soil calcium carbonate levels were determined and used to prepare maps at both sites.

Fertilizer Treatments

In 1997, 1998 and 1999, strip fertility experiments were set out. In 1997, the treatments (Table 5) applied were centered around the N2 treatment (farmer rate) (Table 3). Each strip was 8 rows or 6.7 m wide on the Snowden field and 8 rows or 7.3 m wide on the Russet Burbank field. In 1998, the fertilizer strips were in addition to the farmers' fertilizer rates (Table 6). Each strip was 6 rows wide or 5.03 m at Hays and 5.49 m at Fincastle. This represented one pass of the potato harvester. Yields were acquired and positioned on the fertilizer strips in 1997 and 1998 with GPS and a yield monitor on the farmers' potato harvesters.

In 1999, fertilizer plots were set out at Hays. Each plot was 12 rows or 10.1 m wide by 400 m long and was replicated twice. Compost manure and fertilizer treatments (Table 7) were broadcast on the plots in October of 1998. The plots were not fertilized by the farmer, except for 41 kg/ha N at seeding and a fertigation application of 50 kg/ha N during the growing season. The potatoes were hilled and seeded by the farmer in April of 1999. Snowden potatoes were grown and the field was fertigated (Table 3) and irrigated similar to the remainder of the field. Counts of visibly diseased plants on 600 m rows in each treatment were made in August of 1999.

Table 3. Farmers' soil fertility (N, P and K) before fertilization and N, P and K fertilizers applied and depth of soil samples (kg/ha).

		Hays (kg/ha)	Fincastle (kg/ha)
1996	Soil N Fall 95^{0}	(29) 0.0-0.30 m	(73) 0.0-0.60 m
	Fertilizer N prior to seeding	120	59
	Banded N at hilling	34	0
	Fertigated N	58	11
	Total N	**241**	**144**
	Soil P	(35) 0.0-0.30 m	(67) 0.0-0.30 m
	Fert P	48	32
	Total P	**83**	**99**
	Total K not available		
1997	Soil N 0.0-0.60 m	37	67 (52)
	Fert N Fall 96	90	0
	Banded N at hilling	39	179
	Fertigated N	88	41
	Total N	**254**	**287**

Table 3. Farmers' soil fertility (N, P and K) before fertilization and N, P and K fertilizers applied and depth of soil samples (kg/ha).			
		Hays (kg/ha)	**Fincastle (kg/ha)**
	Soil P 0.0-0.15 m 0.0-0.30 m	24	196
	Fert P Fall 96	59	0
	Fert P Spring 97	0	7
	6 fertigations	22	
	Total P 0.0-0.15 m	**195**	**203**
	Soil K 0.0-0.30 m	685	1066 (1935)
	Fert K Fall 96	56	0
	Fert K Spring 97	0	46
	Total K	**741**	**1112**
1998	Soil N 0.0-0.60 m	28	32
	Fertilizer N Fall 97	179	190
	N at seeding	0	20
	N at hilling	47	35
	6 fertigations	50	31
	Total N	**304**	**308**
	Soil P 0.0-0.15 m	41	67
	Fertilizer P Fall 97	58	46
	Fertilizer P at seeding		29
	Total P	**99**	**142**
	Soil Kelowna K 0.0-0.15 m	591	627
	Fertilizer K Fall 97	74	74
	Total K	**665**	**701**
1999	Soil N 0.0-0.60 m	38	90
	Fertilizer N Fall 98	157	112
	Fertilizer N at hilling	41	20
	Fertigations of N	50	30
	Total N	**286**	**252**
	Soil P 0.0-0.15 m 0.0-0.30 m	47 71	93 127
	Fert P Fall 98	59	39
	Fert P Spring	0	29
	Total 0.0-0.15 Soil P	**106**	**161**
	Soil K 0.0-0.30 m	757	733
	Fertilizer K Fall 98	56	56
	Fertilizer K Spring	0	0
	Total K	**813**	**789**

[0] ( ) soil nutrient values supplied by the farmer from his soil sampling

Table 4. Soil analysis done for the site specific potato project.

Year	Sand (%)	Silt (%)	Clay (%)	NO_3 – N (ppm)	NH4-N (ppm)	Miller Axley PO_4-P (ppm)	Kelowna PO_4-P (ppm)	Ammon Acetate K (ppm)	Kelowna K (ppm)	pH	2:1 extract E.C. (dS/m)	Zn (ppm)	Cu (ppm)	Mn (ppm)	Fe (ppm)	Na (ppm)	CaO_3 (ppm)	S (ppm)
1996 sampled May 26 0.0-0.90 m	✓	✓	✓	-	-	-	-	-	-	-	-	-				-	-	-
1997 sampled Oct.96 0.0-0.90m	✓	✓	✓	✓	1/6 of profiles	✓	0.0-0.15 m 0.15-0.30 m		0.0-0.15 m 0.15-0.30 m	✓	✓	1/6 of 0.0-0.15 m samples					Hays	
1998 sampled Oct. 97 0.0-0.90m	✓	✓	✓	✓	✓	✓	0.0-0.15 m 0.15-0.30 m		0.0-0.15 m 0.15-0.30 m	✓	✓	0/0-0.15 m						
1999 sampled Oct. 98 0.0-0.90 m	✓	✓	✓	✓	✓	✓	0.0-0.15 m 0.15-0.30 m	✓	0.0-0.15 m 0.15-0.30 m	✓	✓	0.0-0.15 m				✓	0.0-.15 0.15-0.30	✓

✓ all samples analyzed

Samples were dug from each treatment and treatment yields were determined using a yield monitor and GPS on the farmer's harvester. Disease counts of the amount (%) of tuber surfaces infected with scab and *Rhizoctonia* were determined on 160 tubers from each treatment. Occurrence of disease was not significantly different between treatments so this data is not reported.

Table 5. Nutrients (N, P and K) in kg/ha applied on fertilizer strips in 1997.

	Hays			Fincastle		
Treatment	**N**	**P**	**K**	**N**	**P**	**K**
N1	30	59	50	53	6	41
N2	92	59	50	176	6	41
N3	182	59	50	311	6	41

Table 6. Nutrients (kg/ha) applied in 1998 on fertilizer strips in excess of farmers rate to Hays and Fincastle fields.

Treatment	N	P
N	67	0
P	0	32
NP	67	32
Check	0	0

Table 7. Fertilizer treatments at Hays in 1999.

		Nutrients kg/ha		
Treatment	**T/ha**	**N**	**P**	**K**
High compost	18.1	199	84	174
Low compost	9.8	107	45	94
High manure	26.8	158	82	216
Low manure	12.8	75	39	103
High phosphorus		90	58	0
Low phosphorus		90	20	0

Tissue Samples

Each field was tissue sampled three times at each of the grid points (early July, late July and the second or third week of August). Tissue samples consisted of 45 to 70 petioles taken from the fourth leaf of plants within 5 m of the grid sampling points. All the tissue samples were analyzed to determine NO_3 N, total N, P, Ca and moisture. In 1996 and 1997, 24% of the samples, and in 1998 and 1999, all the samples, were analyzed to determine K, S, Zn, B, Mn, Fe, Mg, Al, Cu, Na (Table 8). These tissue levels were compared to sufficiency limits (Table 9) based on limits used by various Alberta and USA soils laboratories.

Pest Monitoring

Diseases were monitored by walking the fields. Some areas of the Hays fields received excess water and developed water-induced rot of tubers. These areas were not harvested. In 1999 fertilizer, compost and manure treatments were set out as strips on the Hays field. Disease counts were made on two rows from the three 50 meter long strips from each of the two replicates of the treatments. The 1999 Vauxhall and Fincastle fields had very little disease on all fertilizer treatments so no disease counts were made in these fields.

In 1996 to 1998 weeds in all fields were widely dispersed and not clustered so they were not mapped with GPS or remote sensing techniques. In 1999 dense areas of Canada Thistle (*Cirsium arvense*) occurred on the Hays field. The perimeters of some of these GPS areas were mapped with differential GPS, by walking with a backpack unit obtaining correction data from a base station at the edge of the field. These areas were then located on the CASI images of the field.

Remote Sensing

In July 1996, Itres, a commercial remote sensing firm, collected airborne compact spectographic imager (CASI) data on the Hays potato field. Alberta Environment took color infrared photos at a scale of 1:5,000 and 1:10,000 on July 14, 1997, at Hays and Fincastle; July 23, 1998 at Hays and Fincastle and July 23, 1999 at Hays, Fincastle and 1:15,000 photos at Vauxhall. On July 28, 1999, CASI data were taken of the Hays, Fincastle and Vauxhall potato fields by Itres. GPS positions of ground control points were taken and used to prepare georeferenced images.

Tuber Samples

In 1997, 1998 and 1999, two samples were hand dug near each grid point prior to harvest. Each hand sample consisted of four uniformly spaced plants in 1.22 m of row. The farmer at Fincastle used 0.91 m row spacing between rows and the farmer at Hays used 0.84 m spacing between rows. In addition, in 1999, four samples were hand dug from each replicate of each fertilizer treatment.

The potato samples were washed, graded into size categories and weighed to determine yield. Scab and *Rhizoctonia* scores were made on 20 tubers from each sample from Hays in 1998 and both Hays and Fincastle in 1999. Samples were chipped and chipping quality color scores were done on the Hays tuber samples in 1997, 1998 and 1999. Samples were French fried and French fry quality, color and texture scores were done on the Fincastle tuber samples in 1997, 1998 and 1999.

Global Positioning Systems and Yield Monitoring

Global positioning techniques were used to locate points on the grid for sampling tubers (Table 10). At harvest, the potato fields were mapped using a NovAtel GPS and a Harvestmaster yield monitor mounted on the farmer's potato harvester (Campbell, 1999). The NovAtel RT-20 DGPS delivered accuracies of 0.20 m horizontal and 0.30 m vertical. A topographic map was prepared at the same time as the yield map. In 1997, wheat and barley fields were yield mapped using an Ag Leader yield monitor coupled to an Omnistar receiver, with real-time differential corrections from a geostationary satellite service. This system provided accuracies of 0.5 to 1.0 m horizontal and 1.0 to 2.0 m vertical. The Omnistar information was not suitable to use to prepare topographic maps because of the lack of accuracy in the vertical axis.

Soil Salinity

The site at Vauxhall was chosen in 1999 because it contained a range of soil salinity. Potatoes are considered to be moderately sensitive to salinity. In April, prior to seeding the potatoes, the soil salinity in the field was mapped by towing an EM38 salinity meter behind an all-terrain vehicle and positioning it with GPS technology (Cannon et. al., 1994). On July 28 and September 1, 1999, Itres flew over the field and collected CASI data. In late September, 58 points were selected to represent different levels of soil salinity. At each of these sample points, salinity was determined with an EM38 according to McKenzie et. al. (1989). Tuber samples consisting of two 1.22 m lengths of row each with four uniformly spaced plants, were dug at these sampling points. A regression analysis was developed between tuber yields, tuber specific gravity and soil salinity. The CASI imagery was compared to the salinity map.

Table 8. Petiole analysis volume and parameters.																			
		Sampling date			Analysis														
Year	Location	1st	2nd	3rd	Moisture	N	Ca	P	NO_3 N	K	S	Zn	B	Fe	Mg	Al	Ca	Na
1996	Hays	July 3	July 30	Aug. 20	✓	✓	✓	✓	✓		∉	∉	∉	∉	∉	∉	∉	∉
	Fincastle	July 4	July 30	Aug. 20	✓	✓	✓	✓	✓		∉	∉	∉	∉	∉	∉	∉	∉
1997	Hays	July 3	July 23	Aug. 12	✓	✓	✓	✓	✓	✓	∉	∉	∉	∉	∉	∉	∉	∉
	Fincastle	July 7	July 24	Aug. 13	✓	✓	✓	✓	✓	✓	∉	∉	∉	∉	∉	∉	∉	∉
1998	Hays	July 6	July 22	Aug. 10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Fincastle	July 7	July 23	Aug. 11	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1999	Hays	July 7	July 30	Aug. 17	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Fincastle	July 9	July 28	Aug. 13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Vauxhall	July 6	July 27	Aug. 11	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✓ all samples analyzed

∉ 1/5 of samples were analyzed

Table 9. Potato petiole nutrient sufficiency levels from three soil/plant analysis labs and levels found in this project.				
	Stage/or time after emergence	NO_3-N (%)	P (%)	K (%)
Lab A				
	Vegetative	1.2-1.5	03.0-04.0	7.0-8.0
	Tuber initiation	1.2-1.5	0.25-0.35	7.0-8.0
	Tuber bulking	1.2-1.5	0.25-0.30	6.5-7.5
	Tuber half grown	1.0-1.5	0.20-0.25	6.0-7.0
	Tuber maturing	0.5-1.0	0.15-0.20	3.0-5.0
Lab B				
	+3 weeks	2.5-3.0	0.24-0.44	11.8-13.8
	+9 weeks	1.8-2.3	0.20-0.40	9.8-11.8
	+15 weeks	1.2-1.7	0.16-0.36	7.8-9.8
	Pre-vine kill	0.5-1.0	0.14-0.34	5.8-7.8
Lab C				
	Early season	0.8-1.2	0.12-0.2	9-11
	Mid season	0.6-0.9	0.08-0.16	7-9
	Late season	0.3-0.5	0.05-0.1	4-6
Hays and Fincastle for FL 1625, Russet Burbank or Snowden				
	early July (3^{rd}-7^{th})	1.4-2.2	0.22-0.62	7-9
	late July (23^{rd}-30^{th})	1.2-1.8	0.20-0.50	5-7
	mid August (12^{th}-17^{th})	1.0-1.6	0.16-0.36	3.5-5.5

Table 10. GPS Applications 1996-1999.			
Year/Crop	**Site**	**GPS differential source**	**Monitor**
1996			
Russet Burbank Potatoes	Fincastle	Novatel RT-20 + local base corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
1997			
Russet Burbank Potatoes	Fincastle	Omnistar + geostationary corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
Wheat	Hays	Omnistar + geostationary corrections	Ag Leader
Barley	Fincastle	Omnistar + geostationary corrections	Ag Leader
1998			
Russet Burbank Potatoes	Fincastle	Novatel RT-20 + local base corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
1999			
FL1625 Potatoes	Fincastle	Novatel RT-20 + local base corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
Russet Burbank Potatoes (salinity only)	Vauxhall	Novatel RT-20 + local base corrections	EM38 salinity meter

RESULTS AND DISCUSSION

Soil Moisture, Water Tables and Yields

In 1996, at Hays, potatoes were grown on the east half of a high-pressure pivot (Fig. 3b), which was operated at less than the optimum pressure. This resulted in an uneven distribution of water with excess water applied near the centre and insufficient water applied on the outer parts of the circle. On the same pivot, in the following year, 1997 (Fig. 3a), potatoes were grown on the western half. Meanwhile, the farmer had redesigned his system, converting the high pressure pivot to a low pressure pivot. This new pivot had uneven calibration causing a high application of water on the outer part of the circle and less in the centre. The contrasting distribution patterns from the two years are shown in Fig. 3.

Prior to redesign of the pivot system, excess irrigation near the centre of the pivot caused accumulation of water below the root zone in Hays (1996) (Fig. 4b) while the surface layers (Fig. 4b) had deficient available water, especially in the outer parts of the pivot (30% to 55% of field capacity). These conditions create the possibility for leaching of nutrients below the root zone, waterlogging and increased disease in low areas of the fields. The excess irrigation occurred because the pivot was operating near the center at less than the designed pressure.

In three years, 1997-1999 and six fields, uniformity of irrigation application was a significant factor, influencing yield in four of the six fields. In three fields, Hays 1998 (Fig. 5a), Hays 1999 and Fincastle 1999 (Fig. 5b), total yield significantly increased with increasing irrigation.

Mean tuber weights were increased with increasing irrigation at Hays 1998 (Fig. 6a) and slightly, but not significantly, decreased with increasing irrigation at Hays in 1997 (Fig. 6b).

Irrigation management is one of the critical factors influencing both yield and tuber size. Areas of the field, which received more than average irrigation plus precipitation had increased tuber numbers, reduced mean tuber weights and greater numbers of small tubers, as compared with areas which received less than average irrigation plus precipitation.

At Fincastle in 1996 and in 1999 and on the two halves of a field in 1997 and 1998, corner pivots were used. These pivots did not provide as much water to the corners as the rest of the field. When the corner arm was extended and operating, the remainder of the pivot appeared to have reduced output.

Piezometer measurements of groundwater depth movement and soil NO_3-N content at the Hays site in 1997 (Fig. 7) and Fincastle 1997 (Fig. 8) and 1998 are reported by Rodvang (1998 and 1999). Hays had less than half the NO_3 N than Fincastle. The Hays site was irrigated more than the Fincastle site. Nitrate levels were low at depth but this may be due to reducing conditions, causing denitrification. Once all nitrate is reduced, denitrifying bacteria tend to reduce sulphate to H_2S. The odor of H_2S was present at two of the well sites at Hays in 1997 indicating some sulphate was being reduced (Rodvang, 1998). At some of the wells, the texture was coarse permitting downward movement of water. At Hays, the flow of groundwater occurred from the irrigated field outward to the unirrigated rangeland. Irrigation has caused water table mounding below the sites. Water tables rose during the summer at Hays and reached a peak of 1.2 m below the ground at one site in 1997 and 1.65 m in 1998.

At Fincastle, the irrigation applications generally were less than at Hays. The water table followed the surface topography. In 1997 water table depths ranged from 1.7 to 3.5 m. In 1998 at Fincastle, water table depths varied from 1.5 to 2.5 m below ground level and were over 5 m deep at one of the six sites. Water levels rose during the summer in both years and declined after late August. Vertical hydraulic gradients indicated slight downward flow at most piezometer nests.

In 1997, nitrate was present in soil water at the piezometer sites at levels from 1 to 20 mg/kg at Fincastle. Nitrate levels at Hays were lower, from 1 to 6 mg/kg. Site 6 (R6 in Fig. 7) was located on native range adjacent to the potato field and had almost no nitrate to a depth of 1.5 m. The difference between the nutrient level at this site and the other 5 sites shows the effect of irrigated agriculture for 19 years.

Soil water phosphorus (P) was from 4 to 10 mg/kg at the cultivated Hays replicates (Fig. 9). This was compareble to the Fincastle site, where P ranged from 20 to 40 mg/kg in the 0-0.15 m layer (Fig. 10). The higher levels of P at Fincastle than at Hays was because Fincastle received hog manure applications for a number of years. It is interesting that the P had not move below 0.60 m at the time of sampling.

Soil Fertility

Nitrogen

Nitrogen (N) is the fertilizer used in largest quantities by potato growers and application of 160 to 240 kg of N/ha cost from $100-$150/ha. Site specific applications of N offers possibilities for reduction of costs. Soil nutrient variability was more evident at Fincastle than at Hays. Soil nitrogen was variable on the previous fall samples for the 1997 Fincastle field and to a lesser extent on the 1997 Hays field. The 1997 Fincastle field, for the 0.0-0.60 m depth, had 40% of the sample sites considered to be very deficient, 51% deficient to marginal and 10% adequate to high (Table 11). The farmer applied 179 kg/ha N at hilling and another 41 kg/ha N by fertigation during the growing season. These applications would be anticipated to be in excess of what could be used by the crop in areas of the field that already had 73 and 173 kg/ha soil N and would be expected to reduce potato tuber specific gravity. However, there was no relationship between soil N and specific gravity at the grid sites on the field. The 1997 Fincastle site had 89% of the 0.0-0.60 m soil samples with less than 15% clay, which means excess N could easily move downward. In 1997, Hays had 73% of the sample sites with 31 kg/ha N for 0.0-0.60 m and 26% of the sites with 63 kg/ha N so the whole field was low in nitrogen.

In 1998 at Fincastle in the 0.0-0.60 m layer, 92% of the soil sample sites had less than 5 ppm N (very deficient) with an average of 14 kg/ha N. The remaining 8% (deficient to marginal) had an average of 65 kg/ha N. In 1998 at Hays, 68% of the soil sample sites had less than 5 ppm N and the remaining 32% of the sample sites had between 5 and 7.5 ppm N. The variability at these two fields in 1998 was not sufficient to justify the costs of site specific fertilization of nitrogen.

All the soil sample sites for 0.0-0.60 m at Hays in 1999 were less than 5 ppm N (Table 11). In 1999 at Fincastle the 0.0-0.60 m layer, 90% of the sample sites were very deficient (<5 ppm N),

6% were deficient to marginal (5-15 ppm N) and 4% were high (>20 ppm N). This site would offer possibilities for precision application of N with detailed mapping of soil N. This site had 27% of the 0.60-0.90 m samples with greater than average (165 kg/ha) soil N. The nitrogen at depth is evidence of leaching of nitrogen during previous cropping.

Soil N data collected from grid sampling for two fields for three years indicates only two of the six fields had sufficient variability in soil nitrogen to justify variable rate fertilization. Soil N for 6 fields (Fig. 11b) was not significantly related to petiole NO_3-N on July 3-7. This also indicates that when these fields were grouped together, variable rate application based on soil NO_3-N the previous fall does not offer possibilities for improved nitrogen management. Fincastle in 1997, and perhaps in 1999, had sufficient variability to justify the cost of sampling and analysis to determine soil nitrogen and then to apply variable rates of nitrogen fertilizer. The spatial soil fertility data must be collected before a decision can be made on the feasibility of variable rate fertilization.

Phosphorus

At Fincastle in 1997, soil phosphorus (P) for 0.0-0.15 m was high by Alberta Standards and exceeded 100 kg/ha P for 96% of the grid sample sites and exceeded 168 kg/ha P (20 ppm) for 58% of the sample sites (Table 12). This same field had 88% of the 0.0-0.30 m samples exceeding 200 kg/ha P and 46% of the samples exceeding 320 kg/ha P. The father of the current owners raised hogs from 1964 to about 1975 directly south of the 1997 site and used the 1997 field for spreading hog manure. It is not known how much hog manure was applied or what level the soil phosphorus reached but the subsequent 22 years cropping with little or no phosphorus fertilizer added has not yet reduced the soil P to levels which are environmentally safe. The adjacent field at Fincastle used in 1998 had only 6% of the samples for 0.0-0.15 m with soil P greater than 100 kg/ha.

In October 1998 before fertilizer was applied, the 1999 Fincastle site had high soil P in the 0.0-0.15 m layer (average 117 kg/ha) on the southern 67% of the field and adequate or marginal (average 50 kg/ha P) on the remainder of the field (Fig. 12a). The farmer had spread liquid hog manure on a portion of the field in the fall of 1997. This farmer applied 39 kg/ha P to the entire

field in October 1998 and 29 kg/ha P in the spring of 1999. If phosphorus fertilizer costs $1.25/ kg P, then $1765 could have been saved from not applying P to the part of the field that received hog manure. The farmer's soil sample analysis results were not available from the fertilizer dealer for the fall of 1998 on the 1999 Fincastle field. It is not known if the fertilizer rates were estimated or were based on samples taken on the north end of the field where manure was not applied.

In 1999 at Hays (Table 12) in the 0.0-0.15 m layer, soil P was deficient to marginal on 62% of the field and adequate on 38% of the field (Miller-Axely method of analysis). The Hays fields did not have a history of receiving manure so they were generally lower in soil P than the Fincastle fields, which had received manure.

Potassium

Soil potassium (K) levels in samples from the Fincastle fields (Table 13) were usually adequate and, in a few cases, high. The 1997 field also had 13% of its grid sample sites with high levels of potassium (greater than 300 ppm in the 0.0-0.15 m depth). This appears to be a relic from the hog manure applications made between 1965 and 1974. Tissue potassium was adequate or high on the part of the field that received hog manure. If potassium fertilizer costs $0.55/kg K then $784 could have been saved in 1997 by not applying K to the field. The 1999 Fincastle field also had some sample sites with high levels of K. The sites in 1999 were not related to the portion of the field that received one application of hog manure in 1997. Fincastle sites have received manure applications and have been irrigated since 1956. This is longer than the Hays sites, which have been irrigated since 1978 and have not received manure applications.

The Hays sites in 1997 and 1998 (Table 13) were marginal to adequate in soil K. In 1999, the Hays sites were marginal to high but there was no easily identifiable pattern and the high areas were parts of the outer edge of the field. It does not seem economical to apply site specific applications of K to the Hays fields.

Table 11. Soil nitrogen levels in ppm N (0.0-0.60 m depth) in October of the previous year for grid sample sites grouped by % according to Alberta Agriculture Standards.						
Location	**Year**	**Very deficient**	**Deficient**	**Marginal**	**Adequate**	**High**
ppm		**<5**	**5-7.5**	**7.5-15**	**15-20**	**>20**
Hays	97	73	19	8	0	0
	98	68	32	0	0	0
	99	100	0	0	0	0
Fincastle	97	40	25	26	6	4
	98	92	6	2	0	0
	99	90	2	4	0	4

Table 12. Soil phosphorus levels in ppm P (0.0-0.15 m depth) in October of the previous year for grid sample sites grouped by % according to Alberta Agriculture standards.						
Location	**Year**	**Deficient**	**Marginal**	**Adequate**	**High**	**Very high**
ppm		**<13**	**13-25**	**25-45**	**45-75**	**>75**
Hays	97✦	34	66	0	0	0
	98✦	8	60	31	0	0
	√	12	79	8	0	0
	99✦	2	60	38	0	0
	√	6	74	21	0	0
Fincastle	97✦	0	0	4	38	58
	98✦	20	35	39	6	0
	√	6	30	57	8	0
	99✦	6	16	12	64	0
	√	2	24	22	53	0

✦ Miller Axley method
√ Kelowna method

Table 13. Soil potassium levels in ppm K (0.0-0.15 m depth) in October of the previous year for grid sample sites grouped by % according to Alberta Agriculture standards.						
Location	**Year**	**Deficient**	**Marginal**	**Adequate -**	**Adequate +**	**High**
ppm		**0-75**	**75-150**	**150-225**	**225-300**	**>300**
Hays	97†◊	0	67	23	9	2
	98√	0	38	52	10	0
	99◊	0	26	39	14	21
Fincastle	97†◊	0	0	38	49	13
	98√	4	40	36	15	6
	99◊	0	4	71	16	10

† 0.0-0.30 m depth
√ Kelowna method
◊ Ammonium acetate method

Table 14. Petiole analysis of N, P and K for 1996-99 for 3 dates for potatoes at Hays and Fincastle showing % of samples at adequate level.

	NO₃-N %			P %			K%		
Table 14 a. 1996	**July 3-4**	**July 30**	**Aug. 20♦**	**July 3-4**	**July 30**	**Aug. 20♦**			
Adequate level	1.6-2.4	1.2-1.8	0.08-1.4	0.22-0.62	0.20-0.50	0.10-0.30			
Hays % High % Adequate % Deficient	2 88 10	0 26 74	0 0 100	0 100 0	0 20 80	0 0 100			
Adequate level	1.6-2.4	1.2-1.8	0.10-0.16	0.22-0.62	0.20-0.50	0.16-0.36			
Fincastle % High % Adequate % Deficient	0 88 12	0 0 100	0 0 100	0 100 0	0 63 37	0 88 12			
Table 14 b. 1997	**July 3-7**	**July 23-24**	**Aug. 12-13**	**July 3-7**	**July 23-24**	**Aug. 12-13**	**July 3-7**	**July 23-24**	**Aug. 12-13**
Adequate level	0.16-.24	0.12-0.18	0.10-0.16	0.22-0.62	0.20-0.50	0.16-0.36	7-9	5-7	3.5-5.5
Hays % High % Adequate % Deficient	0 45 55	0 0 100	0 0 100	0 94 6	0 2 98	0 0 100	0 0 100	40 60 0	67 33 0
Fincastle % High % Adequate % Deficient	0 12 88	8 17 75	6 32 62	13 87 0	55 39 6	11 79 9	0 6 94	94 6 0	100 0 0
Table 14 c. 1998	**July 6-7**	**July 22-23**	**Aug. 10-11**	**July 6-7**	**July 22-23**	**Aug. 10-11**	**July 6-7**	**July 22-23**	**Aug. 10-11**
Adequate level	0.16-0.24	0.12-0.18	0.10-0.16	0.22-0.62	0.20-0.50	0.16-0.36	7-9	5-7	3.5-5.5
Hays % High % Adequate % Deficient	0 4 96	0 12 88	4 50 46	17 77 6	0 21 79	0 54 46	0 73 27	67 33 0	100 0 0
Fincastle % High % Adequate % Deficient	3 21 76	24 59 17	22 57 21	0 76 24	0 30 69	0 6 94	0 33 67	19 73 8	57 41 2
Table 14 d. 1999	**July 7**	**July 30**	**Aug. 17**	**July 7**	**July 30**	**Aug. 17**	**July 7**	**July 30**	**Aug. 17**
Adequate level	0.16-0.24	0.10-0.18♦	0.08-0.14♦	0.22-0.62	0.18-0.45♦	0.14-0.34♦	7-9	5-7	3.4-5.4♦
Hays % High % Adequate % Deficient	9 46 44	6 28 66	2 32 66	0 85 15	0 22 88	0 43 57	80 20 0	0 96 4	0 100 0
	July 9	**July 28**	**Aug. 13**	**July 9**	**July 28**	**Aug. 13**	**July 9**	**July 28**	**Aug. 13**
Adequate level	1.6-2.4	1.2-1.8	1.0-1.6	0.22-0.62	0.20-0.50	0.16-0.36	7-9	5-7	3.5-5.5
Fincastle % High % Adequate % Deficient	0 14 86	0 20 80	6 29 65	51 45 4	22 65 14	55 41 4	76 24 0	98 2 0	2 92 6

♦Standards were adjusted downward because of the late sampling date and Snowden, a mid-season variety, was nearing maturity.

Petiole Analysis

Potato producers routinely take petiole samples from late June through mid to late August. The samples are tested for nitrate nitrogen (NO_3-N) to help producers maintain consistent nitrogen health or to make corrections for insufficient N by fertigating the entire field. Historically, potato producers did not test for phosphorous or potassium status nor did they make adjustments for insufficient P and K. In the last 3 or 4 years, many have also been analyzing for P, K in addition to NO_3-N.

Nitrate Nitrogen

In 1996, petiole NO_3–N (Table 14) was adequate at most of the sites at the time of the first sampling but, despite fertigation with additional N, it decreased and became deficient at the time of the second and third sampling.

In 1997, petiole N at Hays (Table 14b) was adequate on 45% and deficient on 55% of the sites at the time of the first sampling and deficient on 100% of the sites at the time of the second or third samplings. Soil nitrate N was deficient on 92% of the sites (Table 11) the previous October and 77% of the field had less than 15% clay in the 0.0-0.60 m. The field received from 0.37-0.45 m of rainfall and irrigation from June 23 to September 9 (Fig. 3a). The coarse textured soils permitted leaching of nitrogen below the root zone, which meant there was excess moisture.

In 1997, the Fincastle site was deficient in petiole N (Table 14) on 88% of the field in early July to 62% by August 12. Fincastle received about the same amount of irrigation and rainfall as Hays but over a period one week longer than the Hays site (June 24 to September 18). The Russet Burbank potatoes at Fincastle used more water in the latter part of the season than the earlier maturing Snowden potatoes at Hays.

In 1998, petiole analysis on both Hays and Fincastle indicated that the percent of samples that were deficient decreased from highs of 96 and 76 early in July to 46 and 21 by August 10 or 11 (Table 14c). Total soil nitrogen plus fertilizer nitrogen (Table 3) was higher in 1998 than in 1997 and 1996. This may be the reason that the tissue nitrogen did not decline like it did in 1996 and

1997. In 1999 at the time of the third petiole sampling (Table 14d), both Hays and Fincastle had about 66% of the samples deficient in petiole N.

Petiole analysis for nitrogen in the first week of July was significantly correlated with soil N the previous October in three of the six fields monitored, such as Hays in 1999 (Fig. 11a). This was before uniform applications of nitrogen fertilizer. However, petiole nitrate for all fields was not significantly correlated to soil nitrogen (Fig. 11b) and had an r of 0.95. Petiole nitrate was significantly positively correlated to soil clay per cent (Fig. 11c) with an r of 0.45. This means it would be more useful to base a variable nitrogen fertilizer application on soil clay content than on soil nitrogen. The fields chosen for this project had most of the samples with a clay content between 6% and 32% (Fig. 2). This is a lower range clay content than is typical for agricultural soils but it is typical for potato soils. The variability of texture of the soils used in this project may be higher than is typical of soils used for potato production.

Petiole nitrate N was significantly negatively correlated to tuber yield in early July (r = 0.25) (Fig. 11d) and in late July there was no significant relationship between petiole nitrate N and yield (Fig. 11e). In August (Fig. 11f) petiole nitrate N was significantly positively correlated (r = 0.155) to yield. This suggests nitrogen supply may be excessive early in the growing season and deficient later in the season. The areas with higher clay content could be expected to retain nitrogen late in the season, while those areas lower in clay content are subject to loss of nitrogen by leaching. These same areas with a higher clay content, and therefore a higher exchange capacity could be expected to have less soluble nitrogen early in the season, thus lower petiole N content than areas with a lower clay content.

Phosphorus

Tissue P at Hays in 1996 and 1997 (Fig. 13) was adequate in the first week of July and declined rapidly to become 100% deficient in the August samples (Tables 14a and 14b). This same decline did not occur at the Fincastle site, which had a higher level of available soil P (36% of soil sample sites tested marginal or higher) in 1997 as compared to Hays, which had 8% of soil P marginal or higher (Table 12).

In 1998, both fields were mostly marginal in soil P (Table 12) but received high applications of fertilizer P (119 kg/ha Hays and 153 kg/ha at Fincastle, Table 3). Despite these high applications of fertilizer, available tissue P declined by Aug. 10-11 to become 46% deficient at Hays and 94% deficient at Fincastle (Table 14c).

In 1999, in early July, the tissue P levels in the Hays field were mostly marginal (85 %) with some areas (15%) high (Table 14d). The Fincastle field was 51% high and 45% marginal and 4% low. Petiole P levels were high or adequate in the part of the field that had received hog manure. In the remainder of the field, petiole P levels were adequate on July 9 and declined to become deficient or adequate on July 28 and August 13.

Petiole phosphorus on six fields for July 3-7 was highly significantly positively correlated to soil P (Fig. 14a) ($r = 0.57^{**}$). On the same six fields, petiole phosphorus content was highly significantly negatively correlated to soil clay content (Fig. 14b) ($r = 0.32^{**}$). This occurs because soil P is tied up in unavailable forms on clay. However, there was no significant correlation between soil P and clay content. In contrast to soil nitrogen, soil phosphorus content can be used as a basis for variable rate application of phosphorus fertilizers. Petiole P was highly significantly positively correlated to yield at all three sampling times (Fig.14c, 14d and 14e). This indicates petiole P was low for optimum yields on these fields.

Potassium

Tissue K analysis was not done in 1996. In 1997, at both Hays and Fincastle, almost all sites were deficient in the first week of July (Table 14). By July 23 and 24 tissue levels increased and by August 12-13 the Hays field had 67% high levels of K and the Fincastle field had 100% high levels of K (Table 14 and Fig. 15). A similar pattern occurred in 1998. In 1997 mean tissue K at Hays was 6.2% July 3, 6.9% July 23 and 6.0% August 12. In 1997 at Fincastle, mean tissue K was 6.5% July 7, 7.5% July 24 and 6.4% August 13. However, in 1999 both Hays and Fincastle showed most of the field with excess levels of tissue K on July 7 and 9 (Fig. 16a) and this decreased to 0% with excess at Hays and 2% with excess at Fincastle by the 13th of August (Fig.16b).

It is not known why these tissue levels in 1997 and 1998 changed so much, in contrast to the standards, which indicate tissue K levels normally decline during the season. Potassium uptake is reduced by low soil temperature. The standards have been developed in parts of the USA where soil temperatures would usually be higher than in southern Alberta. In southern Alberta, June nights are often quite cool.

Tissue K levels at both sites for three years were not significantly related to yield. Apparently these K levels were not appreciably deficient. In another experiment, in 2000 and 2001, field tests with phosphorus fertilizer and compost at a total of 5 locations showed declining tissue potassium levels throughout the season. This problem of petiole K levels deficiencies needs more study in western Canada where soil K levels are usually high but some of the growing season temperatures are lower than required for maximum growth of potatoes.

Fertilizer Treatments

The N_3 treatment (Table 15) at Hays in 1997 gave the highest yield and the potato crop was worth $116/ha more than the N_2 treatment but required $60/ha more nitrogen fertilizer (N fertilizer cost = $0.66/kg) than the N_2 treatment. This increase in yield and value does not account for changes in quality such as low specific gravity, which may occur on the high N treatment. At Fincastle, the N_2 treatment, which was the farmer's rate, showed the highest yield. This N2 treatment also showed losses in nitrogen below the root zone (Rodvang, 1998). In 1998 the nutrients applied (Table 6) were in addition to the farmer's rate (Table 3).

Table 15. 1997 potato yields (t/ha) and gross value on fertilizer strips.

Treatment	Hays		Fincastle	
	Yield	Gross value ($/ha)▲	Yield	Gross value ($/ha)▲
N_1	39.2	4140	39.4	4161
N_2	42.5	4488	42.7	4509
N_3	43.6	4604	42.0	4435

▲ Value is based on 80% marketable at $132/tonne.

At both sites in 1998 (Table 16), the N treatment yielded less than the check or farmer's rate (-4.4% Hays and –7.7% Fincastle). At both sites the NP treatment yielded similar to the check (-0.3% Hays and +1.1% Fincastle). The P treatment at both sites yielded more than the check

(+2.7% Hays and +5.3% Fincastle). These results indicate the farmers are at an optimum rate with respect to nitrogen. Phosphorus rates on these two fields may be low. Both of these fields had high phosphorus fertilizer applications (Table 3) and petiole P levels declined during the season (Table 12).

Table 16. 1998 potato yields (t/ha) and gross value on fertilizer strips.

Treatment	Hays		Fincastle	
	Yield	Gross value ($/ha)▲	Yield	Gross value ($/ha)▲
N	34.9	3685	33.2	3506
P	38.6	4076	37.8	3992
NP	37.5	3961	36.6	3865
Check	37.6	3970	35.9	3791

▲ Value is based on 80% marketable at $132/tonne.

In 1999, six treatments were set out at Hays (Table 7) consisting of two rates of compost, manure and phosphorus fertilizer. Disease counts on the foliage of the plants (Table 17) indicated that the low phosphorus treatment had a greater amount of foliar disease than all other treatments. The three high rate treatments also had a lower incidence of foliar disease than their corresponding low rate treatments, indicating an overall benefit of high rates of P, whatever the form, in terms of foliar disease. Because this field has been used a number of times for growing potatoes in the last 10 years, the level of foliar diseases was quite high. *Rhizoctonia* and scab counts were also made on the tuber surfaces. Variability on tuber disease counts was high and disease occurrence on tubers was low so no conclusions can be made regarding the influence of these treatments on tuber disease.

The 1999 Hays field has a history of developing low P levels in petioles in late July and August despite high rates of P fertilizer being applied. The treatments had no significant effect on tuber yields (Table 17) although compost and manure treatments yielded slightly more than the P treatments. Tuber numbers were also recorded for each treatment.

Table 17. Effect of P, compost and manure on tuber yield and size and disease incidence of potatoes – Hays, 1999.

				% surface infected on 160 tubers		% plants affected
Treatments	**Total tuber Wt (t/ha)**	**Medium Tubers (t/ha)**	**Tubers▲ /1.2 m**	***Rhizoctonia***	**Scab**	**Disease▲ on 600 m row**
Low P	34.6	30.2	65	0.68	0.75	9.0
High P	36.5	32.5	70	0.32	0.88	7.1
Low compost	40.0	33.3	95	0.82	1.20	6.6
High compost	38.7	35.2	82	0.36	0.57	5.9
Low manure	37.2	34.0	81	0.68	0.57	7.6
High manure	39.8	36.2	75	0.86	0.73	6.1

▲significant at 5% level

Pest Monitoring

Weeds

In most fields, the weeds did not occur in large numbers in any one area so they were not suitable for site specific management. In 1999 on the Hays field, there were patches from 10 m to 50 m in diameter, which were heavily infested with Canada Thistle. In late August prior to harvest, the perimeters of some of these patches were mapped with GPS. It was not possible to identify these patches on remote sensed imagery taken on July 28. If accurately identified, these patches of Canada Thistle could be controlled with spot applications of chemicals such as Lontrel (clopyralid) or Roundup (glyphosate). These chemicals are toxic to potatoes so this is an extreme treatment and the herbicides need to be applied precisely. The potential exists for developing an irrigation system, which will provide site specific applications of herbicides, as well as water (Eberlein, 1999).

Disease

Diseases were monitored each year on all fields. Disease incidence was low and diseased plants were scattered. No attempt was made to map disease. Late blight did occur in varying degrees on the fields prior to harvest and it would have been possible to map this disease but it is difficult to distinguish from vine senescence. Disease surveys were done in the middle of August when the incidence of late blight was low.

Insects

Colorado potato beetles were the only insect pest present at sufficient levels to require insecticide application by the farmers. Colorado potato beetles are native to southern Alberta so the problem of resistance to insecticides is not as important as in areas where it only occurs on potatoes. It is not necessary to retain non resistant populations for reproduction in portions of the fields as described by Weisz et. al.(1996). Flescher et. al.(1999) describes how Colorado potato beetle are most dense near the edge of fields thus making them suitable for site specific management. However, due to farmer vigilance and spray programs, the Colorado potato beetles never became a serious problem in any areas of the fields tested, so were not suitable for site specific management.

Remote Sensing

Potato fields are closely monitored during the growing season for the onset of nutrient deficiencies, disease and pests. With respect to nutrients, typically test areas are established in a field and 40 to 50 petioles from representative plants are collected at each sampling date for determination of primarily N but also P and K content (Schaupmeyer, 1992). This method of petiole sampling provides only limited information regarding spatial variability across the whole field and does not provide information suitable for use with variable rate equipment. Remote sensing data offers one source of spatial information suitable for use in site-specific management systems. Digital imaging systems provide the potential to delineate management zones within a field based upon soil characteristics and the detection of crop stresses both in the short and long term (Brisco et al., 1998, Moran et al., 1997). A number of algorithms have been proposed to measure chlorophyll or N content of plants using remote sensing (Table 18). The close correlation between leaf chlorophyll and N availability suggests that chlorophyll content can be use to characterize N status and vice versa (Filella and Peñuelas, 1994). The majority of the algorithms or indices are based upon reflectance in the green (530-600 nm), red (670-680 nm) or so-called 'red-edge' (690-710 nm) normalized to reflectance in the near-infrared (750-900 nm) range of the electromagnetic spectrum. Reflectance at wavelengths above 735 nm is relatively insensitive to chlorophyll or N levels while reflectance at 550 and 690-710 nm is most sensitive. Sensitivity to N stress at 670-680 nm is variable due to the signal being saturated and reflectance reaching a minimum at relatively low chlorophyll levels (Gitelson et al., 1999). The objective within this study was to test, using airborne remote sensing imagery, the suitability of the reported algorithms to estimate petiole-N content in potatoes and examine the spatial information regarding N status across the field.

Table 18. Published algorithms for chlorophyll/N estimation using remote sensing data.

Index	Formula	Citation	CASI bands
Simple ratio			
$SR_{800\ 670}$	(R_{800nm}/R_{670nm})		17, 25
$SR_{695\ 430}$	$(R_{695nm}R_{430nm})$	Carter 1994	1, 18
$SR_{605\ 760}$	(R_{605nm}/R_{760nm})	Carter 1994	12, 23
$SR_{695\ 760}$	(R_{695nm}/R_{760nm})	Carter 1994	18, 23
$SR_{695\ 670}$	(R_{695nm}/R_{670nm})	Carter 1994	17, 18
SR_{750_705}	(R_{750nm}/R_{705nm})	Gitelson and Merzlyak 1996, Sims and Gamon 2002	19, 22
SR_{750_550}	(R_{750nm}/R_{550nm})	Gitelson and Merzlyak 1996, Lichtenthaler et al. 1996	9, 22
$SR_{667\ 717}$	(R_{667nm}/R_{717nm})	Leblon et al. 2001	17, 20
$SR_{550\ 850}$	(R_{550nm}/R_{850nm})	Schepers et al. 1996	9, 28
$SR_{710\ 850}$	(R_{710nm}/R_{850nm})	Schepers et al. 1996	19, 28
$SR_{800\ 680}$	(R_{800nm}/R_{680nm})	Sims and Gamon 2002	17, 25
$SR_{735\ 700}$	(R_{735nm}/R_{700nm})	Gitelson and Merzlyak. 1999	19, 21
Pigment specific simple ratio (PSSR)	(R_{810nm}/R_{676nm})	Blackburn 1998	17, 26
Normalized difference index			
Normalized green difference vegetation index (NGVDI)	$(R_{750nm} - R_{550nm})/(R_{750nm} + R_{550nm})$	Gitelson et al. 1996	9, 22
Photochemical reflectance index (PRI)	$(R_{531nm} - R_{570nm})/(R_{531nm} + R_{570nm})$	Gamon et al. 1992	8, 10
Pigment specific normalized difference (PSND)	$(R_{810nm} - R_{676nm})/(R_{810nm} + R_{676nm})$	Blackburn 1998	17, 26
Normalized difference index ($NDI_{750\ 700}$)	$(R_{750nm} - R_{700nm})/(R_{750nm} + R_{700nm})$	Gitelson and Merzylak 1994, Sims and Gamon 2002	19, 22
Normalized difference index ($NDI_{800\ 680}$)	$(R_{800nm} - R_{680nm})/(R_{800nm} + R_{680nm})$	Sims and Gamon 2002	17, 25
Normalized pigments chlorophyll ratio index (NPCI)	$(R_{680nm} - R_{430nm})/(R_{680nm} + R_{430nm})$	Peñuelas et al. 1994	1, 17
Structure-insensitive pigment index (SIPI)	$(R_{800nm} - R_{445nm})/(R_{800nm} + R_{680nm})$	Peñuelas et al. 1995	2, 17, 25
Others			
Modified simple ratio ($mSR_{750\ 445}$)	$(R_{750nm} - R_{445nm})/(R_{705nm} - R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Modified normalized ratio ($mNR_{750\ 445}$)	$(R_{750nm} - R_{705nm})/(R_{750nm} + R_{705nm} - 2*R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Optimized soil adjusted vegetation index (OSAVI)	$(1 + 0.16)*(R_{800nm} - R_{670nm})/(R_{800nm} + R_{670nm} + 0.16)$	Rondeaux et al. 199	17, 25
Modified chlorophyll absorption in reflectance index (MCARI)	$[(R_{700nm} - R_{670nm}) - (0.2*(R_{700nm} - R_{550nm}))*(R_{700nm}/R_{670nm})]$	Daughtry et al. 2000	9, 17, 19
Transformed chlorophyll absorption in reflectance index (TCARI)	$3*[(R_{700nm} - R_{670nm}) - (0.2*(R_{700nm} - R_{550nm}))*(R_{700nm}/R_{670nm})]$	Haboudane et al. 2002	9, 17, 19
Plant senescence reflectance index (PSRI)	$(R_{680nm} - R_{500nm})/(R_{750nm})$	Merzlyak et al. 1999	6, 17, 22
Carotenoids	$[4.145*(S_{760nm}/S_{500nm})*(R_{500nm}/R_{760nm})]-1.171$	Chapelle et al. 1992	5, 23
Chlorophyll b	$2.94*[((S_{675nm}/R_{650nm}*S_{700nm})*(R_{650nm}*R_{700nm}/R_{675nm}))]+0.378$	Chapelle et al. 1992	15, 17, 18
Chlorophyll a	$22.735[=(S_{675nm}/S700_{nm})*(R_{700nm}/R_{675nm})] - 10.407$	Chapelle et al. 1992	17, 18

Nitrogen

On July 28, 1999, Itres acquired digital images over the Hays and Fincastle test fields. The image data were acquired over the spectral range 420-965 nm using a Compact Airborne Spectrographic Imager (CASI) at 2 and 3 m resolution. The spectral bands in which data were acquired varied with the resolution from 36 to 48 nm respectively. The image data were radiometrically corrected and geocoded by Itres.

The data were imported into the ENVI™ image analysis software package (Research Systems Inc. Colorado, USA) and converted from spectral radiance units ($\mu W\ cm^{-2}\ sr^{-1}\ nm^{-1}$) to surface reflectance (%) using the FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) atmospheric correction model (Anon., 2001). The input parameters used in the model are shown in Table 19.

Table 19. Input parameters for the FLAASH atmospheric correction model.

Parameter	**Input**
Latitude/Longitude	49.9867N, 111.8523W
Sensor altitude	2.286 km
Ground elevation	0.786 km
Atmospheric model	Sub-Artic Summer
Aerosol model	Rural
Visibility	40 km

Images of the various chlorophyll/N indices outlined in Table 18 were created using the band math function in the image analysis software. The spatial patterns of the indices across the sites were visually examined and compared to those in the kriged maps derived from the ground based petiole nitrate N samples. The grid sampling points were overlaid on the imagery and the reflectance values under a 3 x 3-pixel window centered over each grid point were extracted for each band and each chlorophyll/N index. The relationship between the various chlorophyll/N indices and the petiole nitrate N values was assessed using correlation and regression analyses.

True colour images derived from the 2 m resolution airborne imagery for both the Fincastle and Hays sites are shown in Fig. 17. Both the 2 and 3 m resolution images were processed but due to the similarity in the information content only the 2 m data will be discussed. The images show differential "greeness" across the fields, particularly in the Hays field. The spatial patterns tend

to correspond to soil texture, particularly in the northern end of the field at Hays and likely results from poorer growth on the coarse textured soils. Consistent with the observation that many of the proposed indices involve reflectance in similar wavebands, the spatial patterns in the images derived for the various indices were similar (Table 18). Only the images showing the spatial variability in the index SR_{550_850} derived from reflectance at 550 and 850 nm are shown (Fig. 18 and 19). Visual comparison of the petiole-N maps derived in Surfer™ using the grid point petiole nitrate N data and the index SR_{550_850} shows similarities in the patterns across both fields. Generally, areas of low petiole nitrate N exhibited high values for the SR_{550_850} index.

Fincastle Site

Correlation analysis showed a strong relationship between most of the chlorophyll/N indices and petiole nitrate N for the Fincastle site (Table 20). The strongest relationships were evident with simple ratios involving either reflectance in the green band (550 nm) or the red-edge (700-710 nm) and the near infrared reflectance (750-850 nm). These observations can be attributed to the greater range of chlorophyll/N content to which reflectance at 550 and 700-710 nm responds. The absorption feature at 660-680 nm saturates at relatively low chlorophyll content and thus relative to 550 or 700-710 nm is insensitive to variation in chlorophyll/N.

Hays Site

At the Hays site, visually there were some similarities between the spatial patterns within the image of the SR_{550_850} index and the kriged map of the ground based sampling. The extent of the N deficient areas in the remote sensing image appeared less than in the kriged map. The imagery may provide a more accurate representation of the spatial variability given that each pixel in the remote sensing image represents information from an area of 2 x 2 m on the ground while the ground data is an interpolation from grid points at greater than 100 m apart. Quantitative analysis showed only a limited number of indices were significantly related to petiole nitrate N. The strength of the relationship was poor compared to that at the Fincastle site. The lack of a strong relationship may reflect uncertainty in the georeferencing of the airborne imagery and the sampling sites and the heterogeneity of the crop reflectance in the areas selected for sampling (Deguise et al., 1998).

Table 20. Relationship between the various proposed indices and petiole nitrate N samples.		
Index	**Fincastle**	**Hays**
Simple ratio		
SR800_680	0.751	NS
SR695_430	-0.734	-0.356
SR605_760	-0.781	NS
SR695_760	-0.748	NS
SR695_670	0.449	-0.318
SR750_705	0.820	NS
SR750_550	0.821	NS
SR677_717	-0.639	NS
SR550_850	-0.832	NS
SR710_850	-0.832	NS
SR735_700	0.821	NS
PSSR	0.764	NS
Normalized difference index		
NGVDI	0.809	NS
PRI	0.770	NS
PSND	0.706	NS
NDI750_700	0.809	NS
NDI750_705	0.696	NS
NDI800_680	0.707	NS
SIPI	-0.660	NS
Other		
mSR750_705	0.821	0.326
mNR750_705	0.813	0.308
OSAVI	0.722	NS
MCARI	0.445	-0.298
TCARI	-0.800	-0.317
PSRI	-0.597	
Carotenoids	0.746	NS
Chlorophyll a	-0.448	0.313
Chlorophyll b	-0.674	NS
PSRI	-0.597	NS
NPCI	-0.702	NS
# of Observations	**N=51**	**N=54**

Summary

The results of the study indicated that potato petiole nitrate N could be estimated from remote sensing imagery at one test site but not the other. At the Fincastle site, visually the spatial patterns in the remote sensing derived maps for N levels and those derived from ground based plant sampling were similar. Errors in the overlay of petiole sampling points on the remote

sensing imagery may account for the lack of a significant quantitative relationship at the Hays site. Further studies are being conducted to determine the ability to estimate plant N content using remote sensing techniques.

Soil Salinity

A soil salinity map was made of the additional Vauxhall potato field in 1999 (Fig. 20). This permitted identifying those areas of the field where problem levels of salinity occurred. Tuber samples in these areas were compared to measurements of electrical conductivity (E.C.) calculated from EM38 readings and a tolerance of potatoes to salinity was developed for this field (Fig. 21a). A 50% yield reduction of potatoes occurred at an E.C. of about 6 dS/m. This method is suitable for precision applications to potato production. A salinity tolerance limit and a salinity map means it is then possible to identify those areas where it is not feasible to grow potatoes. Specific gravity of tubers was found to be higher in saline soils than non-saline soils (Fig. 21b).

CONCLUSIONS

A yield monitor was successfully adapted to two farmers' potato harvesters. Maps of tuber yields were developed based on data collected from the harvester. Difficulties were encountered on parts of fields where soil lumps occurred. These lumps usually occurred on areas with a high clay content and resulted in false high yield readings from the mass-based yield sensor. This will be a major restriction to yield mapping of potatoes unless technology can be developed to separate tubers from soil lumps on the harvester belt.

Yield maps were also developed from grid sampling. These grid samples were used to determine tuber yield, average tuber size and tuber quality as measured by specific gravity, chipping score and French fry score. Uniformity of tuber quality is a major concern of processors. Uniformity of irrigation affected tuber size. No relationship was found between chipping and French fry score and the measured factors of soil or water in the field.

Grid sampling was used to develop numerous maps of irrigation and precipitation, consumptive water use, soil texture and nutrient contents, plant petiole (tissue) nutrient contents and the tuber characteristics just described.

Grid sampling of the fields showed variability in soil texture. Most of the fields contained about 6 to 30% clay with a few sites with as much as 40% clay. The texture was correlated to various soil and plant chemical properties.

When yield mapping with differential GPS using a base station in the corner of the field, accurate topographic maps could be developed. When differential corrections were obtained from a geostationary satellite service, the vertical accuracy was no longer suitable for confident topographical mapping.

Soil levels and fertilizer applications of nitrogen by the farmers were in most cases equal to what a crop of potatoes yielding 50 t/ha would be anticipated to take up. No allowance was made for release of nitrogen from soil organic matter. Tissue nitrate levels were frequently deficient according to standards used by Alberta potato growers. Two of six fields had sufficient variability of soil nitrogen to justify the cost of soil sampling and variable rate application. However, petiole NO_3-N in the first week of July was significantly negatively related to clay content (0.0-0.60 m) and was not significantly related to soil NO_3-N. This means it would be more useful for farmers on these fields to base a site specific nitrogen application on soil clay content than on soil NO_3-N content.

Soil P was significantly positively correlated to petiole P content. Soil P was not significantly correlated to clay content or other easily-measured soil characteristics. Opportunities exist for precision applications of phosphorus particularly on two of the fields that had a history of receiving non-uniform applications of manure. Thus, in the absence of any easily-measured factors that are correlated to P, a strategy of phosphorus fertilizer applications based on grid

sampling of soil phosphorus should provide some improvement in efficiency of uptake of phosphorus.

Potassium levels in the soil from 1997 to 1999 were marginal to adequate on most grid sample sites. In 1997 and 1998 petiole K levels were deficient in the first week of July but became adequate to high in two later samplings. The reason for this is not known. It may be due to lower soil temperatures in early July restricting uptake, rather than the higher soil temperatures in the USA where the standards were developed. There is a need for research that will develop local standards for petiole K levels.

Diseases and insect pests were examined but their occurrence was very infrequent and highly variable, thus not predictable or manageable with site specific technologies. Weeds were carefully managed by farmers thus fields were too weed-free to allow for examination of the usefulness of site specific management for weed control. The sites used in the trials, like most potato fields, were extremely flat, which eliminated the opportunity for relating landscape position to potato yield.

Economic analysis indicated that grid sampling and site specific applications of P and K, on a field that received uneven manure applications, would have realized significant savings.

Remote sensing imagery was successful correlated to plant petiole NO3-N at one test site but not the other. Errors in the overlay of petiole sampling points on the remote sensing imagery may account for the lack of a significant quantitative relationship at the Hays site.

Piezometers were used to measure groundwater depth movement and soil NO_3-N content at the Hays (1997) and Fincastle (1997, 1998) sites. Overall, nitrate levels were low at depth but this may have been due to reducing conditions, causing denitrification. At the Hays site, flow of groundwater occurred from the irrigated field outward to an unirrigated rangeland. Irrigation has caused water table mounding below the sites and water tables rose during the summer at the Hays site.

FIGURES

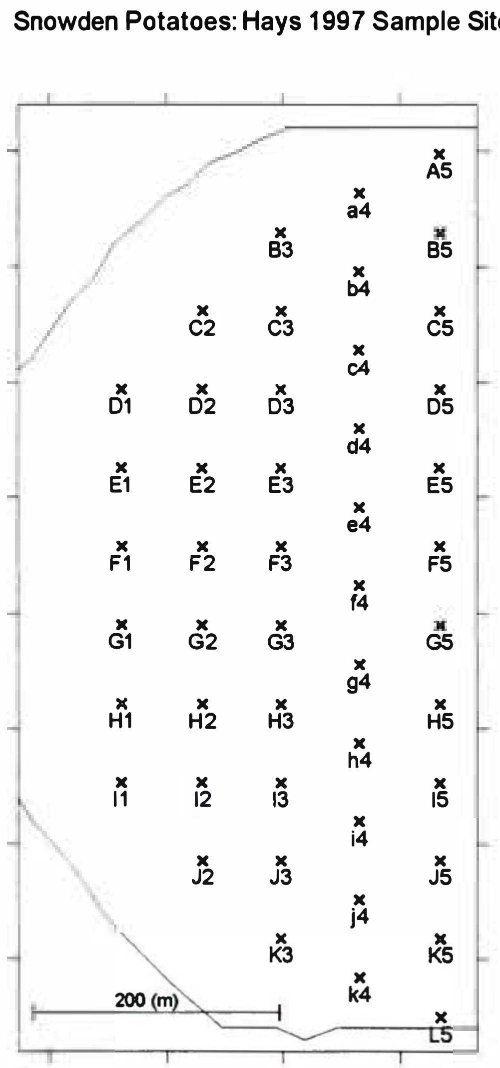


Figure 1. Sampling grid for yield, petioles, water and soil samples for Snowden potatoes grown at Hays in 1997.

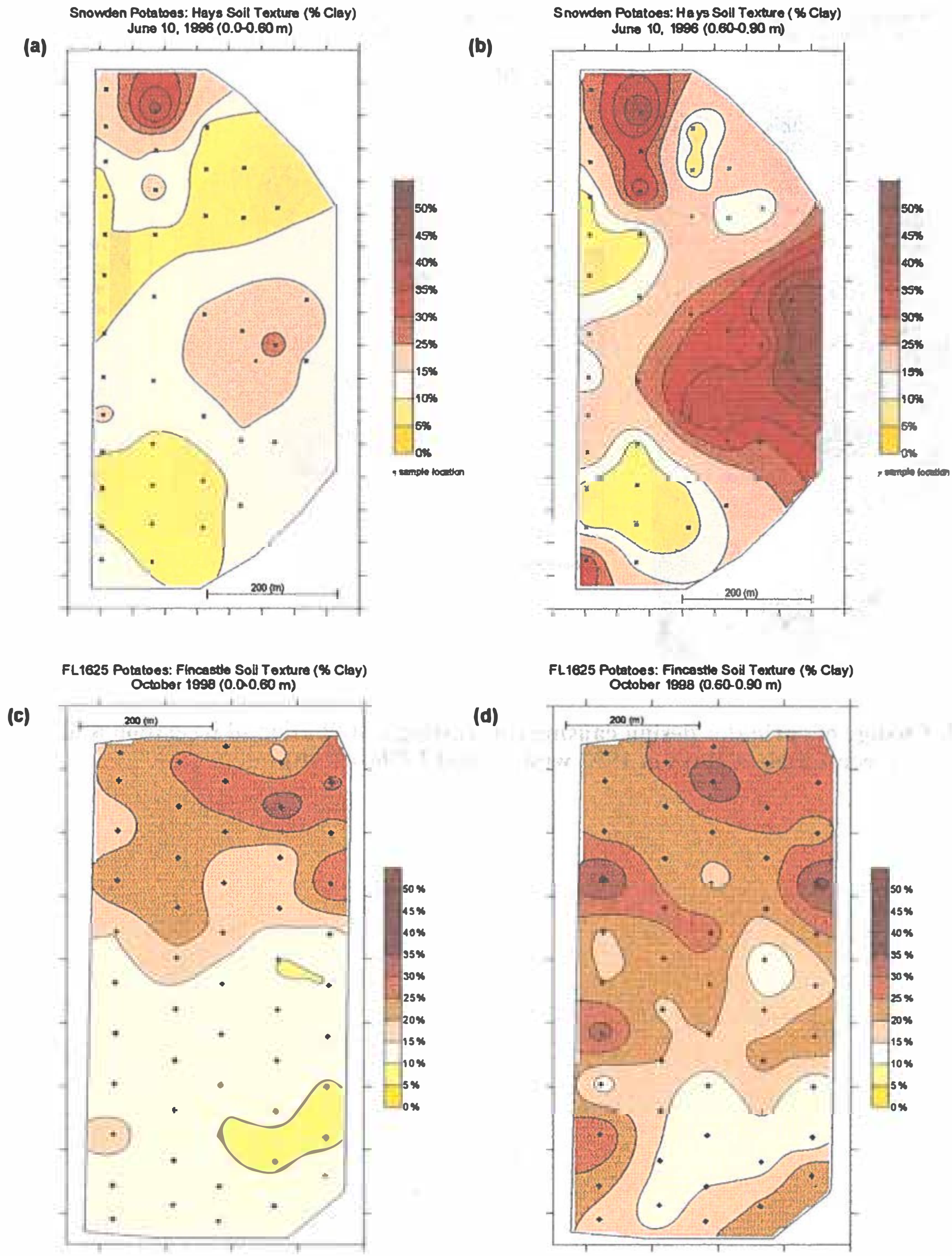


Figure 2. Soil texture maps of Hays 1996 (a and b) and Fincastle 1999 (c and d) fields for two soil depths 0.0-0.60 m and 0.60-0.90 m.

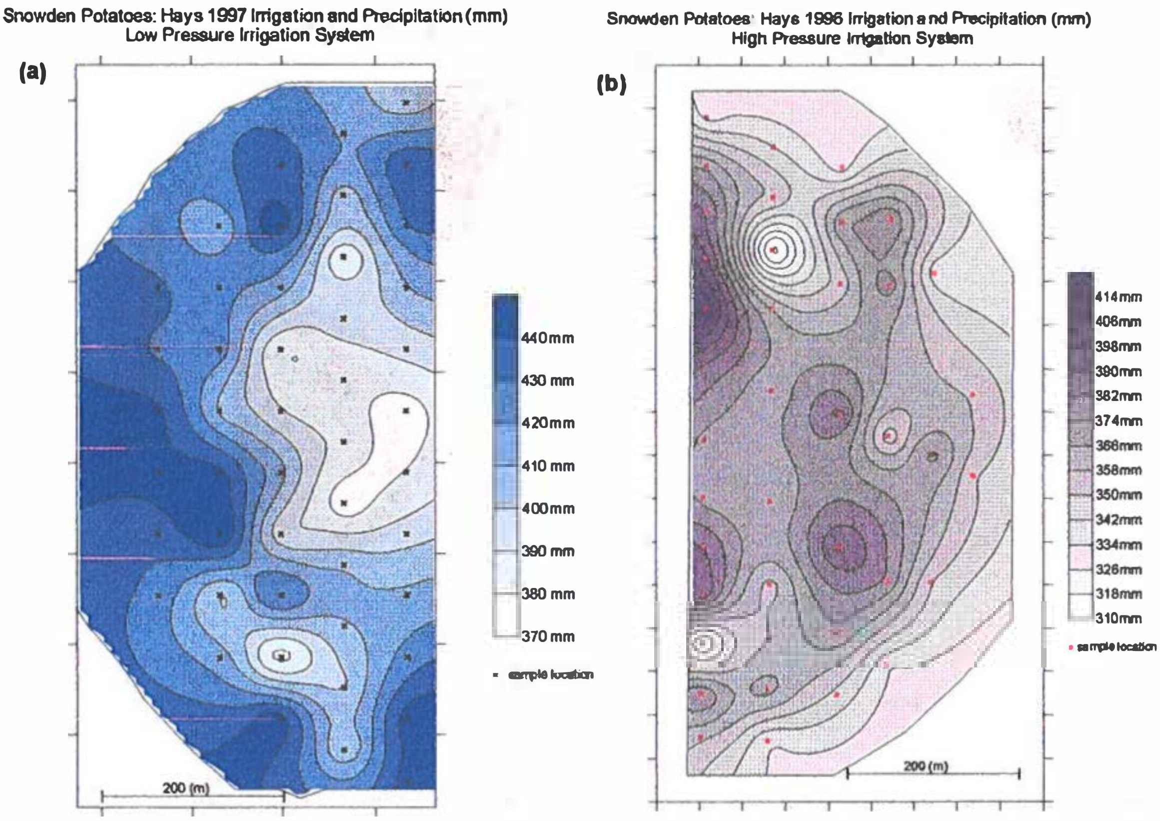


Figure 3. Change of sprinkler design causing contrasting distribution of irrigation and precipitation at Hays in 1997 west (a) and 1996 east (b).

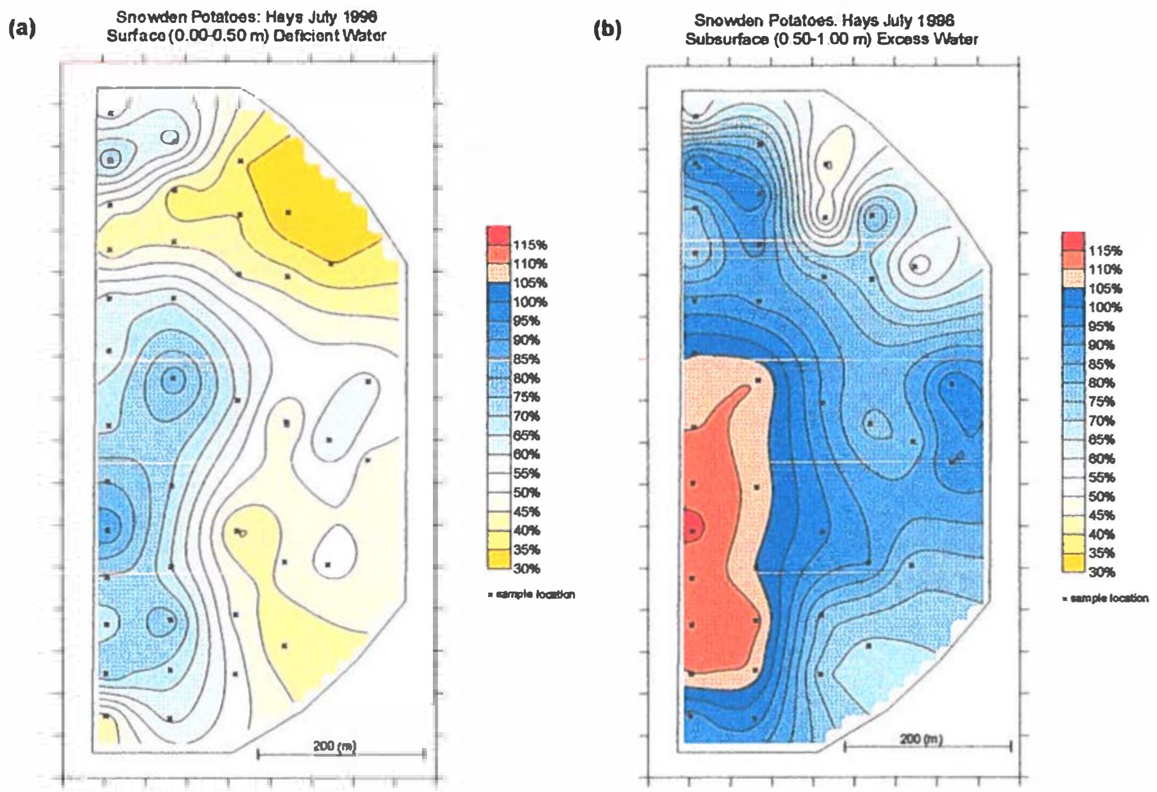
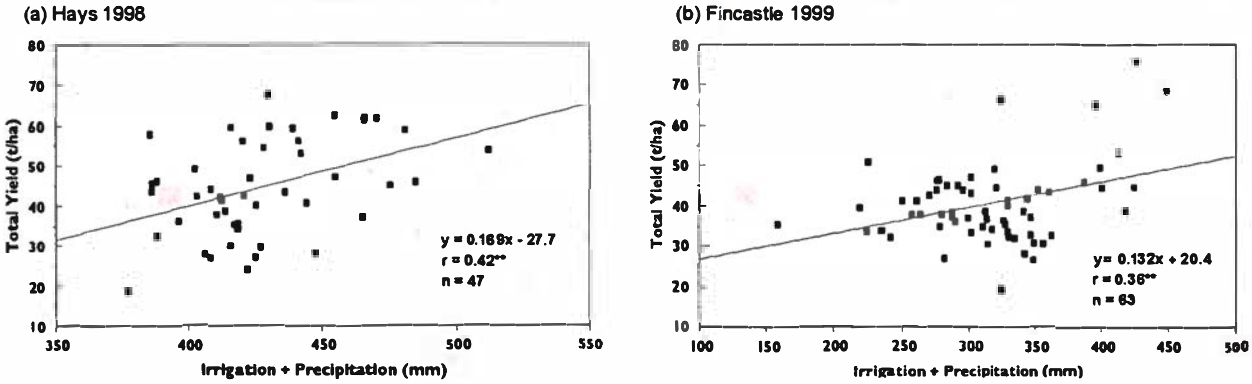
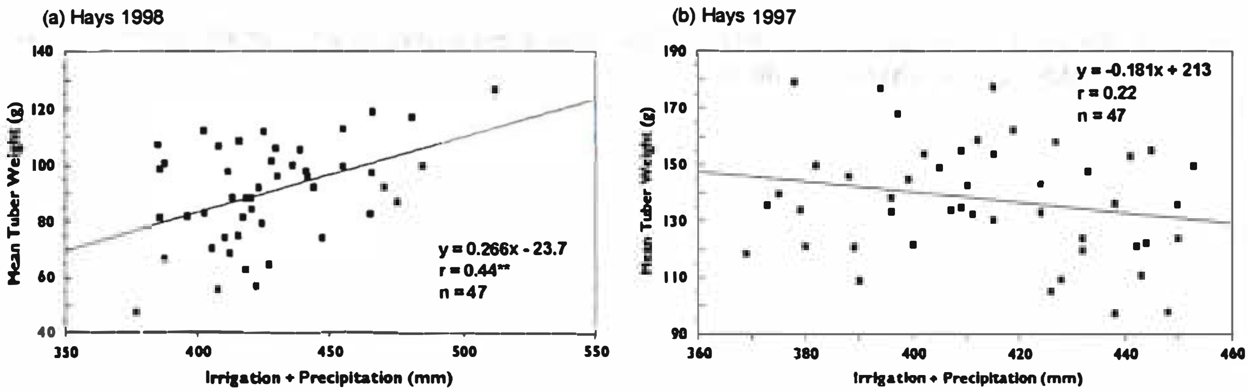


Figure 4. Percent of available moisture (100% = field capacity) in 1996 at Hays for (a) 0.0-0.50 m and (b) 0.50-1.00 m.



** = r significant at the 0.01 level

Figure 5. Correlation between total potato yield and total added water (irrigation + precipitation) at (a)Hays 1998 and (b)Fincastle 1999.



** = r significant at the 0.01 level

Figure 6. Correlation between mean tuber weight and total added water (irrigation + precipitation) at (a)Hays 1998 and (b)Hays 1997.

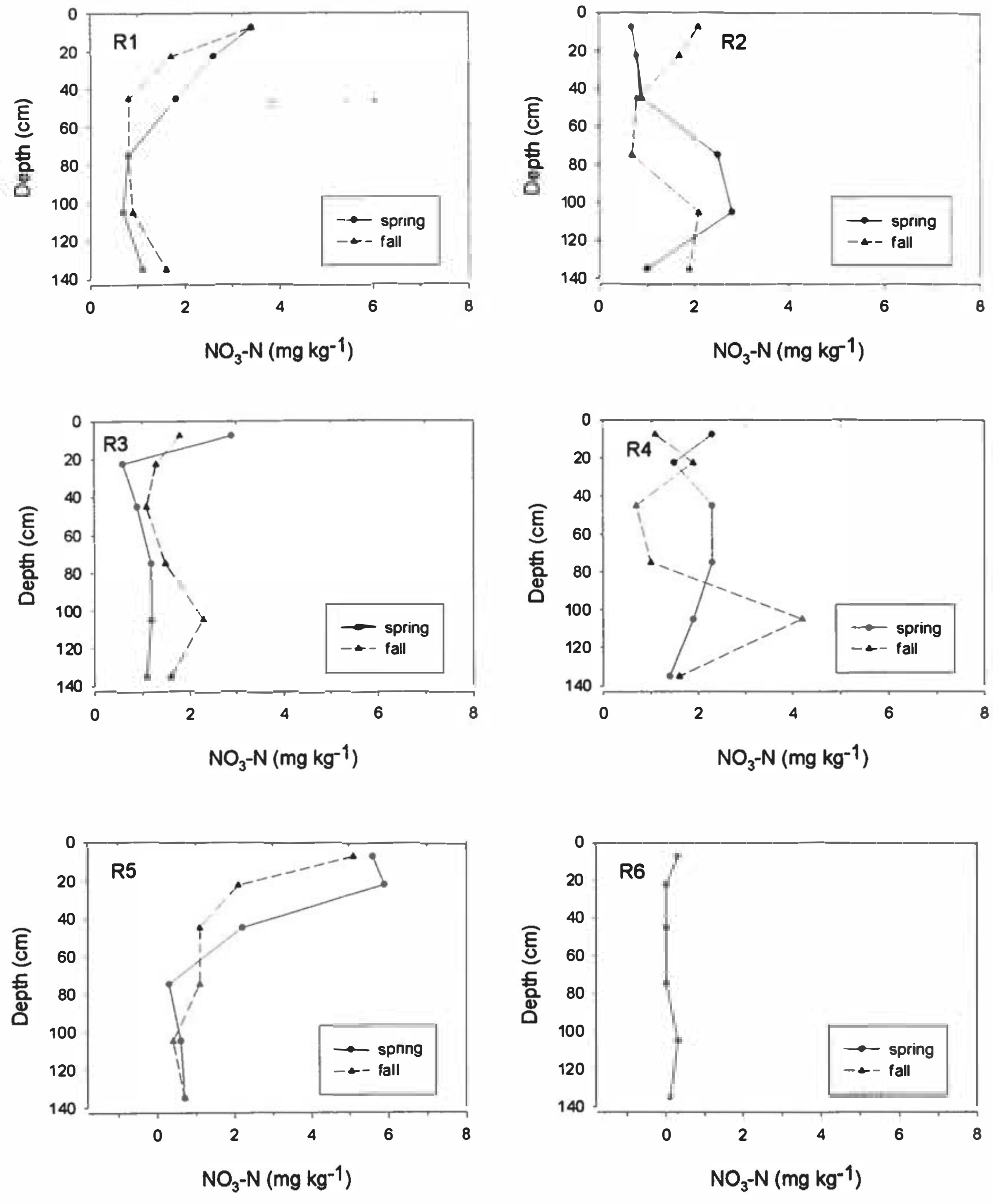


Figure 7. Soil NO_3-N at piezometer sites from 1997 at Hays.

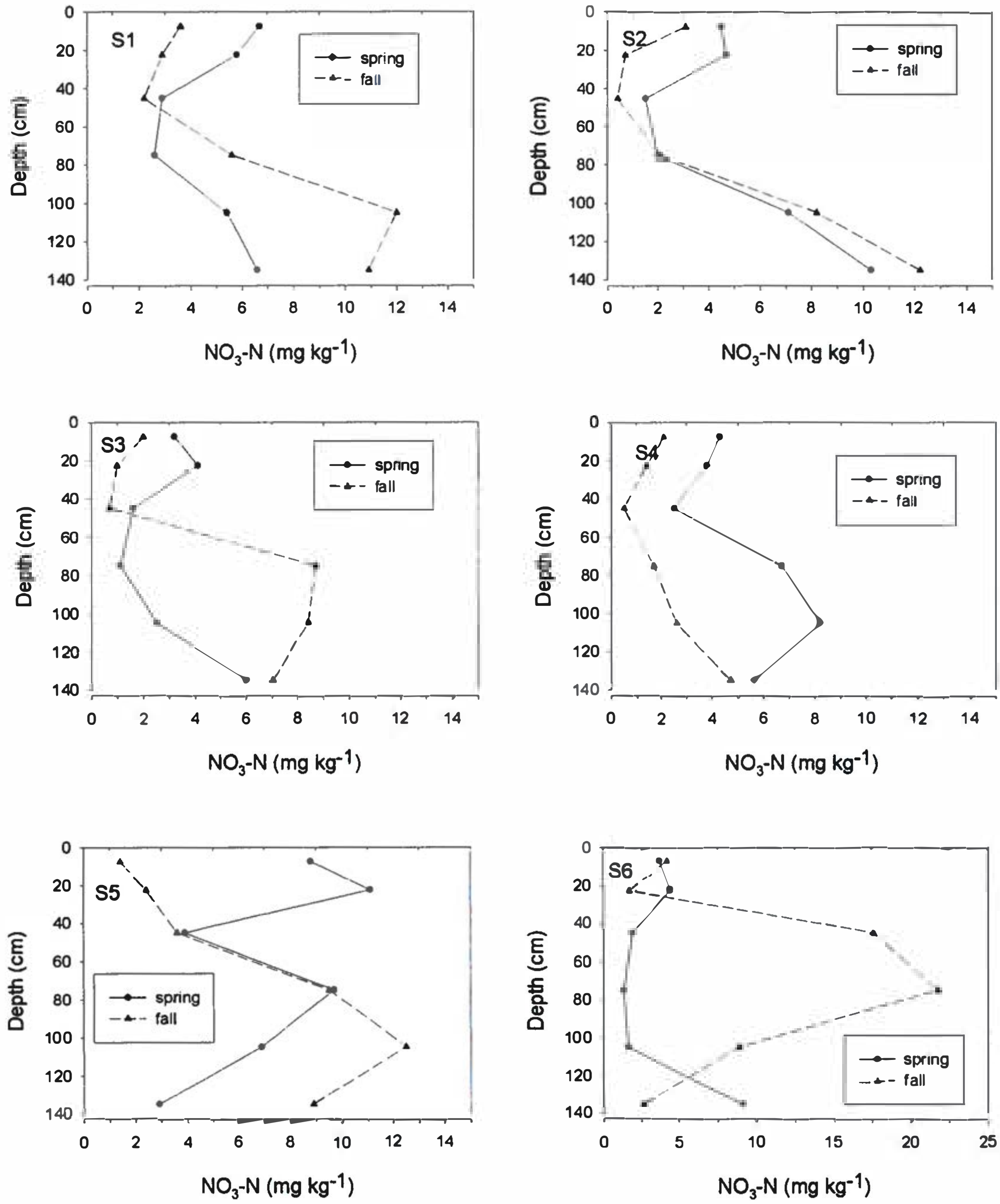


Figure 8. Soil NO_3-N levels at piezometer sites from 1997 at Fincastle.

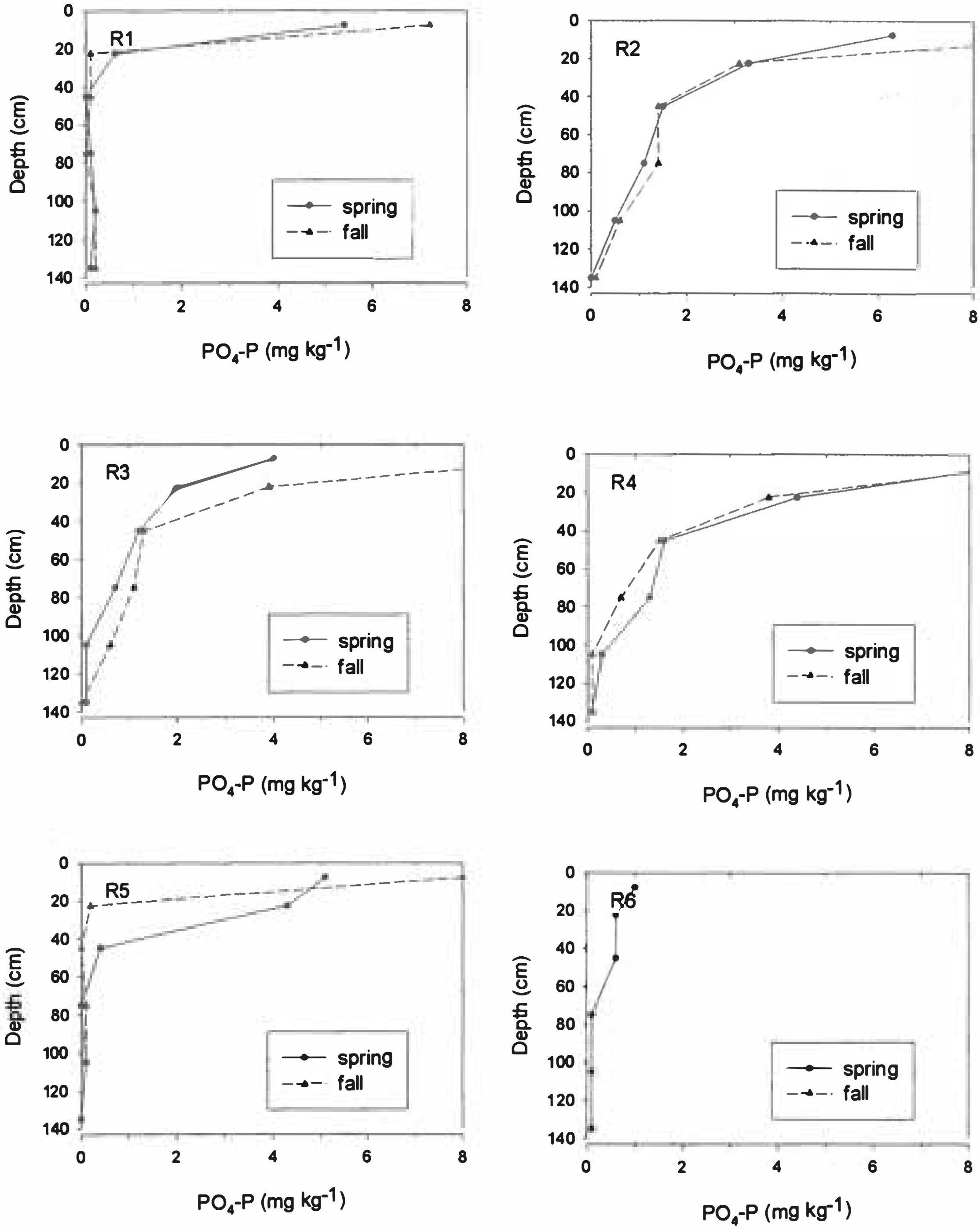


Figure 9. Soil PO_4-P at piezometer sites from 1997 at Hays.

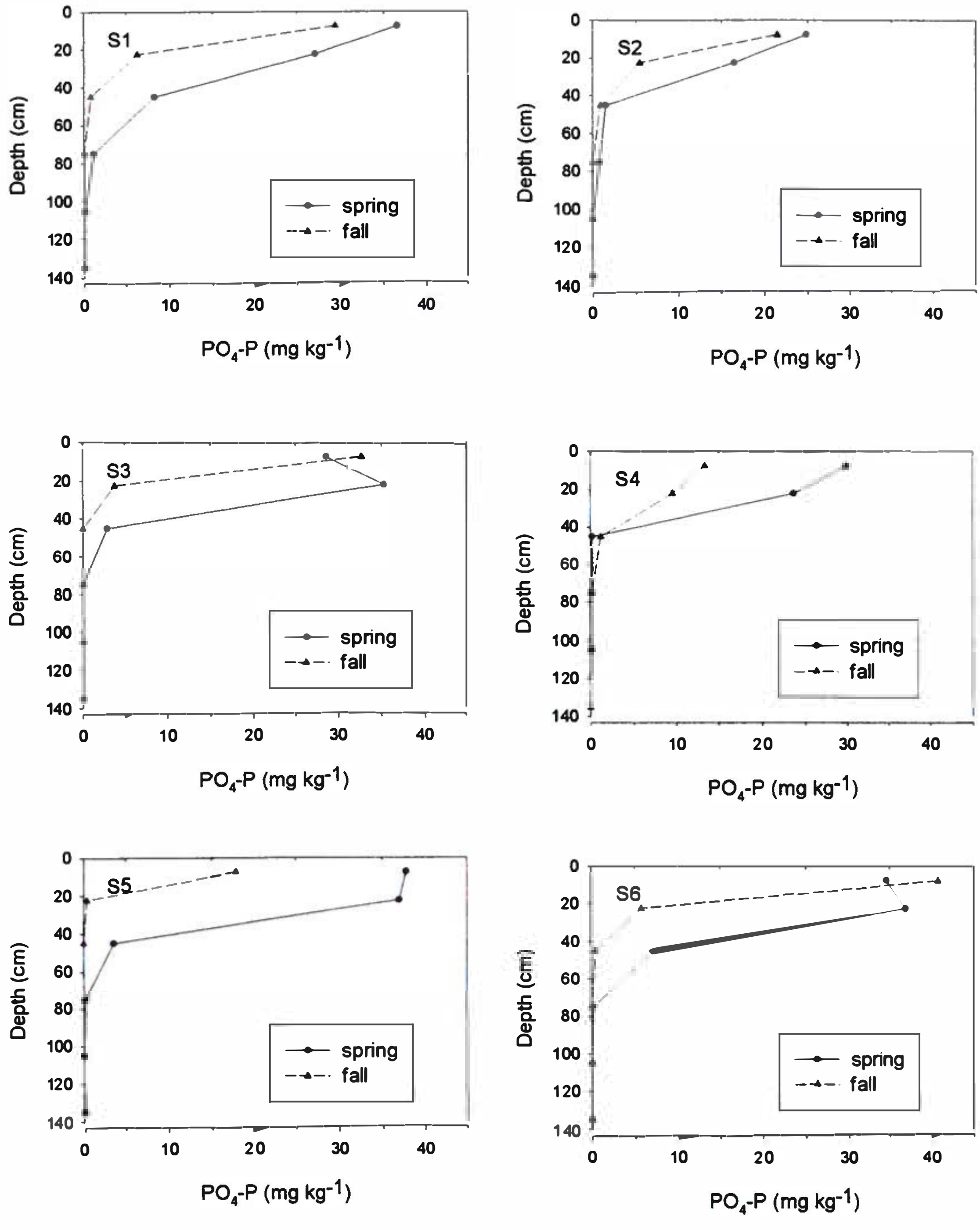
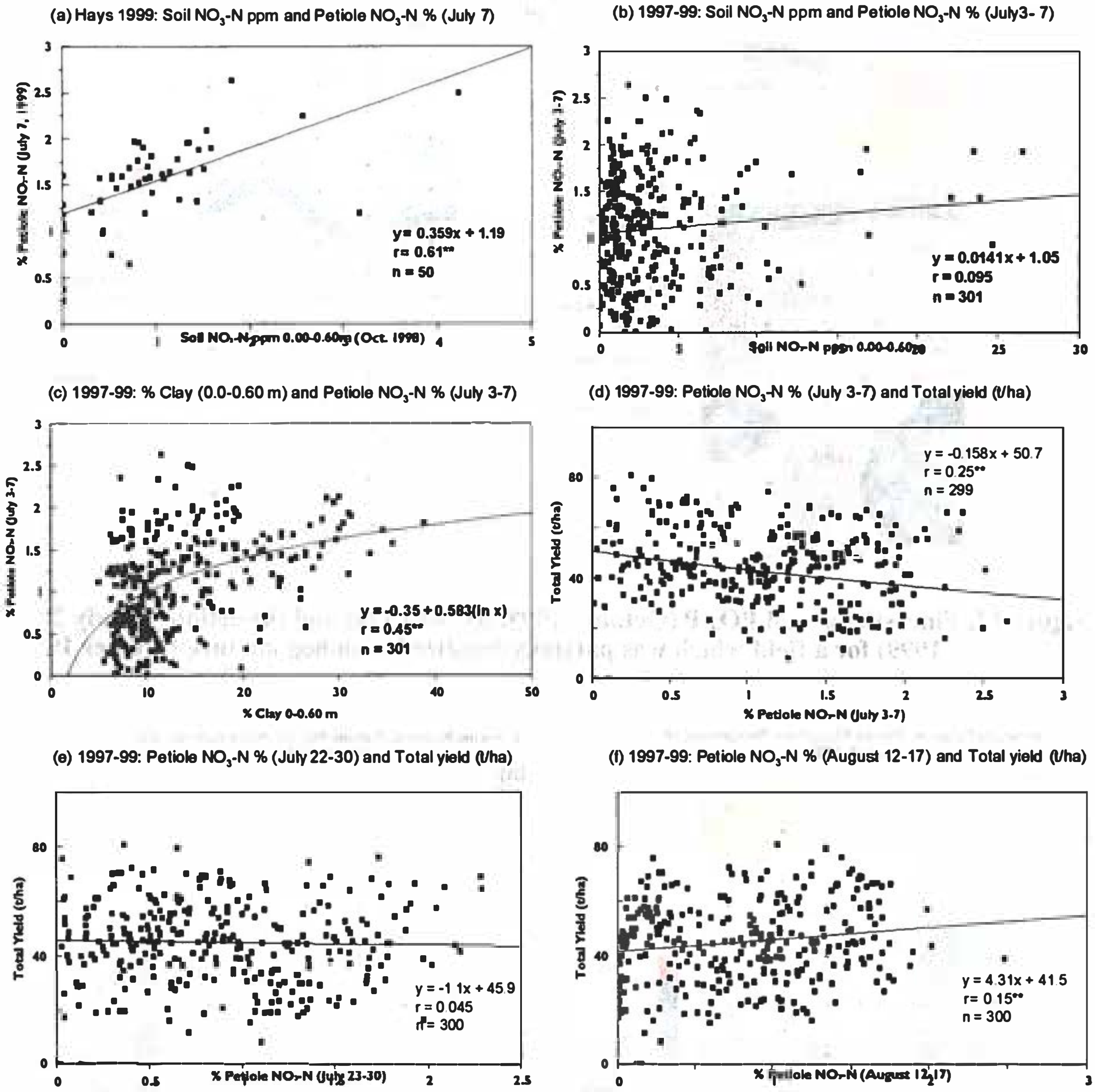


Figure 10. Soil PO_4-P at piezometer sites from 1997 at Fincastle.



* = r significant at the 0.05 level, ** = r significant at the 0.01 level

Figure 11. Correlation between potato petiole NO3-N and (a) soil NO3-N for Hays 1999 and (b) soil NO3-N, (c) soil clay and (d, e and f) total yield for Fincastle and Hays potatoes 1997-1999.

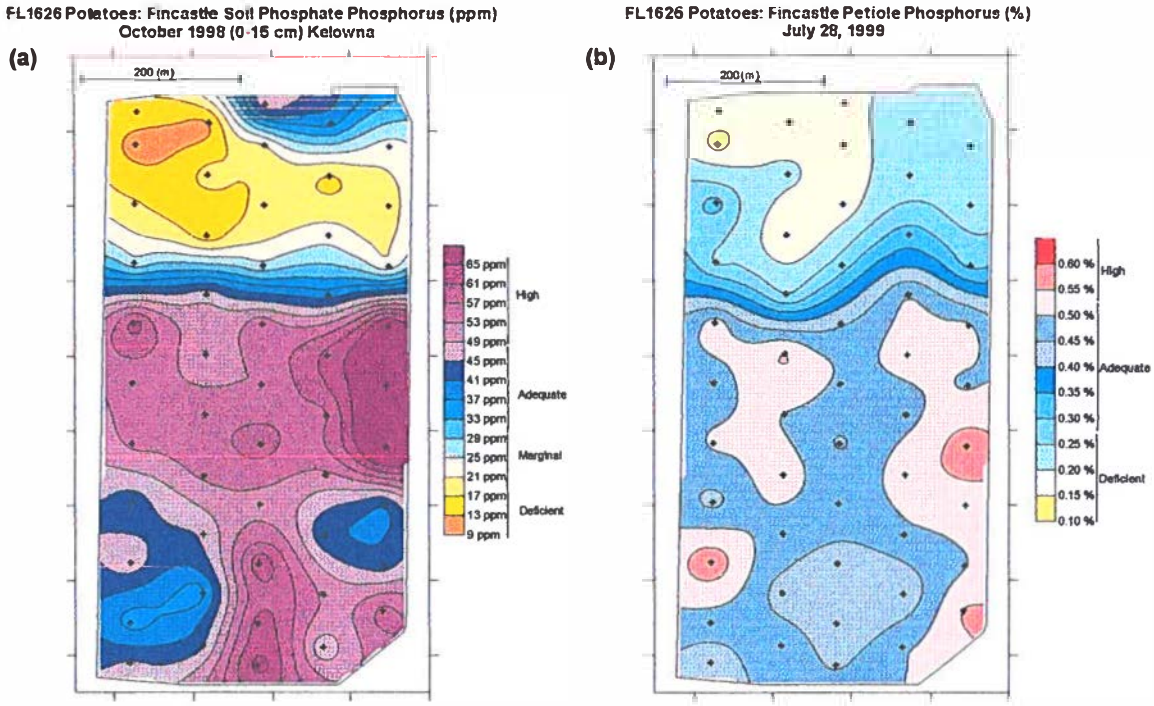


Figure 12. Fincastle (a) soil PO_4-P (October 1998, 0.00-0.15 m) and (b) petiole P (July 28, 1999) for a field which was partially fertilized with hog manure October 1997.

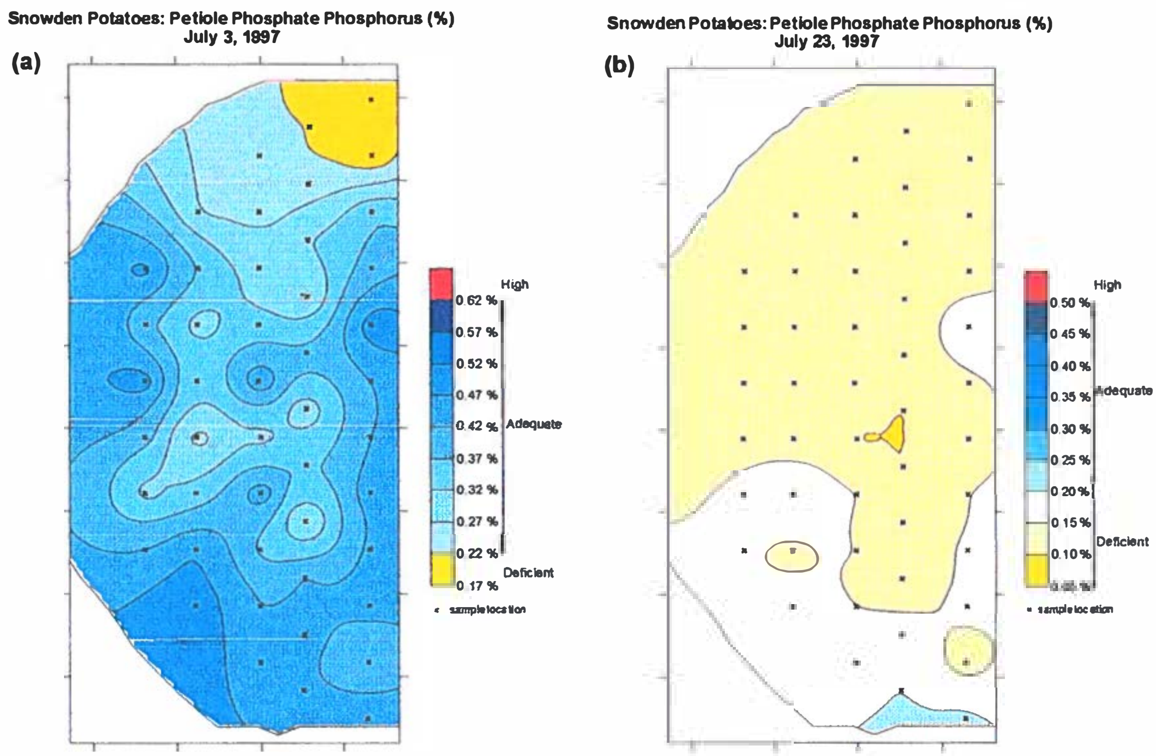


Figure 13. Petiole P levels at Hays (July 1998) showing rapid decline of petiole P from (a) July 3 to (b) July 23, 1997.

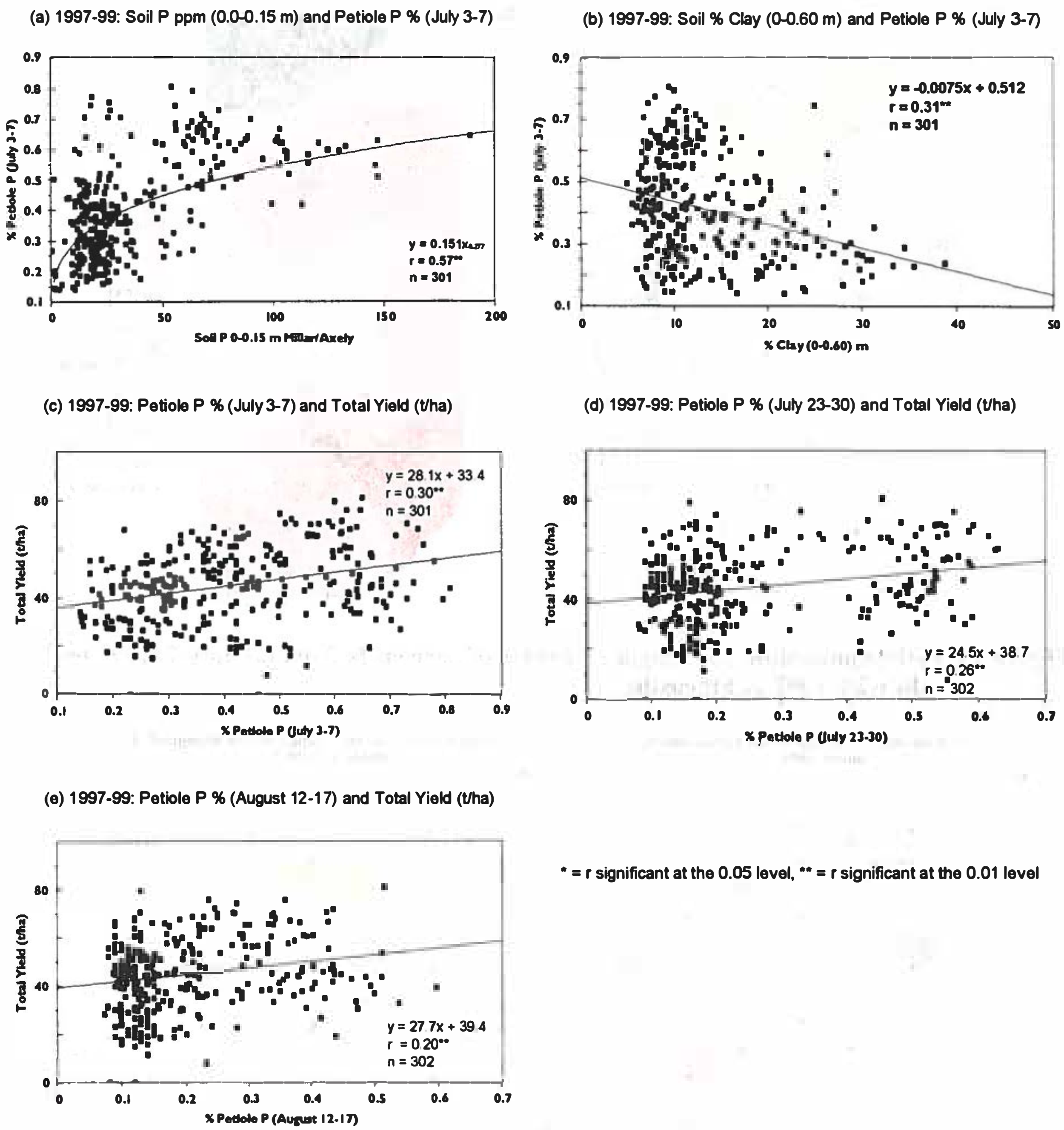


Figure 14. Correlation between potato petiole P and (a) soil PO_4-P, (b) soil clay and (c, d and e) total yield for 3 sampling dates at Hays and Fincastle for 1997-1999.

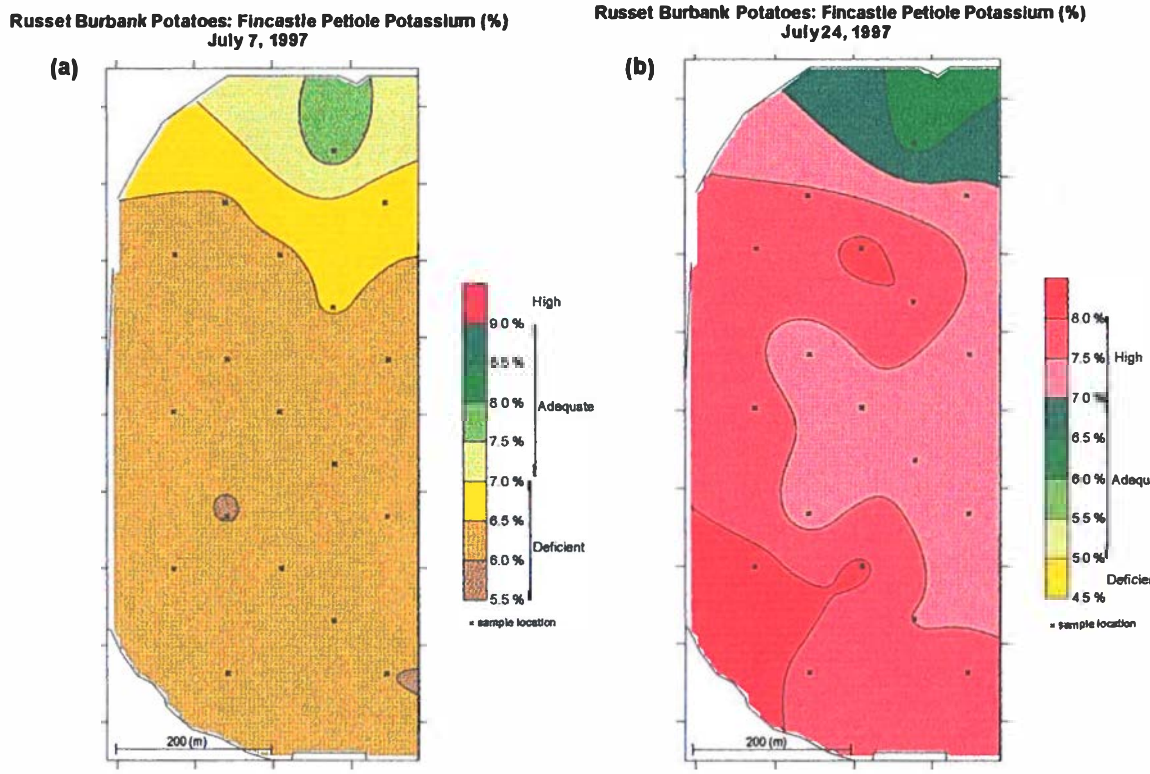


Figure 15. Petiole potassium showing an increase of percent K from (a) July 7, 1997 to (b) July 24, 1997 at Fincastle.

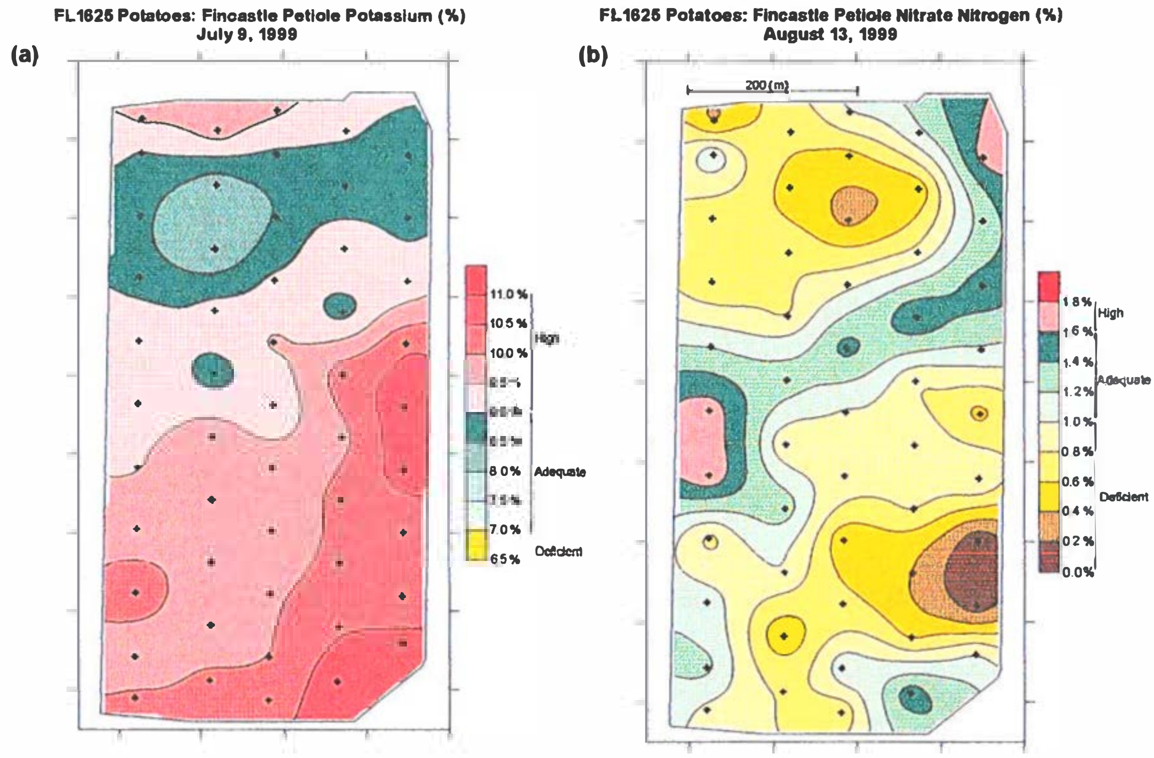


Figure 16. Petiole potassium showing a slight decrease of percent K from (a) July 9, 1999 to (b) August 13, 1999 at Fincastle.

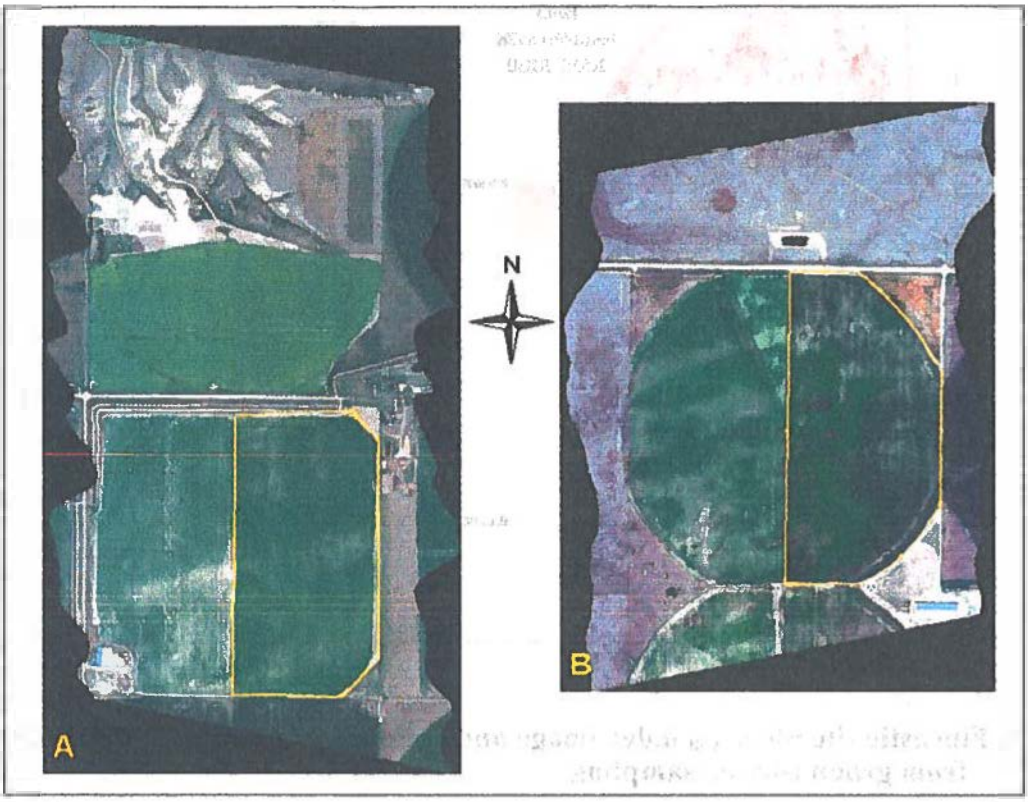


Figure 17. True colour composite images acquired July 28, 1999 at the (a) Fincastle and (b) Hays sites.

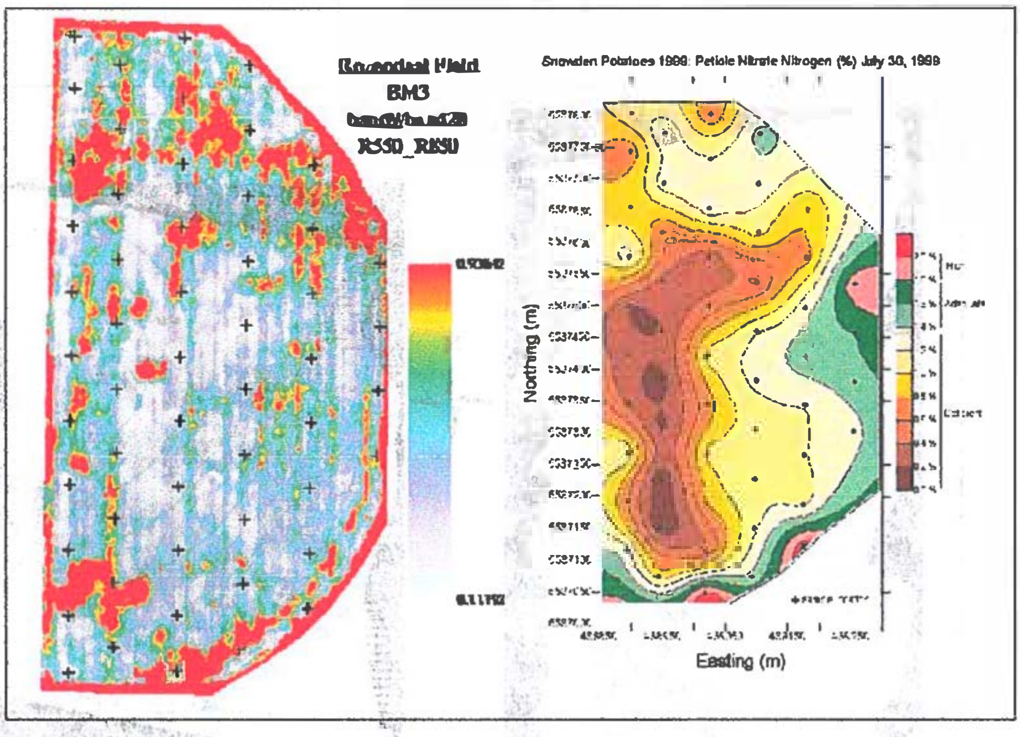


Figure 18. Fincastle site SR_{550_850} index image and petiole N map (July 28, 1999) derived from ground-based sampling.

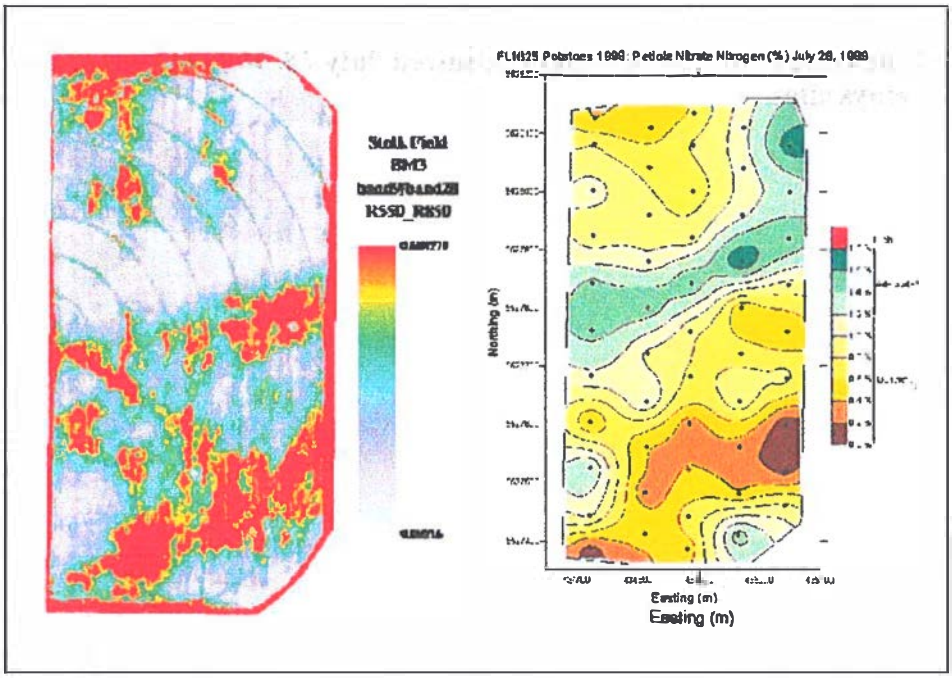


Figure 19. Hays site SR_{550_850} index image and petiole N map (July 30, 1999) derived from ground-based sampling.

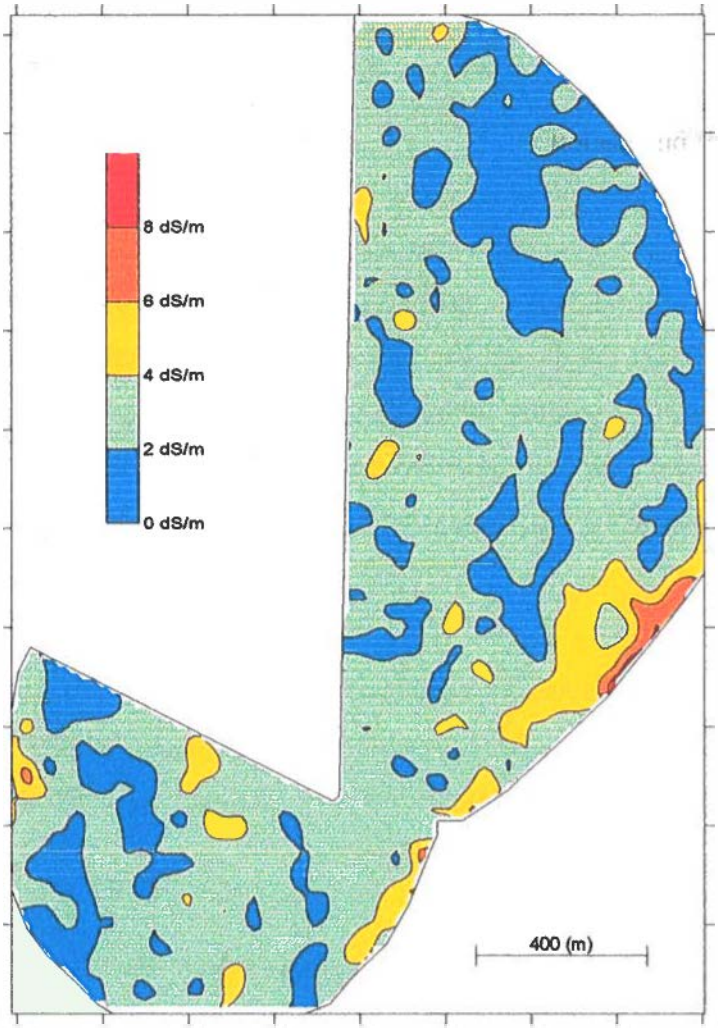
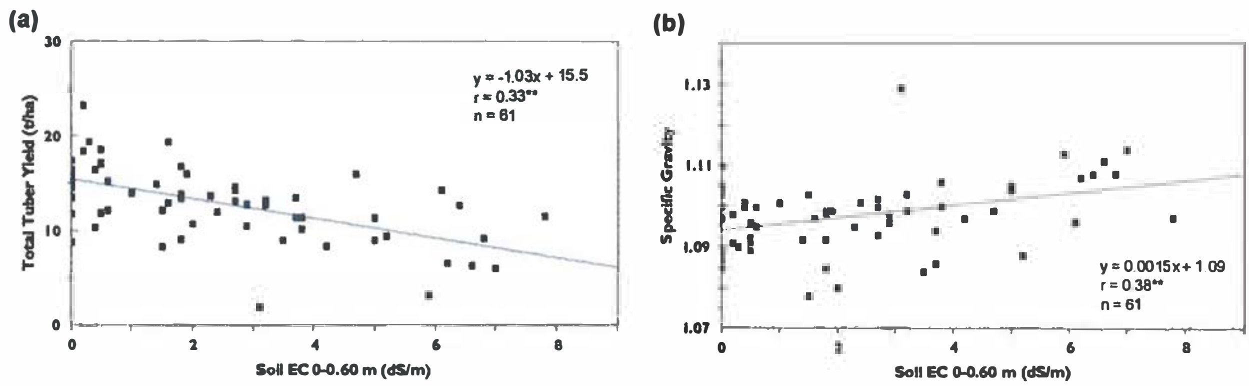


Figure 20. Soil salinity map (E.C. dS/m) for Vauxhall potatoes, April 1999.



** = r significant at the 0.01 level

Figure 21. The effect of soil salinity on (a) tuber yield and (b) tuber specific gravity for Vauxhall potatoes 1999.

IMPLICATIONS OF THE STUDY WITH REGARD TO THE IMPROVEMENT OF ALBERTA'S AGRICULTURAL AND FOOD INDUSTRY AND ADVANCEMENT OF AGRICULTURAL KNOWLEDGE

This project showed the difficulties using current yield monitoring equipment on many commercial fields. When soil variability is present, there are areas, which contain a high percentage of clay and form lumps on the harvester. The yield monitor weighs the material on the harvester belt and does not distinguish between potatoes and other material. Yield monitors usually work satisfactorily on fields, which do not contain medium or fine textured areas. Upper limits of currently used potato petiole nutrient sufficiency standards for phosphorus were found to be high. Subsequent experiments with rates of phosphorus on potatoes have confirmed this.

Petiole nutrient contents of potassium were shown to be unreliable as an indication of potassium deficiency. Research needs to be done to determine what are critical levels for yield or quality and what factors influence the potassium of petioles when grown under conditions with cold night temperatures like those of southern Alberta.

Field variability and lack of uniformity of output of irrigation water were found to be factors, which influence the growth and quality of potatoes. Farmers would do well to measure the output and uniformity of their irrigation systems.

Soil salinity was shown to be a measurable characteristic, which can be used to select portions of potential fields, which are not suitable for growing potatoes.

Site specific monitoring and yield mapping of a potato field, which is sampled by grid is a useful research technique to identify factors, which may be influencing yield and quality of potatoes.

ACKNOWLEDGEMENTS

Support for this project was received from the Alberta Agriculture Research Institute, Potato Growers of Alberta, Cargill, Potash and Phosphate Institute of Canada, Southern Agri Services, Westco and The Snack Food Association of Canada. Laboratory analysis was provided by the AAFRD Soil and Crop Diagnostic Centre, Edmonton. Two farm operations – one at Hays, the other Fincastle – allowed access to their fields and their potato and grain harvesters.

J. Rodvang monitored ground water at a series of piezometer nests in 1997 and 1998 and prepared the related portion of this document, including the text and Figures 7-10.

A. Smith of Agriculture and Agri-Food Canada, Lethbridge interpreted the 1999 CASI data and prepared the related portion of this document, including the text, Tables.18-20 and Figure 17-19. A. Smith's full report also appears as an appendix in this document.

L. Hingley, technologist for the Soil and Water Agronomy Program, conducted yield monitoring, sample collection and data organization and he prepared the figures and appendices for this document.

The Precision Agriculture Project with Potatoes was operated by an Alberta Agriculture, Food and Rural Development (AAFRD) team. Soil moisture budgets were determined by R. Hohm and T. Harms. D. McKenzie, R. Skretting, B. winter, T. Dell, A. Harms, H. Harms and L. Wenger collected and processed samples. J. Panford organized measurement of tuber chipping and French fry scores. M. Eliason and D. McKay assisted with setting up yield monitoring equipment. C. Murray proofread the manuscript. Word processing of the manuscript was done by S. Day and M. Bunney.

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APPENDICES

Appendices I to VIII list the raw data collected from the grid sample sites, including soil characteristics, plant tissue nutrients, rain gauge readings and hand-dug tuber sample attributes. Appendix IX provides the data from the 1999 Vauxhall soil salinity site. Appendix X is the remote sensing document provided by A. Smith.

Personal Data Sheet for Research Team Members

The personal information being collected is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

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Past experience relevant to project:

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2. Precision farming systems to maximize profits and minimize environmental impacts (1996).
3. Precision farming management systems for potatoes (1995).
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B.Sc. (Soil Science)	Univ. of Alberta (1962)

Publications and Patents:

# of Refereed papers:	Conference proceedings:
Relevant Patents obtained: 0	Other relevant citations:

Other evidence of productivity during past 6 years:

Personal Data Sheet for Research Team Members

The personal information being collected is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

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1. Development and evaluation of precision farming technologies for canola production and research (1996-1999).
2. Landscape analysis for precision farming and model applications (1996-1999).
3. Geographic management of agronomic practice. (1995-96)
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B. Sc. (Agriculture)	Univ. of Alberta (1979)

Publications and Patents:

# of Refereed papers: 8	Conference proceedings: 45
Relevant Patents obtained: 0	Other relevant citations: 4

Other evidence of productivity during past 6 years:

1. Development of Scientifically Defensible Estimates of N_2O Emissions from Agricultural Ecosystems in Canada (CCAF, 00-03), Grant, Juma, Goddard, Kryzanowski, Zhang Solberg, Pattey.
2. Assessing the Nitrous Oxide Tradeoffs to Carbon Sequestering Management Practices (CCAF, 00-01) Lemke, Desjardins, Keng, Kharabata, Smith, Goddard, Ellert, Monreal, Drury, Rochette, Pattey.
3. Landscape dynamics and crop-soil model verification. (ARI, AESA, 99-01) Kryzanowski, Grant, Goddard.
4. Impacts of Cropping Systems to Climate Change and Adaptation Strategies for Agriculture in the Prairie Regions. (PARC, 00-01) Manunta, Goddard, Cannon.
5. Phosphorus mobility in soil landscapes: a site-specific approach. (CABIF, 99-02). Li, Chang, Amrani, Goddard, Heaney, Olson, Zhang, Feng.
6. Soil landscape management study crop yields. (MII, 01) Nolan, Lohstraeter, Coen, Brierley, Pettapiece, Goddard
7. Carbon sequestration and greenhouse gas flux in selected Alberta catenas containing wetlands (IWWR 02-07) Goddard/Fuller, Kryzanowski, Brierley, Zhang.
8. Emissions of N_2O from Cereal-Pea and Cereal-Lentil rotations in western Canada (NRCan 01-02). Lemke, Goddard, Selles.
9. Soil Variability for Agronomic and Environmental Crop Production - SVAECP (boardmember)
10. Advisory committee member – Land Information Systems program, Olds College
11. Invited committee member – Managed Ecosystems program development, Canadian Institute of Advanced Research (CIAR).

Personal Data Sheet for Research Team Members

The personal information being collected is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

Title: Mr.	**First Name:** Murray	**Last Name:** Green	
Position: Farm Machine Engineer *(retired)*			
Organization/Institution:		**Department:** AAFRD	
Mailing Address:	**City:**	**Prov:**	**Postal Code:**
E-mail Address: murray.green@shaw.ca			
Phone Number:	**Fax Number:**		

Past experience relevant to project:

1. Variable rate fertilizer application system to control the input of fertilizer based on prescribed requirements (1994-1996).
2. Precision farming systems to maximize profits and miniize environmental impacts (1993-1996).
3. Site-specific management of potatoes (1996-1999).
4. Yield mapping of irrigated edible beans (1997-1998).

Degrees /Certificates /Diplomas:	**Institution Received From:**
B.Sc.Eng. (Agricultural Engineering)	Univ. of Saskatchewan (1967)

Publications and Patents:

# of Refereed papers:	Conference proceedings:
Relevant Patents obtained: 0	Other relevant citations:

Other evidence of productivity during past 6 years:

Personal Data Sheet for Research Team Members

Title: Mr. | **First Name:** Clive A. | **Last Name:** Schaupmeyer

Position: Potato Specialist *(retired)*

Organization/Institution: | **Department:** AAFRD

Mailing Address: 2207 – 16 Ave. | **City:** Coaldale | **Prov:** AB | **Postal Code:** T1M 1N7

E-mail Address: clives@shaw.ca

Phone Number: (403)345-6457 | **Fax Number:** n/a

Past experience relevant to project:

1. Agronomic research projects aimed at improving potato plant stands, population, plant performance, quality and yields.
2. Effects of in-row spacing on yield and size distribution of potatoes (1993-1996).
3. Development of optimum management profiles for new potato varieties (1995-1998).

Degrees /Certificates /Diplomas:	Institution Received From:
M.Sc. (Extension Education)	Univ. of Guelph (1976)
B.Sc. (Soils/Horticulture)	Univ. of Alberta (1968)

Publications and Patents:

# of Refereed papers: 10	Conference proceedings: Several
Relevant Patents obtained: 0	Other relevant citations:

Other evidence of productivity during past 6 years:

Personal Data Sheet for Research Team Members

The personal information being collected is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

Title: Ms	**First Name:** Shelley		**Last Name:** Woods
Position: Soil and Water Research Scientist			
Organization/Institution: Crop Diversification Centre South		**Department:** AAFRD	
Mailing Address: SS #4	**City:** Brooks	**Prov:** AB	**Postal Code:** T1R 1E6
E-mail Address: Shelley.A.Woods@gov.ab.ca			
Phone Number: (403)362-1352	**Fax Number:** (403)362-1311		

Past experience relevant to project: (Point form, concise.)

Involved as junior research scientist and senior technologist in the following relevant projects. Duties included management of field work, data organization and analysis, report writing and presentation of results.

- Phosphorus and Compost on Potatoes 2000-2001
- Precision Farming of Potatoes 1996-1999
- Precision Farming of Dry Beans and Peas 1995, 1997-1998
- Salinity Tolerance of Forage and Turf Grasses (1991-1993, 2002)
- Nutrient Requirements of Irrigated Alfalfa (1994-1997)

Degrees /Certificates /Diplomas:	**Institution Received From:**
Ph.D. (Soil Physics) - In Progress	University of Saskatchewan
Master of Environmental Design (Env. Sci.) 1992	University of Calgary
Bachelor of Science (Physics) 1989	University of Alberta

Publications and Patents:

# of Refereed papers: 2	Conference proceedings: >15
Relevant Patents obtained: 0	Other relevant citations: 1 Master's thesis. 1 textbook chapter, 2 magazine articles, 2 Ropin' the Web articles

Other evidence of productivity during past 6 years: (Point form, concise)

- currently completing a Ph.D. in soil physics (AAFRD sponsored)
- managed the Alberta component of a national agricultural greenhouse gas emissions study
- successfully solicited Potato Growers of Alberta for substantial funding
- completed program reviews and published annual report in the absence of my supervisor
- gave seminars to a variety of college, university and industry groups
- presented papers, posters and oral reports at provincial, national and international conferences
- won second prize for student presentations at the 2002 Alberta Soil Science Workshop
- two-year recipient of the University of Saskatchewan's Soil Science tuition scholarship (2000 and 2001)

Research Team Information

a) Research Team Leader:		
Title: Dr.	**First Name:** R. Colin	**Last Name:** McKenzie
Position: Research Scientist, Soil and Water Agronomy *(deceased)*		
Organization/Institution: Crop Diversification Centre South		
Department: Alberta Agriculture, Food and Rural Development		
Address:	**City:**	**Prov./State:**
Postal Code/Zip:	**E-mail Address:**	
Phone Number:	**Fax Number:**	

Past experience relevant to project:

1. Determining nutrient content of feedlot manure (2001-2002).
2. The influence of compost and phosphorus fertilizer on disease in potatoes (1999-2000).
3. Response of irrigated potatoes to phosphorus fertilizer and compost (1999-2001).
4. Site specific management of irrigated potatoes (1996-1999).
5. Salinity tolerance of forage and turf grasses (1993-1995).
6. Phosphorus and potassium requirement of irrigated alfalfa (1989-1994).

Degrees /Certificates /Diplomas:	Institution Received From:
Ph.D., The effect of subsoil acidity on root development and crop growth of several crops.	Univ. of Alberta (1970-1973)
MSc., The effect of coal humic acids on soil structure and as a slow release source of nitrogen.	Univ. of Alberta (1968-1970)
BSA in Agriculture	Univ. of Saskatchewan

Publications and Patents:

# of Refereed papers: 15	**Conference proceedings:** 16
Relevant Patents obtained: 0	**Other relevant citations:** 3 Chapters in Books

Other evidence of productivity during past 6 years:

- Invited speaker at International Drainage Conference in India (Feb. 2000).
- External examiner for 2 Ph.D. graduate students (2000-2002).
- Provided a course on measurement of salinity for Pakistan engineers and soil specialist (2001-2002).

b) Research Team Members

Name	*Institution*
1. R. C. McKenzie	CDC South, AAFRD
2. C.A. Shaupmeyer	AAFRD
3. M. Green	AAFRD
4. T.W. Goddard	AAFRD
5. D.C. Penney	AAFRD

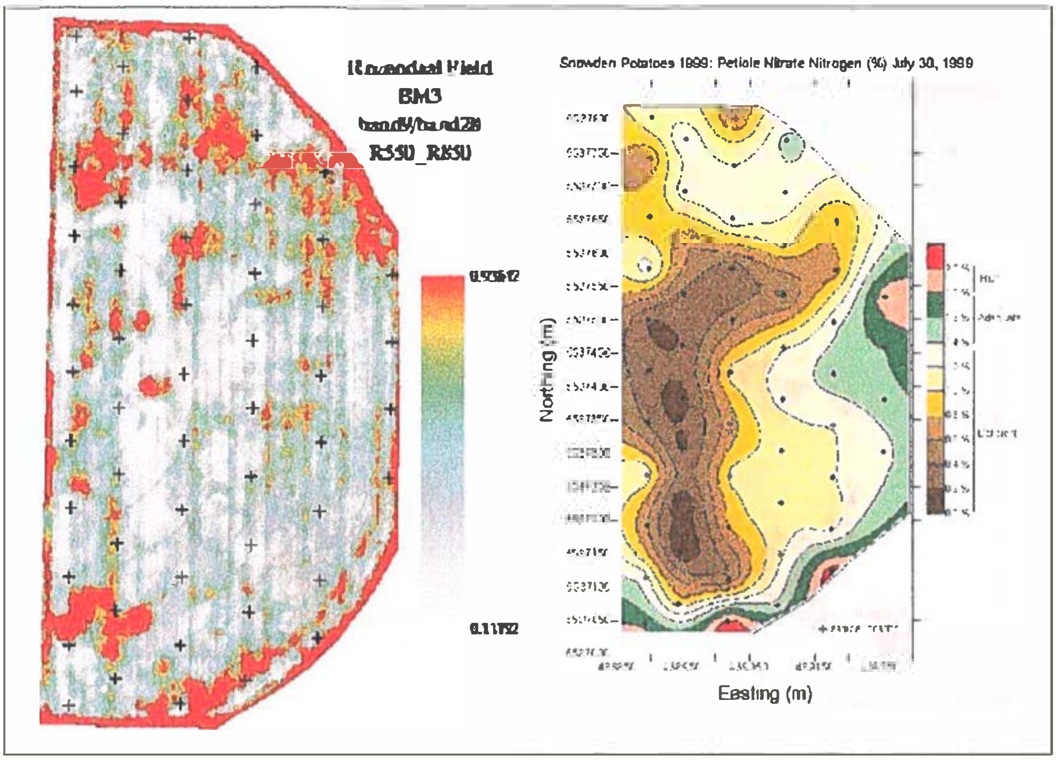

FIGURE 3 HAYS SITE: SR_{550_850} INDEX IMAGE AND PETIOLE-N MAPS DERIVED FROM GROUND-BASED SAMPLING.

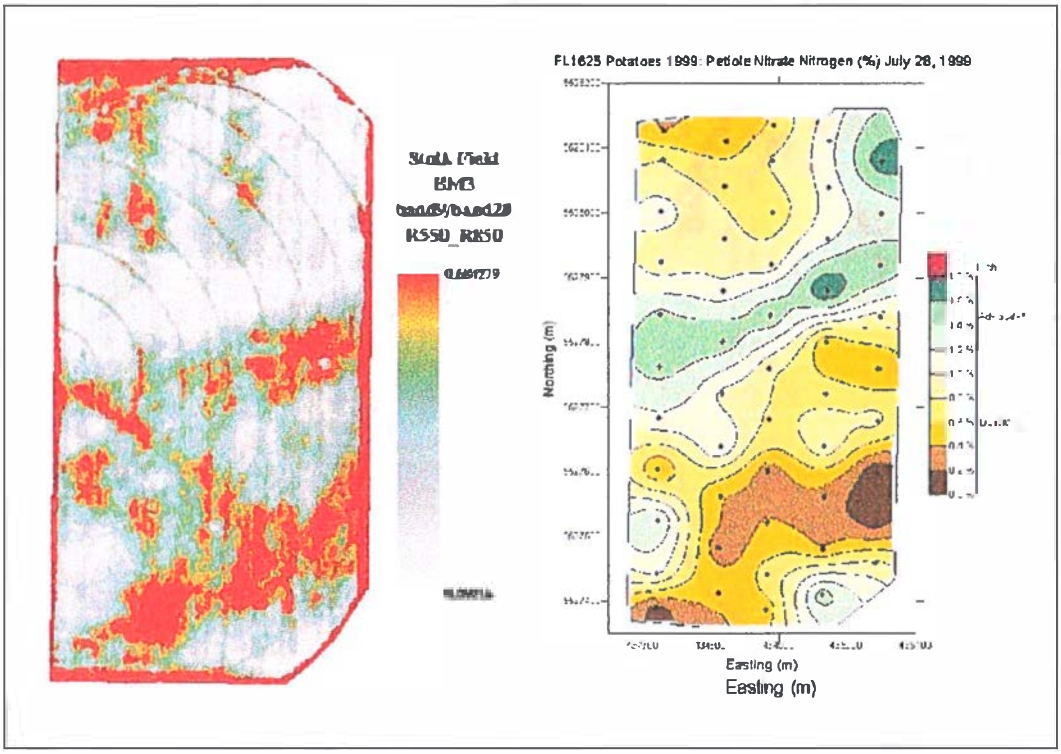

FIGURE 2. FINCASTLE SITE: SR_{550_850} INDEX IMAGE AND PETIOLE-N MAPS DERIVED FROM GROUND-BASED SAMPLING

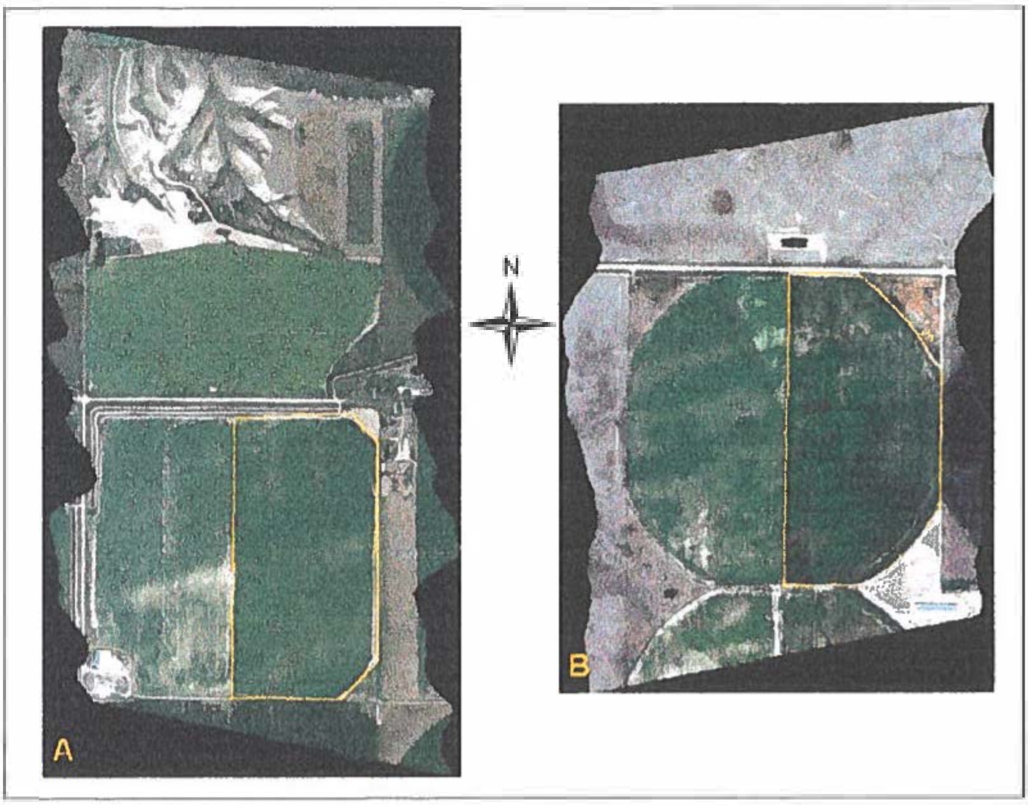

FIGURE 1. TRUE COLOUR COMPOSITE IMAGES ACQUIRED JULY 28, 1999 OF THE FINCASTLE (A) AND HAYS (B) SITES.

TABLE 5. RELATIONSHIP BETWEEN THE VARIOUS PROPOSED INDICES AND PETIOLE NITRATE N SAMPLES

Index	Fincastle	Hays
SIMPLE RATIO		
SR_{800_680}	0.751	NS
SR_{695_430}	-0.734	-0.356
SR_{605_760}	-0.781	NS
SR_{695_760}	-0.748	NS
SR_{695_670}	0.449	-0.318
SR_{750_705}	0.820	NS
SR_{750_550}	0.821	NS
SR_{677_717}	-0.639	NS
SR_{550_850}	-0.832	NS
SR_{710_850}	-0.832	NS
SR_{735_700}	0.821	NS
PSSR	0.764	NS
NORMALIZED DIFFERENCE INDEX		
NGVDI	0.809	NS
PRI	0.770	NS
PSND	0.706	NS
NDI_{750_700}	0.809	NS
NDI_{750_705}	0.696	NS
NDI_{800_680}	0.707	NS
SIPI	-0.660	NS
OTHER		
mSR_{750_705}	0.821	0.326
mNR_{750_705}	0.813	0.308
OSAVI	0.722	NS
MCARI	0.445	-0.298
TCARI	-0.800	-0.317
PSRI	-0.597	
Carotenoids	0.746	NS
Chlorophyll a	-0.448	0.313
Chlorophyll b	-0.674	NS
PSRI	-0.597	NS
NPCI	-0.702	NS
# OF OBSERVATIONS	N=51	N=54

TABLE 3. SITE CHARACTERISTICS

	Fincastle	Hays
Field size (ha)	31	28
Soil type	Chin light loam, fluvial lacustrine	Aeolian loamy sand overlying fine lacustrine till
# of grid sampling points	51	54
Type of irrigation	High pressure corner	Low pressure
Cultivar	Frito-Lay 1625	Snowden
N Fertilizer	Fall 1998 112 kg/ha	Fall 1998 157 kg/ha,
	At hilling 20 kg/ha	At hilling 41 kg/ha
	Fertigation 30 kg/ha	Fertigation 50 kg/ha
P Fertilizer	Fall 1998 39 kg/ha	Fall 1998 59 kg/ha
	Spring 1999 29 kg/ha	Spring 1999 0 kg/ha
K Fertilizer	Fall 1998 56 kg/ha	Fall 1998 56 kg/ha
	Spring 1999 0 kg/ha	Spring 1999 0 kg/ha
Petiole N sampling	July 9, 28 and August 13	July 7, 30 and August 17
Seeded	April	April
Hilled	April	April
Harvested	September 15-17	September 20, 24-25,27

TABLE 4. INPUT PARAMETERS FOR THE FLAASH ATMOSPHERIC CORRECTION MODEL.

Parameter	Input
Latitude/Longitude	49.9867N, 111.8523W
Sensor altitude	2.286 km
Ground elevation	0.786 km
Atmospheric model	Sub-Artic Summer
Aerosol model	Rural
Visibility	40 km

TABLE 2. PUBLISHED ALGORITHMS FOR CHLOROPHYLL/N ESTIMATION USING REMOTE SENSING DATA

Index	Formula	Citation	CASI bands
Simple ratio			
SR_{800_670}	(R_{800nm}/R_{670nm})		17, 25
SR_{695_430}	$(R_{695nm}R_{430nm})$	Carter 1994	1, 18
SR_{605_760}	(R_{605nm}/R_{760nm})	Carter 1994	12, 23
SR_{695_760}	(R_{695nm}/R_{760nm})	Carter 1994	18, 23
SR_{695_670}	(R_{695nm}/R_{670nm})	Carter 1994	17, 18
SR_{750_705}	(R_{750nm}/R_{705nm})	Gitelson and Merzlyak 1996, Sims and Gamon 2002	19, 22
SR_{750_550}	(R_{750nm}/R_{550nm})	Gitelson and Merzlyak 1996, Lichtenthaler et al. 1996	9, 22
SR_{667_717}	(R_{667nm}/R_{717nm})	Leblon et al. 2001	17, 20
SR_{550_850}	(R_{550nm}/R_{850nm})	Schepers et al. 1996	9, 28
SR_{710_850}	(R_{710nm}/R_{850nm})	Schepers et al. 1996	19, 28
SR_{800_680}	(R_{800nm}/R_{680nm})	Sims and Gamon 2002	17, 25
SR_{735_700}	(R_{735nm}/R_{700nm})	Gitelson and Merzlyak. 1999	19, 21
Pigment specific simple ratio (PSSR)	(R_{610nm}/R_{676nm})	Blackburn 1998	17, 26
Normalized difference index			
Normalized green difference vegetation index (NGVDI)	$(R_{750nm} - R_{550nm})/(R_{750nm} + R_{550nm})$	Gitelson et al. 1996	9, 22
Photochemical reflectance index (PRI)	$(R_{531nm} - R_{570nm})/(R_{531nm} + R_{570nm})$	Gamon et al. 1992	8, 10
Pigment specific normalized difference (PSND)	$(R_{610nm} - R_{676nm})/(R_{810nm} + R_{676nm})$	Blackburn 1998	17, 26
Normalized difference index (NDI_{750_700})	$(R_{750nm} - R_{700nm})/(R_{750nm} + R_{700nm})$	Gitelson and Merzylak 1994, Sims and Gamon 2002	19, 22
Normalized difference index (NDI_{800_680})	$(R_{800nm} - R_{680nm})/(R_{800nm} + R_{680nm})$	Sims and Gamon 2002	17, 25
Normalized pigments chlorophyll ratio index (NPCI)	$(R_{680nm} - R_{430nm})/(R_{680nm} + R_{430nm})$	Peñuelas et al. 1994	1, 17
Structure-insensitive pigment index (SIPI)	$(R_{800nm} - R_{445nm})/(R_{800nm} + R_{680nm})$	Peñuelas et al. 1995	2, 17, 25
Others			
Modified simple ratio (mSR_{750_445})	$(R_{750nm} - R_{445nm})/(R_{705nm} - R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Modified normalized ratio (mNR_{750_445})	$(R_{750nm} - R_{705nm})/(R_{750nm} + R_{705nm} - 2*R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Optimized soil adjusted vegetation index (OSAVI)	$(1 + 0.16)*(R_{800nm} - R_{670nm})/(R_{800nm} + R_{670nm} + 0.16)$	Rondeaux et al. 199	17, 25
Modified chlorophyll absorption in reflectance index (MCARI)	$[(R_{700nm} - R_{670nm}) - (0.2*(R_{700nm} - R_{550nm}))*(R_{700nm}/R_{670nm})]$	Daughtry et al. 2000	9, 17, 19
Transformed chlorophyll absorption in reflectance index (TCARI)	$3*[(R_{700nm}-R_{670nm})-(0.2*(R_{700nm}-R_{550nm}))*(R_{700nm}/R_{670nm})]$	Haboudane et al. 2002	9, 17, 19
Plant senescence reflectance index (PSRI)	$(R_{680nm} - R_{500nm})/(R_{750nm})$	Merzlyak et al. 1999	6, 17, 22
Carotenoids	$[4.145*(S_{760nm}/S_{500nm})*(R_{500nm}/R_{760nm})]-1.171$	Chapelle et al. 1992	5, 23
Chlorophyll b	$2.94*[((S_{675nm}/R_{650nm}*S_{700nm})*(R_{650nm}*R_{700nm}/R_{675nm}))]+0.378$	Chapelle et al. 1992	15, 17, 18
Chlorophyll a	$22.735[=(S_{675nm}/S700_{nm})*(R_{700nm}/R_{675nm})] - 10.407$	Chapelle et al. 1992	17, 18

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Conclusions

The results of the study indicated that potato petiole nitrate N could be estimated from remote sensing imagery at one test site but not the other. At the second site, visually the spatial patterns in the remote sensing derived maps for N levels and those derived from ground based plant sampling were similar. Errors in the overlay of petiole sampling points on the remote sensing imagery may account for the lack of a significant quantitative relationship at the second site. Further studies are being conducted to determine the ability to estimate plant N content using remote sensing techniques.

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3). Visual comparison of the petiole-N maps derived in Surfer™ using the grid point petiole nitrate N data and the index SR_{550_850} shows similarities in the patterns across both fields. Generally, areas of low petiole nitrate N exhibited high values for the SR_{550_850} index. Correlation analysis showed a strong relationship between most of the chlorophyll/N indices and petiole nitrate N for the Fincastle site (Table 4). The strongest relationships were evident with simple ratios involving either reflectance in the green band (550 nm) or the red-edge (700-710 nm) and the near infrared reflectance (750-850 nm). These observations can be attributed to the greater range of chlorophyll/N content to which reflectance at 550 and 700-710 nm responds. The absorption feature at 660-680 nm saturates at relatively low chlorophyll content and thus relative to 550 or 700-710 nm is insensitive to variation in chlorophyll/N.

At the Hays site, visually there were some similarities between the spatial patterns within the image of the SR_{550_850} index and the kriged map of the ground based sampling. The extent of the N deficient areas in the remote sensing image appeared less than in the kriged map. The imagery may provide a more accurate representation of the spatial variability given that each pixel in the remote sensing image represents information from an area of 2 x 2 m on the ground while the ground data is an interpolation from grid points at greater than 100 m apart. Quantitative analysis showed only a limited number of indices were significantly related to petiole nitrate N. The strength of the relationship was poor compared to that at the Fincastle site. The lack of a strong relationship may reflect uncertainty in the georeferencing of the airborne imagery and the sampling sites and the heterogeneity of the crop reflectance in the areas selected for sampling. (Deguise et al. 1998).

cm^{-2} sr^{-1} nm^{-1}) to surface reflectance (%) using the FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) atmospheric correction model (Anon 2001). The input parameters used in the model are shown in Table 3.

Images of the various chlorophyll/N indices outlined in Table 1 were created using the band math function in the image analysis software. The spatial patterns of the indices across the sites were visually examined and compared to those in the kriged maps derived from the ground based petiole nitrate N samples. The grid sampling points were overlaid on the imagery and the reflectance values under a 3 x 3-pixel window centered over each grid point were extracted for each band and each chlorophyll/N index. The relationship between the various chlorophyll/N indices and the petiole nitrate N values was assessed using correlation and regression analyses.

Results & Discussion

True colour images derived from the 2-m resolution airborne imagery for both the Fincastle and Hays sites are shown in Figure 1. Both the 2 and 3-m resolution images were processed but due to the similarity in the information content only the 2-m data will be discussed. The images show differential "greeness" across the fields, particularly in the Hays field. The spatial patterns tend to correspond to soil texture, particularly in the northern end of the field at Hays and likely results from poorer growth on the coarse textured soils. Consistent with the observation that many of the proposed indices involve reflectance in similar wavebands, the spatial patterns in the images derived for the various indices were similar (Table 1). Only the images showing the spatial variability in the index SR_{550_850} derived from reflectance at 550 and 850 nm are shown (Figures 2 and

and harvesting of the potato crop. The characteristics of the sites and fertilizer applications are given in Table 2.

Petiole Sampling

A sampling grid was set up in each field in the fall of 1998; the grid sampling points were located with differential GPS methods. Petiole samples were collected at each grid sampling point at Fincastle on July 9, July 28 and August 13 and at Hays on July 7, July 30 and August 17, 1999. Within 5 m of each grid sampling point, 45 to 70 petioles were taken from the fourth leaf of representative plants. The tissues were analyzed to determine nitrate N and total N as well as a number of other elements (McKenzie et al. 2002). The N levels in the tissues were compared to sufficiency limits used by various Alberta and USA soils laboratories. The geographic coordinates of the grid points together with their associated petiole nitrate N values were imported into the grid-based graphics program Surfer™ (Golden Software Inc, Colorado, USA). The data between the grid points were interpolated using kriging to produce a map delineating petiole nitrate N levels across each of the test fields.

Remote sensing data

On July 28, 1999, Itres acquired digital images over the test fields. The image data were acquired over the spectral range 420-965 nm using a Compact Airborne Spectrographic Imager at 2 and 3-m resolution. The spectral bands in which data were acquired varied with the resolution from 36 to 48 respectively. The image data were radiometrically corrected and geocoded by Itres.

The data were imported into the ENVI™ image analysis software package (Research Systems Inc. Colorado, USA) and converted from spectral radiance units (μW

Remote sensing data offers one source of spatial information suitable for use in site-specific management systems. Digital imaging systems provide the potential to delineate management zones within a field based upon soil characteristics and the detection of crop stresses both in the short and long term (Brisco et al. 1998, Moran et al. 1997). A number of algorithms have been proposed to measure chlorophyll or N content of plants using remote sensing (Table 1). The close correlation between leaf chlorophyll and N availability suggests that chlorophyll content can be use to characterize N status and vice versa (Filella and Peñuelas 1994). The majority of the algorithms or indices are based upon reflectance in the green (530-600 nm), red (670-680 nm) or so-called 'red-edge' (690-710 nm) normalized to reflectance in the near-infrared (750-900 nm) range of the electromagnetic spectrum. Reflectance at wavelengths above 735 nm is relatively insensitive to chlorophyll or N levels while reflectance at 550 and 690-710 nm is most sensitive. Sensitivity to N stress at 670-680 nm is variable due to the signal being saturated and reflectance reaching a minimum at relatively low chlorophyll levels (Gitelson et al. 1999). The objective within this study was to test, using airborne remote sensing imagery, the suitability of the reported algorithms to estimate petiole-N content in potatoes and examine the spatial information regarding N status across the field.

Materials and Methods

Fields Sites

Two field sites were identified one near Fincastle and the other at Hays, Alberta. The producers used their normal methods for seeding, cultivation, irrigation, pest control

Introduction

Potato, a high value crop in southern Alberta, requires large amounts of fertilizers, pesticides and irrigation water. With respect to nitrogen (N), a balance between supply and utilization is required to optimize crop growth and economic return as well as minimize environmental impact. Application of excess N results in delayed maturity, reduced tuber set and dry matter yield, and increased incidence of hollow heart. Thus, too much nitrogen leads to a reduction in net returns and potentially ground water contamination due to leaching. Conversely, too little N reduces profitability due to a reduction in yield and an increase in susceptibility to blight (Schaupmeyer 1992). Early detection of N deficiency in crops such as potatoes allows producers an opportunity to more closely match their application rates to the real time N requirements of the crop thereby optimizing returns and alleviating concerns about environmental contamination.

Potato fields are closely monitored during the growing season for the onset of nutrient deficiencies, disease and pests. With respect to nutrients, typically test areas are established in a field and 40 to 50 petioles from representative plants are collected at each sampling date for determination of primarily N but also P and K content. In Alberta in mid-July, the target range for petiole nitrate N for potatoes under irrigation is 1.0 to 2.0%; below 1.0% the plants are considered to be deficient in N. Based upon the petiole sampling, N can be applied through fertigation. This method of petiole sampling provides only limited information regarding spatial variability across the whole field and does not provide information suitable for use with variable rate equipment.

ESTIMATING POTATO PETIOLE NITRATE NITROGEN USING REMOTE SENSING TECHNIQUES

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IX. 1999 Vauxhall Grid Sample Data

	Position Data		EM38 Soil Salinity Data		Hand-Sampled Tuber Data			
Site	Easting (m)	Northing (m)	E.C. Horizontal (dS/m)	E.C. Vertical (dS/m)	Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity
Depth (cm)			(0-60)	(0-120)				
2	417803.452	5545198.060	5.0	5.7	27	21	99.2	1.105
3	417802.606	5545208.771	0.5	4.3	36	27	98.4	1.091
4	417803.706	5545217.884	3.7	4.7	34	24	95.8	1.086
5	417802.545	5545231.981	3.7	5.4	40	34	122.8	1.094
6	417804.655	5545250.974	3.2	5.0	40	35	114.5	1.103
7	417804.179	5545258.717	2.7	4.6	44	31	103.5	1.102
8	417806.070	5545284.676	2.7	4.7	43	35	105.0	1.100
9	417806.324	5545311.932	3.8	5.7	30	25	131.4	1.106
10	417807.379	5545353.228	0.3	0.1	49	40	101.6	1.110
11	417807.760	5545368.950	0.3	0.2	46	38	107.9	1.105
12	417805.729	5545433.224	0.3	0.2	35	28	104.9	1.089
13	417734.776	5545134.595	4.2	3.9	25	14	103.0	1.097
14	417732.885	5545139.708	3.8	4.1	34	29	118.9	1.100
15	417734.047	5545146.255	2.9	3.9	38	30	108.1	1.096
16	417735.376	5545160.364	1.8	3.2	41	36	106.0	1.098
17	417735.460	5545160.352	2.7	3.7	39	32	112.6	1.093
18	417735.746	5545177.626	3.2	4.8	38	32	103.8	1.099
19	417735.340	5545186.596	0.3	3.8	44	34	114.2	1.100
20	417735.547	5545201.099	4.7	5.3	48	35	91.3	1.099
21	417735.846	5545227.155	2.3	4.4	41	34	101.8	1.095
22	417736.294	5545240.162	1.8	3.8	40	29	95.8	1.099
23	417737.002	5545292.974	1.6	3.3	39	29	82.9	1.097
24	417742.783	5545420.668	0.6	2.1	36	29	105.3	1.095
25	417741.043	5545425.065	0.4	1.7	31	20	93.3	1.100
26	417742.753	5545437.498	0.3	0.8	47	37	105.4	1.087
27	417743.677	5545453.048	0.3	0.9	40	36	127.3	1.089
28	417744.943	5545473.627	0.3	1.2	27	18	80.6	1.085
29	416599.690	5545133.444	6.4	6.0	38	31	118.3	1.108
30	416601.295	5545137.559	6.8	6.1	28	20	125.4	1.108
31	416604.731	5545132.820	6.6	6.1	20	14	115.6	1.111
32	416611.542	5545131.133	7.0	6.1	18	14	101.4	1.114
33	416624.477	5545146.228	6.2	6.0	20	16	108.2	1.107
34	416628.008	5545148.094	5.0	5.5	34	27	134.4	1.104
35	416633.429	5545150.672	1.8	3.4	50	40	124.9	1.092
36	416637.308	5545159.760	0.5	2.2	56	48	148.9	1.096
37	416643.724	5545165.115	2.9	4.2	32	21	119.5	1.098
38	416652.716	5545157.126	1.9	3.4	48	40	138.4	1.099
39	416663.907	5545183.050	1.0	2.5	46	41	134.2	1.101
40	416671.818	5545173.875	0.4	1.6	49	43	147.6	1.101
41	416677.985	5545170.589	0.6	2.2	46	38	153.3	1.100
42	416684.811	5545190.281	0.4	1.8	49	37	157.0	1.101
43	416689.479	5545197.304	0.2	1.6	55	50	142.5	1.098
44	416704.301	5545206.294	0.3	1.2	44	37	147.9	1.097
45	416712.669	5545218.766	0.3	1.2	52	47	154.4	1.103
46	417011.817	5545102.675	5.9	7.3	10	4	86.2	1.113
47	417009.936	5545087.434	6.1	6.7	43	17	81.7	1.096
48	417011.213	5545067.675	7.8	8.5	27	12	117.2	1.097
49	416989.494	5545069.341	2.0	3.2	32	10	60.1	1.080
50	416990.820	5545052.866	1.5	2.6	25	13	78.9	1.078
51	416988.397	5545040.775	1.8	2.7	27	8	37.6	1.085
52	417010.838	5545041.948	5.2	5.5	28	13	89.6	1.088
53	417014.113	5545023.477	3.5	4.6	27	17	79.9	1.084
54	417012.063	5545009.248	3.1	4.6	6	3	19.4	1.129
55	417010.002	5544984.904	1.6	3.0	58	48	172.1	1.097
56	417011.943	5544966.075	1.4	2.7	45	38	186.5	1.092
57	417011.061	5544955.561	0.5	1.9	51	48	224.0	1.089
58	417014.215	5544939.563	2.4	4.0	36	32	179.8	1.101
59	417020.608	5544932.424	1.5	3.4	37	33	140.2	1.103
60	417020.454	5544919.843	0.2	1.7	49	44	157.8	1.091
61	417010.756	5544922.446	0.3	1.7	58	52	176.1	1.090
62	417025.447	5544919.278	0.5	1.9	51	46	150.4	1.092
Means			**2.5**	**3.6**	**38**	**30**	**117.1**	**1.098**

Site Specific Management of Potatoes

AARI Project No. 96M979

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ABSTRACT

Potato crops have many characteristics that make them suitable for precision agriculture, such as a high value with costly inputs of pesticides, fertilizer and water. The application of fertilizer and pesticides on potatoes may cause environmental problems and the risks of these can be reduced by using precision farming techniques. This potential for use of precision agriculture technology has not been exploited to any great extent because problems exist which have not been fully resolved. Between 1996 and 1999 a project on the site specific management (or precision farming) of potatoes was undertaken. The goals of the project were to utilize yield monitoring and global positioning technology to generate maps and to measure the variability of the yield of potatoes in a field; to determine the effect of soil type, landscape position, nutrient level, fertility treatments, disease and weeds on the yield of potatoes; to determine yield and variability of crops over several years and relate this to field characteristics and to potato yield and quality; to evaluate the use of remote sensing and digital image analysis to detect nutrient deficiencies and diseases of potatoes; to measure the financial and environmental benefits of site specific management of potatoes; and to measure the movement of nitrogen below the root zone.

A yield monitor was successfully adapted to two farmers' potato harvesters and used to map tuber yields. Difficulties were encountered on parts of fields where soil lumps occurred, usually on areas with a high clay content. Yield maps were also developed from grid sampling. These grid samples were used to determine tuber yield, average tuber size and tuber quality as measured by specific gravity, chipping score and French fry score. Uniformity of irrigation affected tuber size. No relationship was found between chipping and French fry score and the measured factors of soil or water in the field. Grid sampling of the fields also showed variability in soil texture, which was correlated to various soil and plant chemical properties.

Two of six fields had sufficient variability of soil nitrogen to justify the cost of soil sampling and variable rate application. However, petiole NO_3-N in the first week of July was significantly negatively related to 0.0-0.60 m depth of soil clay and was not significantly related to soil NO_3-N. This means it would be more useful for farmers on these fields to base a site specific nitrogen application on soil clay content than on soil NO_3-N content. Soil P was significantly positively correlated to petiole P content but not clay content. Opportunities exist for precision applications of phosphorus particularly on two of the fields that had a history of receiving non-uniform applications of manure. However, phosphorus fertilizer applications based on grid sampling of soil phosphorus should provide some improvement in efficiency of uptake of phosphorus. Potassium levels in the soil from 1997 to 1999 were marginal to adequate on most grid sample sites. In 1997 and 1998 petiole K levels were deficient in the first week of July but became adequate to high in two later samplings. The reason for this is not known. It may be due to lower soil temperatures in early July restricting uptake, rather than the higher soil temperatures in the USA where the standards for petiole K were developed. There is a need to develop local standards for petiole K levels.

Precision fertilizer application is practiced on some potato farms in Canada, but the use of this technology is limited by the cost of soil sampling and analysis to accurately describe the field. If precision agriculture technology is to have widespread adoption in the potato industry, solutions to the obstacles of cost, soil lumps and other problems need to be incorporated into the technology.

INTRODUCTION

Since 1991, Global Positioning System (GPS) technology and yield monitoring equipment has made it possible to develop detailed yield maps of various crops. Farmers in the USA, Canada and Australia are interested in GPS as a means to increase profits by optimizing fertilizer applications. In western Europe, GPS has been used to avoid environmental contamination from excess application of fertilizers and manure. Other computer technology makes it possible to overlay maps of yields, soil or crops and measure relationships between them.

Since 1994, site specific management of cereal and oilseed crops in Alberta has increased steadily. Today, about 300 farmers in Alberta use yield monitors and some of these prepare yield maps of their fields. Site specific management of inputs can be done in a detailed or in a general manner by dividing the field into a few categories (Bouma et. al., 1995). Variable rate inputs can be applied with the assistance of GPS by a programmable fertilizer or herbicide applicator. Prototype irrigation systems have been developed to apply variable rates of water. (King et. al., 1995).

Potatoes are a high value crop requiring a lot of inputs, such as fertilizer, pesticides and irrigation. Potatoes are often grown on coarse textured soils that have low nutrient holding capacity and are high in field variability. Excess nitrogen can delay maturity of the crop and contribute to groundwater contamination. With the use of site specific management zones, with soil texture as a variable, the contamination of water can be reduced (Delgado and Duke, 2000; Whitley et. al., 2000). Insufficient nitrogen will reduce yield and increase the severity of early blight in potatoes. Phosphorus fertilizer applications for potatoes are higher than other crops, which represents an appreciable cost to farmers who are often growing potatoes on rented land. High phosphorus application may cause excess soil phosphorus, the major agricultural factor that contributes to water contamination. This results in the rapid growth and decay of algae in lakes, streams and rivers causing eutrophication and fish death. Recommendations for phosphorus requirements of potatoes by Tindall et. al. (1991) exceed those measured in a precision agriculture experiment by Davenport et. al. (1999). Traditional research under small plot conditions does not account for field variability and is usually conducted on uniform sites. The production of irrigated potatoes in southern Alberta has increased from about 9,000 ha in 1992 to

18,000 ha in 2000 and further increases are expected. If potatoes are grown in a one crop per four years rotation, 72,000 ha will be required or more than 13% of the irrigated land in Alberta. This expansion means fields are being used which are less than optimum for potato production.

Potato processors are concerned about uniform quality of tubers. By controlling storage conditions, processors can alter the sugar content of a storage bin of potatoes to an optimum level for processing. However, this is difficult in a storage bin of potatoes where the original quality is not uniform. For processing, the size and shape of tubers are important. As well, a high specific gravity in potatoes means there is more dry matter for making chips or French fries and the tubers will store well. However, two producers of French fries have encountered problems with some Alberta tubers having excessively high specific gravities, which interfered with processing. Other factors that are detrimental are the presence of disease or hollow heart.

Potato fields are closely monitored during the growing season. Many growers sample leaf petioles and monitor each field on a weekly or biweekly basis for nitrogen nutrition. During the growing season when required, fertilizers are added by fertigation or pesticides are applied to control diseases, insects or weeds. Most observations are based upon repeated sampling of a specific area within the field. The area sampled may only be representative of a portion of the field. Growers need to have some idea of the variability within a field when applying inputs to the field (King et. al., 1999; Verhagen, 1997).

A yield monitor for potatoes consisting of load cells mounted under the harvester belt was first built by Harvestmaster (Campbell, 1999) and tested by the USDA near Prosser, Washington in 1995 (Rawlins et. al., 1995; Schneider et. al., 1997). The harvester position in the field was continually located by means of a differential global positioning system. C. McKenzie and M. Green observed these tests and concluded it merited evaluation on Alberta fields as a means to measure tuber yield and correlate this to soil and crop conditions. Since that time, other yield monitors have been developed consisting of load cells on a weigh wagon (Godwin et. al., 1999) or with a camera and computer to identify tubers from other irregular objects (Wooten et. al., 2000).

OBJECTIVES

1. To use a potato harvester equipped with a yield monitor and global positioning technology to generate maps and to measure the variability of the yield of potatoes in a field;

2. To determine the effect of soil type, landscape position, nutrient level, fertility treatments, disease and weeds on the yield of potatoes;

3. To determine yield and variability of crops over several years and relate this to field characteristics and to potato yield and quality;

4. To evaluate the use of remote sensing and digital image analysis to detect nutrient deficiencies and diseases of potatoes;

5. To measure the financial and environmental benefits of site specific management of potatoes;

6. To measure the movement of nitrogen below the root zone.

DEVIATIONS FROM OBJECTIVES

Remote sensing data with spectral analysis was obtained in the first year (1996) of the project on one field at Hays and in the fourth year (1999) at Hays and Fincastle. In 1997 and 1998 false color infrared imagery data was obtained on two fields. This type of infrared imagery was not useful for detailed analysis. In 1998 satellite multispectral imagery was obtained from Resource 21 and it was not feasible to do detailed analysis.

Yield of potatoes and yields of the previous crops on these fields was only obtained on two fields in 1997. Some of the other crops were sugarbeets for which a yield monitor was not available. Some of the grain was harvested with an older model combine, which was not suitable for attaching a yield monitor. Some grain fields were harvested with a custom operator who was not agreed upon until commencement of harvest. This did not provide an opportunity to install a yield monitor, so these fields were not monitored.

Nitrogen movement below the root zone was difficult to distinguish from residual nitrogen, which was also present in the till parent material. Only estimates of nitrogen movement through the soil profiles could be made.

In 1999, at the Hays site, treatments of compost and manure were applied in strips, to determine whether or not they would affect the incidence of *Rhizoctonia* and scab on tuber surfaces.

Soil Salinity

Using Global Positioning techniques (Cannon et. al., 1994), soil salinity was mapped on a field with an EM38 meter (McKenzie et. al., 1989) in order to compare growth of potatoes to soil salinity (McKenzie et. al., 1997). This method would evaluate the potential of mapping a field for soil salinity and limiting planting of potatoes only on those areas with less than a critical salinity level. A salt tolerant crop could be planted on the remainder of the field. This objective was not included in the original objectives.

RESEARCH DESIGN AND METHODS

Fields Monitored

In April 1996, two cooperating farmers were selected who agreed to provide one potato field each year for four years. Each irrigated field consisted of half a center pivot or 27 to 31 ha. The farmers were using a three-year rotation. This meant in the fourth year the project would return to the field monitored in the first year. The fields for one farm were located about 12 to 13 km south of Hays, Alberta, and fields for the other farm were from 3 to 10 km north of Fincastle, Alberta.

The legal location, soil type, number of grid sampling points, type of irrigation system and variety of potatoes grown for the fields monitored are given in Table 1. A sampling grid was set up on each field (Fig. 1). In 1996, this grid was established in the spring after seeding of potatoes. In 1996, the single soil samples taken were used to determine soil texture and water holding capacity. In the next three years, the grid was established in the fall of the preceding year with a set of composite soil samples from about 12 cores taken before fertilizer was applied. These samples (Table 2) were used to determine texture, water holding capacity and soil fertility. The grid sampling points were located with differential GPS.

The choice of potato cultivars and field practices were left up to the individual farmer cooperators. Field practices and cultivars can be considered as typical for irrigated potato

production in southern Alberta. The cultivars Snowden and Frito Lay 1625 are both chipping types while the Russet Burbank are fryers (Table 2). They are all considered as "late" varieties. Farmer experiences are that Russet Burbank have demonstrated better response to higher nitrogen fertilizer applications thus, they are fertilized more heavily. Frito Lay 1625 are also noted for their extensive rooting (vertical and horizontal) so they may be able to better exploit soil fertility. Farmers used their normal methods of seeding, cultivation, irrigation, pest control and harvest of their potato fields. The farmers' fertilizer applications are given in Table 3. Soil nitrogen, phosphorus, potassium values in 1996 were obtained from the farmers' records and in 1997, 1998 and 1999 were obtained from the grid samples (Table 4) and from the farmers' or fertilizer company's records. Soil phosphorus was determined by the Kelowna method (Van Lorop, 1988) and soil potassium was determined by the ammonium acetate methods in 1999. In 1997 and 1998, soil potassium was determined by the Kelowna method (Van Lorop, 1988), which gives lower values than the ammonium acetate method.

Table 1. Legal location and legal description of potato fields monitored and date first irrigated.

Year/Site	Legal Land Location	Soil Type	First Irrigated	Pivot Irrigated
1996				
Hays	E½ NE 9 12 14 W of 4	from 0-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994
Fincastle	E½ NW 7 11 14 W of 4	Chin light loam Fluvial lacustrine	1956	1984
1997				
Hays	W½ NE 9 12 14 W of 4	from 0-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994*
Fincastle	W½ NW 27 10 15 W of 4	Cavendish loamy sand and dune sand	1956	1987
1998				
Hays	W½ SE 9 12 14 W of 4	from 10-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994*
Fincastle	E½ NW 27 10 15 W of 4 E½ SW 34 10 15 W of 4	Cavendish loamy sand and dune sand	1956	1987
1999				
Hays	E½ NE 9 12 14 W of 4	from 10-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994*
Fincastle	E½ NW 7 11 14 W of 4	Chin light loam Fluvial lacustrine	1956	1984
Vauxhall	S½ SW 5 13 6 W of 4 E½ 5 13 6 W of 4	Clay loam to loam overlying Clay loam to clay till at about 1 m	1921	1995

* pivot converted from high pressure to low pressure in 1997

Table 2. Sampling sites, irrigation systems, field size and variety of potatoes grown.				
Year/Site	**# of grid sampling sites**	**Type of pivot Irrigation system**	**Field area (ha)**	**Cultivar of Potatoes**
1996				
Hays	40	High pressure	28	Snowden
Fincastle	8	High pressure corner	30	Frito Lay 1625
1997				
Hays	47	Low pressure	29	Snowden
Fincastle	53	High pressure corner	31	Russet Burbank
1998				
Hays	48	Low pressure	29	Snowden and others
Fincastle	63	High pressure corner	30	Russet Burbank
1999				
Hays	53	Low pressure	28	Snowden
Fincastle	51	High pressure corner	31	Frito-Lay 1625
Vauxhall	33	2 low pressure	115	Russet Burbank

Soil Moisture and Water Tables

Alberta Agriculture Food and Rural Development (AAFRD) Irrigation Branch staff from Taber and Brooks monitored soil water at each of the grid sampling points with a neutron probe. Soil moisture was determined to a depth of 1.0 m. Available moisture limits were calculated from particle size data according to Oostervelt and Chang (1980). A rain gauge was installed at each sampling point and rainfall and irrigation measurements were made approximately biweekly.

In 1997 and 1998 the groundwater was measured with 3 to 6 piezometer nests in each field (Rodvang, 1998 and 1999). The goal was to characterize groundwater flow and chemistry on the sites and determine whether agricultural nitrate occurred in the groundwater. Soil samples were collected during drilling and groundwater samples were collected during the season.

Fertilizer and Soils

Soil available nitrogen (N), phosphorus (P), and potassium (K) and soil pH maps were made for the 1997, 1998 and 1999 fields based on data collected the previous October from the sampling grid (Table 4). Soil texture maps were made from all fields based on grid samples (Fig. 2), which were used to develop relationships between texture and nutrient availability. In 1999, at Fincastle and Hays, soil calcium carbonate levels were determined and used to prepare maps at both sites.

Fertilizer Treatments

In 1997, 1998 and 1999, strip fertility experiments were set out. In 1997, the treatments (Table 5) applied were centered around the N2 treatment (farmer rate) (Table 3). Each strip was 8 rows or 6.7 m wide on the Snowden field and 8 rows or 7.3 m wide on the Russet Burbank field. In 1998, the fertilizer strips were in addition to the farmers' fertilizer rates (Table 6). Each strip was 6 rows wide or 5.03 m at Hays and 5.49 m at Fincastle. This represented one pass of the potato harvester. Yields were acquired and positioned on the fertilizer strips in 1997 and 1998 with GPS and a yield monitor on the farmers' potato harvesters.

In 1999, fertilizer plots were set out at Hays. Each plot was 12 rows or 10.1 m wide by 400 m long and was replicated twice. Compost manure and fertilizer treatments (Table 7) were broadcast on the plots in October of 1998. The plots were not fertilized by the farmer, except for 41 kg/ha N at seeding and a fertigation application of 50 kg/ha N during the growing season. The potatoes were hilled and seeded by the farmer in April of 1999. Snowden potatoes were grown and the field was fertigated (Table 3) and irrigated similar to the remainder of the field. Counts of visibly diseased plants on 600 m rows in each treatment were made in August of 1999.

Table 3. Farmers' soil fertility (N, P and K) before fertilization and N, P and K fertilizers applied and depth of soil samples (kg/ha).

		Hays (kg/ha)	**Fincastle (kg/ha)**
1996	Soil N Fall 95[?]	(29) 0.0-0.30 m	(73) 0.0-0.60 m
	Fertilizer N prior to seeding	120	59
	Banded N at hilling	34	0
	Fertigated N	58	11
	Total N	**241**	**144**
	Soil P	(35) 0.0-0.30 m	(67) 0.0-0.30 m
	Fert P	48	32
	Total P	**83**	**99**
	Total K not available		
1997	Soil N 0.0-0.60 m	37	67 (52)
	Fert N Fall 96	90	0
	Banded N at hilling	39	179
	Fertigated N	88	41
	Total N	**254**	**287**

Table 3. Farmers' soil fertility (N, P and K) before fertilization and N, P and K fertilizers applied and depth of soil samples (kg/ha).			
		Hays (kg/ha)	**Fincastle (kg/ha)**
	Soil P 0.0-0.15 m 0.0-0.30 m	24	196
	Fert P Fall 96	59	0
	Fert P Spring 97	0	7
	6 fertigations	22	
	Total P 0.0-0.15 m	**195**	**203**
	Soil K 0.0-0.30 m	685	1066 (1935)
	Fert K Fall 96	56	0
	Fert K Spring 97	0	46
	Total K	**741**	**1112**
1998	Soil N 0.0-0.60 m	28	32
	Fertilizer N Fall 97	179	190
	N at seeding	0	20
	N at hilling	47	35
	6 fertigations	50	31
	Total N	**304**	**308**
	Soil P 0.0-0.15 m	41	67
	Fertilizer P Fall 97	58	46
	Fertilizer P at seeding		29
	Total P	**99**	**142**
	Soil Kelowna K 0.0-0.15 m	591	627
	Fertilizer K Fall 97	74	74
	Total K	**665**	**701**
1999	Soil N 0.0-0.60 m	38	90
	Fertilizer N Fall 98	157	112
	Fertilizer N at hilling	41	20
	Fertigations of N	50	30
	Total N	**286**	**252**
	Soil P 0.0-0.15 m 0.0-0.30 m	47 71	93 127
	Fert P Fall 98	59	39
	Fert P Spring	0	29
	Total 0.0-0.15 Soil P	**106**	**161**
	Soil K 0.0-0.30 m	757	733
	Fertilizer K Fall 98	56	56
	Fertilizer K Spring	0	0
	Total K	**813**	**789**

? ( ) soil nutrient values supplied by the farmer from his soil sampling

Table 4. Soil analys is done for the site specific potato project.

Year	Sand (%)	Silt (%)	Clay (%)	NO_3 – N (ppm)	NH4-N (ppm)	Miller Axley PO_4-P(ppm)	Kelowna PO_4-P (ppm)	Ammon Acetate K (ppm)	Kelowna K (ppm)	pH	2:1 extract E.C. (dS/m)	Zn (ppm)	Cu (ppm)	Mn (ppm)	Fe (ppm)	Na (ppm)	CaO_3 (ppm)	S (ppm)
1996 sampled May 26 0.0-0.90 m	†	†	†	-	-	-	-	-	-	-	-	-				-	-	-
1997 sampled Oct.96 0.0-0.90m	†	†	†	†	1/6 of profiles	†	0.0-0.15 m 0.15-0.30 m		0.0-0.15 m 0.15-0.30 m	†	†	1/6 of 0.0-0.15 m samples					Hays	
1998 sampled Oct. 97 0.0-0.90m	†	†	†	†	†	†	0.0-0.15 m 0.15-0.30 m		0.0-0.15 m 0.15-0.30 m	†	†	0/0-0.15 m						
1999 sampled Oct. 98 0.0-0.90 m	†	†	†	†	†	†	0.0-0.15 m 0.15-0.30 m	†	0.0-0.15 m 0.15-0.30 m	†	†	0.0-0.15 m				†	0.0-.15 0.15-0.30	†

† all samples analyzed

Samples were dug from each treatment and treatment yields were determined using a yield monitor and GPS on the farmer's harvester. Disease counts of the amount (%) of tuber surfaces infected with scab and *Rhizoctonia* were determined on 160 tubers from each treatment. Occurrence of disease was not significantly different between treatments so this data is not reported.

Table 5. Nutrients (N, P and K) in kg/ha applied on fertilizer strips in 1997.

	Hays			Fincastle		
Treatment	**N**	**P**	**K**	**N**	**P**	**K**
N1	30	59	50	53	6	41
N2	92	59	50	176	6	41
N3	182	59	50	311	6	41

Table 6. Nutrients (kg/ha) applied in 1998 on fertilizer strips in excess of farmers rate to Hays and Fincastle fields.

Treatment	N	P
N	67	0
P	0	32
NP	67	32
Check	0	0

Table 7. Fertilizer treatments at Hays in 1999.

		Nutrients kg/ha		
Treatment	**T/ha**	**N**	**P**	**K**
High compost	18.1	199	84	174
Low compost	9.8	107	45	94
High manure	26.8	158	82	216
Low manure	12.8	75	39	103
High phosphorus		90	58	0
Low phosphorus		90	20	0

Tissue Samples

Each field was tissue sampled three times at each of the grid points (early July, late July and the second or third week of August). Tissue samples consisted of 45 to 70 petioles taken from the fourth leaf of plants within 5 m of the grid sampling points. All the tissue samples were analyzed to determine NO_3 N, total N, P, Ca and moisture. In 1996 and 1997, 24% of the samples, and in 1998 and 1999, all the samples, were analyzed to determine K, S, Zn, B, Mn, Fe, Mg, Al, Cu, Na (Table 8). These tissue levels were compared to sufficiency limits (Table 9) based on limits used by various Alberta and USA soils laboratories.

Pest Monitoring

Diseases were monitored by walking the fields. Some areas of the Hays fields received excess water and developed water-induced rot of tubers. These areas were not harvested. In 1999 fertilizer, compost and manure treatments were set out as strips on the Hays field. Disease counts were made on two rows from the three 50 meter long strips from each of the two replicates of the treatments. The 1999 Vauxhall and Fincastle fields had very little disease on all fertilizer treatments so no disease counts were made in these fields.

In 1996 to 1998 weeds in all fields were widely dispersed and not clustered so they were not mapped with GPS or remote sensing techniques. In 1999 dense areas of Canada Thistle (*Cirsium arvense*) occurred on the Hays field. The perimeters of some of these GPS areas were mapped with differential GPS, by walking with a backpack unit obtaining correction data from a base station at the edge of the field. These areas were then located on the CASI images of the field.

Remote Sensing

In July 1996, Itres, a commercial remote sensing firm, collected airborne compact spectographic imager (CASI) data on the Hays potato field. Alberta Environment took color infrared photos at a scale of 1:5,000 and 1:10,000 on July 14, 1997, at Hays and Fincastle; July 23, 1998 at Hays and Fincastle and July 23, 1999 at Hays, Fincastle and 1:15,000 photos at Vauxhall. On July 28, 1999, CASI data were taken of the Hays, Fincastle and Vauxhall potato fields by Itres. GPS positions of ground control points were taken and used to prepare georeferenced images.

Tuber Samples

In 1997, 1998 and 1999, two samples were hand dug near each grid point prior to harvest. Each hand sample consisted of four uniformly spaced plants in 1.22 m of row. The farmer at Fincastle used 0.91 m row spacing between rows and the farmer at Hays used 0.84 m spacing between rows. In addition, in 1999, four samples were hand dug from each replicate of each fertilizer treatment.

The potato samples were washed, graded into size categories and weighed to determine yield. Scab and *Rhizoctonia* scores were made on 20 tubers from each sample from Hays in 1998 and both Hays and Fincastle in 1999. Samples were chipped and chipping quality color scores were done on the Hays tuber samples in 1997, 1998 and 1999. Samples were French fried and French fry quality, color and texture scores were done on the Fincastle tuber samples in 1997, 1998 and 1999.

Global Positioning Systems and Yield Monitoring

Global positioning techniques were used to locate points on the grid for sampling tubers (Table 10). At harvest, the potato fields were mapped using a NovAtel GPS and a Harvestmaster yield monitor mounted on the farmer's potato harvester (Campbell, 1999). The NovAtel RT-20 DGPS delivered accuracies of 0.20 m horizontal and 0.30 m vertical. A topographic map was prepared at the same time as the yield map. In 1997, wheat and barley fields were yield mapped using an Ag Leader yield monitor coupled to an Omnistar receiver, with real-time differential corrections from a geostationary satellite service. This system provided accuracies of 0.5 to 1.0 m horizontal and 1.0 to 2.0 m vertical. The Omnistar information was not suitable to use to prepare topographic maps because of the lack of accuracy in the vertical axis.

Soil Salinity

The site at Vauxhall was chosen in 1999 because it contained a range of soil salinity. Potatoes are considered to be moderately sensitive to salinity. In April, prior to seeding the potatoes, the soil salinity in the field was mapped by towing an EM38 salinity meter behind an all-terrain vehicle and positioning it with GPS technology (Cannon et. al., 1994). On July 28 and September 1, 1999, Itres flew over the field and collected CASI data. In late September, 58 points were selected to represent different levels of soil salinity. At each of these sample points, salinity was determined with an EM38 according to McKenzie et. al. (1989). Tuber samples consisting of two 1.22 m lengths of row each with four uniformly spaced plants, were dug at these sampling points. A regression analysis was developed between tuber yields, tuber specific gravity and soil salinity. The CASI imagery was compared to the salinity map.

Table 8. Petiole analysis volume and parameters.

		Sampling date			Analysis													
Year	**Location**	**1st**	**2nd**	**3rd**	**Moisture**	**N**	**Ca**	**P**	**NO_3 N**	**K**	**S**	**Zn**	**B**	**Fe**	**Mg**	**Al**	**Ca**	**Na**
1996	Hays	July 3	July 30	Aug. 20	†	†	†	†	†		?	?	?	?	?	?	?	?
	Fincastle	July 4	July 30	Aug. 20	†	†	†	†	†		?	?	?	?	?	?	?	?
1997	Hays	July 3	July 23	Aug. 12	†	†	†	†	†	†	?	?	?	?	?	?	?	?
	Fincastle	July 7	July 24	Aug. 13	†	†	†	†	†	†	?	?	?	?	?	?	?	?
1998	Hays	July 6	July 22	Aug. 10	†	†	†	†	†	†	†	†	†	†	†	†	†	†
	Fincastle	July 7	July 23	Aug. 11	†	†	†	†	†	†	†	†	†	†	†	†	†	†
1999	Hays	July 7	July 30	Aug. 17	†	†	†	†	†	†	†	†	†	†	†	†	†	†
	Fincastle	July 9	July 28	Aug. 13	†	†	†	†	†	†	†	†	†	†	†	†	†	†
	Vauxhall	July 6	July 27	Aug. 11	†	†	†	†	†	†	†	†	†	†	†	†	†	†

† all samples analyzed

? 1/5 of samples were analyzed

Table 9. Potato petiole nutrient sufficiency levels from three soil/plant analysis labs and levels found in this project.				
	Stage/or time after emergence	**N0$_3$-N (%)**	**P (%)**	**K (%)**
Lab A				
	Vegetative	1.2-1.5	03.0-04.0	7.0-8.0
	Tuber initiation	1.2-1.5	0.25-0.35	7.0-8.0
	Tuber bulking	1.2-1.5	0.25-0.30	6.5-7.5
	Tuber half grown	1.0-1.5	0.20-0.25	6.0-7.0
	Tuber maturing	0.5-1.0	0.15-0.20	3.0-5.0
Lab B				
	+3 weeks	2.5-3.0	0.24-0.44	11.8-13.8
	+9 weeks	1.8-2.3	0.20-0.40	9.8-11.8
	+15 weeks	1.2-1.7	0.16-0.36	7.8-9.8
	Pre-vine kill	0.5-1.0	0.14-0.34	5.8-7.8
Lab C				
	Early season	0.8-1.2	0.12-0.2	9-11
	Mid season	0.6-0.9	0.08-0.16	7-9
	Late season	0.3-0.5	0.05-0.1	4-6
Hays and Fincastle for FL 1625, Russet Burbank or Snowden				
	early July (3rd-7th)	1.4-2.2	0.22-0.62	7-9
	late July (23rd-30th)	1.2-1.8	0.20-0.50	5-7
	mid August (12th-17th)	1.0-1.6	0.16-0.36	3.5-5.5

Table 10. GPS Applications 1996-1999.			
Year/Crop	**Site**	**GPS differential source**	**Monitor**
1996			
Russet Burbank Potatoes	Fincastle	Novatel RT-20 + local base corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
1997			
Russet Burbank Potatoes	Fincastle	Omnistar + geostationary corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
Wheat	Hays	Omnistar + geostationary corrections	Ag Leader
Barley	Fincastle	Omnistar + geostationary corrections	Ag Leader
1998			
Russet Burbank Potatoes	Fincastle	Novatel RT-20 + local base corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
1999			
FL1625 Potatoes	Fincastle	Novatel RT-20 + local base corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
Russet Burbank Potatoes (salinity only)	Vauxhall	Novatel RT-20 + local base corrections	EM38 salinity meter

RESULTS AND DISCUSSION

Soil Moisture, Water Tables and Yields

In 1996, at Hays, potatoes were grown on the east half of a high-pressure pivot (Fig. 3b), which was operated at less than the optimum pressure. This resulted in an uneven distribution of water with excess water applied near the centre and insufficient water applied on the outer parts of the circle. On the same pivot, in the following year, 1997 (Fig. 3a), potatoes were grown on the western half. Meanwhile, the farmer had redesigned his system, converting the high pressure pivot to a low pressure pivot. This new pivot had uneven calibration causing a high application of water on the outer part of the circle and less in the centre. The contrasting distribution patterns from the two years are shown in Fig. 3.

Prior to redesign of the pivot system, excess irrigation near the centre of the pivot caused accumulation of water below the root zone in Hays (1996) (Fig. 4b) while the surface layers (Fig. 4b) had deficient available water, especially in the outer parts of the pivot (30% to 55% of field capacity). These conditions create the possibility for leaching of nutrients below the root zone, waterlogging and increased disease in low areas of the fields. The excess irrigation occurred because the pivot was operating near the center at less than the designed pressure.

In three years, 1997-1999 and six fields, uniformity of irrigation application was a significant factor, influencing yield in four of the six fields. In three fields, Hays 1998 (Fig. 5a), Hays 1999 and Fincastle 1999 (Fig. 5b), total yield significantly increased with increasing irrigation.

Mean tuber weights were increased with increasing irrigation at Hays 1998 (Fig. 6a) and slightly, but not significantly, decreased with increasing irrigation at Hays in 1997 (Fig. 6b).

Irrigation management is one of the critical factors influencing both yield and tuber size. Areas of the field, which received more than average irrigation plus precipitation had increased tuber numbers, reduced mean tuber weights and greater numbers of small tubers, as compared with areas which received less than average irrigation plus precipitation.

At Fincastle in 1996 and in 1999 and on the two halves of a field in 1997 and 1998, corner pivots were used. These pivots did not provide as much water to the corners as the rest of the field. When the corner arm was extended and operating, the remainder of the pivot appeared to have reduced output.

Piezometer measurements of groundwater depth movement and soil NO_3-N content at the Hays site in 1997 (Fig. 7) and Fincastle 1997 (Fig. 8) and 1998 are reported by Rodvang (1998 and 1999). Hays had less than half the NO_3 N than Fincastle. The Hays site was irrigated more than the Fincastle site. Nitrate levels were low at depth but this may be due to reducing conditions, causing denitrification. Once all nitrate is reduced, denitrifying bacteria tend to reduce sulphate to H_2S. The odor of H_2S was present at two of the well sites at Hays in 1997 indicating some sulphate was being reduced (Rodvang, 1998). At some of the wells, the texture was coarse permitting downward movement of water. At Hays, the flow of groundwater occurred from the irrigated field outward to the unirrigated rangeland. Irrigation has caused water table mounding below the sites. Water tables rose during the summer at Hays and reached a peak of 1.2 m below the ground at one site in 1997 and 1.65 m in 1998.

At Fincastle, the irrigation applications generally were less than at Hays. The water table followed the surface topography. In 1997 water table depths ranged from 1.7 to 3.5 m. In 1998 at Fincastle, water table depths varied from 1.5 to 2.5 m below ground level and were over 5 m deep at one of the six sites. Water levels rose during the summer in both years and declined after late August. Vertical hydraulic gradients indicated slight downward flow at most piezometer nests.

In 1997, nitrate was present in soil water at the piezometer sites at levels from 1 to 20 mg/kg at Fincastle. Nitrate levels at Hays were lower, from 1 to 6 mg/kg. Site 6 (R6 in Fig. 7) was located on native range adjacent to the potato field and had almost no nitrate to a depth of 1.5 m. The difference between the nutrient level at this site and the other 5 sites shows the effect of irrigated agriculture for 19 years.

Soil water phosphorus (P) was from 4 to 10 mg/kg at the cultivated Hays replicates (Fig. 9). This was compareble to the Fincastle site, where P ranged from 20 to 40 mg/kg in the 0-0.15 m layer (Fig. 10). The higher levels of P at Fincastle than at Hays was because Fincastle received hog manure applications for a number of years. It is interesting that the P had not move below 0.60 m at the time of sampling.

Soil Fertility

Nitrogen

Nitrogen (N) is the fertilizer used in largest quantities by potato growers and application of 160 to 240 kg of N/ha cost from $100-$150/ha. Site specific applications of N offers possibilities for reduction of costs. Soil nutrient variability was more evident at Fincastle than at Hays. Soil nitrogen was variable on the previous fall samples for the 1997 Fincastle field and to a lesser extent on the 1997 Hays field. The 1997 Fincastle field, for the 0.0-0.60 m depth, had 40% of the sample sites considered to be very deficient, 51% deficient to marginal and 10% adequate to high (Table 11). The farmer applied 179 kg/ha N at hilling and another 41 kg/ha N by fertigation during the growing season. These applications would be anticipated to be in excess of what could be used by the crop in areas of the field that already had 73 and 173 kg/ha soil N and would be expected to reduce potato tuber specific gravity. However, there was no relationship between soil N and specific gravity at the grid sites on the field. The 1997 Fincastle site had 89% of the 0.0-0.60 m soil samples with less than 15% clay, which means excess N could easily move downward. In 1997, Hays had 73% of the sample sites with 31 kg/ha N for 0.0-0.60 m and 26% of the sites with 63 kg/ha N so the whole field was low in nitrogen.

In 1998 at Fincastle in the 0.0-0.60 m layer, 92% of the soil sample sites had less than 5 ppm N (very deficient) with an average of 14 kg/ha N. The remaining 8% (deficient to marginal) had an average of 65 kg/ha N. In 1998 at Hays, 68% of the soil sample sites had less than 5 ppm N and the remaining 32% of the sample sites had between 5 and 7.5 ppm N. The variability at these two fields in 1998 was not sufficient to justify the costs of site specific fertilization of nitrogen.

All the soil sample sites for 0.0-0.60 m at Hays in 1999 were less than 5 ppm N (Table 11). In 1999 at Fincastle the 0.0-0.60 m layer, 90% of the sample sites were very deficient (<5 ppm N),

6% were deficient to marginal (5-15 ppm N) and 4% were high (>20 ppm N). This site would offer possibilities for precision application of N with detailed mapping of soil N. This site had 27% of the 0.60-0.90 m samples with greater than average (165 kg/ha) soil N. The nitrogen at depth is evidence of leaching of nitrogen during previous cropping.

Soil N data collected from grid sampling for two fields for three years indicates only two of the six fields had sufficient variability in soil nitrogen to justify variable rate fertilization. Soil N for 6 fields (Fig. 11b) was not significantly related to petiole NO_3-N on July 3-7. This also indicates that when these fields were grouped together, variable rate application based on soil NO_3-N the previous fall does not offer possibilities for improved nitrogen management. Fincastle in 1997, and perhaps in 1999, had sufficient variability to justify the cost of sampling and analysis to determine soil nitrogen and then to apply variable rates of nitrogen fertilizer. The spatial soil fertility data must be collected before a decision can be made on the feasibility of variable rate fertilization.

Phosphorus

At Fincastle in 1997, soil phosphorus (P) for 0.0-0.15 m was high by Alberta Standards and exceeded 100 kg/ha P for 96% of the grid sample sites and exceeded 168 kg/ha P (20 ppm) for 58% of the sample sites (Table 12). This same field had 88% of the 0.0-0.30 m samples exceeding 200 kg/ha P and 46% of the samples exceeding 320 kg/ha P. The father of the current owners raised hogs from 1964 to about 1975 directly south of the 1997 site and used the 1997 field for spreading hog manure. It is not known how much hog manure was applied or what level the soil phosphorus reached but the subsequent 22 years cropping with little or no phosphorus fertilizer added has not yet reduced the soil P to levels which are environmentally safe. The adjacent field at Fincastle used in 1998 had only 6% of the samples for 0.0-0.15 m with soil P greater than 100 kg/ha.

In October 1998 before fertilizer was applied, the 1999 Fincastle site had high soil P in the 0.0-0.15 m layer (average 117 kg/ha) on the southern 67% of the field and adequate or marginal (average 50 kg/ha P) on the remainder of the field (Fig. 12a). The farmer had spread liquid hog manure on a portion of the field in the fall of 1997. This farmer applied 39 kg/ha P to the entire

field in October 1998 and 29 kg/ha P in the spring of 1999. If phosphorus fertilizer costs $1.25/ kg P, then $1765 could have been saved from not applying P to the part of the field that received hog manure. The farmer's soil sample analysis results were not available from the fertilizer dealer for the fall of 1998 on the 1999 Fincastle field. It is not known if the fertilizer rates were estimated or were based on samples taken on the north end of the field where manure was not applied.

In 1999 at Hays (Table 12) in the 0.0-0.15 m layer, soil P was deficient to marginal on 62% of the field and adequate on 38% of the field (Miller-Axely method of analysis). The Hays fields did not have a history of receiving manure so they were generally lower in soil P than the Fincastle fields, which had received manure.

Potassium

Soil potassium (K) levels in samples from the Fincastle fields (Table 13) were usually adequate and, in a few cases, high. The 1997 field also had 13% of its grid sample sites with high levels of potassium (greater than 300 ppm in the 0.0-0.15 m depth). This appears to be a relic from the hog manure applications made between 1965 and 1974. Tissue potassium was adequate or high on the part of the field that received hog manure. If potassium fertilizer costs $0.55/kg K then $784 could have been saved in 1997 by not applying K to the field. The 1999 Fincastle field also had some sample sites with high levels of K. The sites in 1999 were not related to the portion of the field that received one application of hog manure in 1997. Fincastle sites have received manure applications and have been irrigated since 1956. This is longer than the Hays sites, which have been irrigated since 1978 and have not received manure applications.

The Hays sites in 1997 and 1998 (Table 13) were marginal to adequate in soil K. In 1999, the Hays sites were marginal to high but there was no easily identifiable pattern and the high areas were parts of the outer edge of the field. It does not seem economical to apply site specific applications of K to the Hays fields.

Table 11. Soil nitrogen levels in ppm N (0.0-0.60 m depth) in October of the previous year for grid sample sites grouped by % according to Alberta Agriculture Standards.						
Location	**Year**	**Very deficient**	**Deficient**	**Marginal**	**Adequate**	**High**
ppm		**<5**	**5-7.5**	**7.5-15**	**15-20**	**>20**
Hays	97	73	19	8	0	0
	98	68	32	0	0	0
	99	100	0	0	0	0
Fincastle	97	40	25	26	6	4
	98	92	6	2	0	0
	99	90	2	4	0	4

Table 12. Soil phosphorus levels in ppm P (0.0-0.15 m depth) in October of the previous year for grid sample sites grouped by % according to Alberta Agriculture standards.						
Location	**Year**	**Deficient**	**Marginal**	**Adequate**	**High**	**Very high**
ppm		**<13**	**13-25**	**25-45**	**45-75**	**>75**
Hays	97🗳	34	66	0	0	0
	98🗳	8	60	31	0	0
	🗳	12	79	8	0	0
	99🗳	2	60	38	0	0
	🗳	6	74	21	0	0
Fincastle	97🗳	0	0	4	38	58
	98🗳	20	35	39	6	0
	🗳	6	30	57	8	0
	99🗳	6	16	12	64	0
	🗳	2	24	22	53	0

🗳 Miller Axley method
🗳 Kelowna method

Table 13. Soil potassium levels in ppm K (0.0-0.15 m depth) in October of the previous year for grid sample sites grouped by % according to Alberta Agriculture standards.						
Location	**Year**	**Deficient**	**Marginal**	**Adequate -**	**Adequate +**	**High**
ppm		**0-75**	**75-150**	**150-225**	**225-300**	**>300**
Hays	97† 🗳	0	67	23	9	2
	98🗳	0	38	52	10	0
	99🗳	0	26	39	14	21
Fincastle	97† 🗳	0	0	38	49	13
	98🗳	4	40	36	15	6
	99🗳	0	4	71	16	10

† 0.0-0.30 m depth
🗳 Kelowna method
🗳 Ammonium acetate method

Table 14. Petiole analysis of N, P and K for 1996-99 for 3 dates for potatoes at Hays and Fincastle showing % of samples at adequate level.

	NO_3-N %			P %			K%		
Table 14 a. 1996	**July 3-4**	**July 30**	**Aug. 20**[?]	**July 3-4**	**July 30**	**Aug. 20**[?]			
Adequate level	1.6-2.4	1.2-1.8	0.08-1.4	0.22-0.62	0.20-0.50	0.10-0.30			
Hays % High	2	0	0	0	0	0			
% Adequate	88	26	0	100	20	0			
% Deficient	10	74	100	0	80	100			
Adequate level	1.6-2.4	1.2-1.8	0.10-0.16	0.22-0.62	0.20-0.50	0.16-0.36			
Fincastle % High	0	0	0	0	0	0			
% Adequate	88	0	0	100	63	88			
% Deficient	12	100	100	0	37	12			
Table 14 b. 1997	**July 3-7**	**July 23-24**	**Aug. 12-13**	**July 3-7**	**July 23-24**	**Aug. 12-13**	**July 3-7**	**July 23-24**	**Aug. 12-13**
Adequate level	0.16-.24	0.12-0.18	0.10-0.16	0.22-0.62	0.20-0.50	0.16-0.36	7-9	5-7	3.5-5.5
Hays % High	0	0	0	0	0	0	0	40	67
% Adequate	45	0	0	94	2	0	0	60	33
% Deficient	55	100	100	6	98	100	100	0	0
Fincastle % High	0	8	6	13	55	11	0	94	100
% Adequate	12	17	32	87	39	79	6	6	0
% Deficient	88	75	62	0	6	9	94	0	0
Table 14 c. 1998	**July 6-7**	**July 22-23**	**Aug. 10-11**	**July 6-7**	**July 22-23**	**Aug. 10-11**	**July 6-7**	**July 22-23**	**Aug. 10-11**
Adequate level	0.16-0.24	0.12-0.18	0.10-0.16	0.22-0.62	0.20-0.50	0.16-0.36	7-9	5-7	3.5-5.5
Hays % High	0	0	4	17	0	0	0	67	100
% Adequate	4	12	50	77	21	54	73	33	0
% Deficient	96	88	46	6	79	46	27	0	0
Fincastle % High	3	24	22	0	0	0	0	19	57
% Adequate	21	59	57	76	30	6	33	73	41
% Deficient	76	17	21	24	69	94	67	8	2
Table 14 d. 1999	**July 7**	**July 30**	**Aug. 17**	**July 7**	**July 30**	**Aug. 17**	**July 7**	**July 30**	**Aug. 17**
Adequate level	0.16-0.24	0.10-0.18[?]	0.08-0.14[?]	0.22-0.62	0.18-0.45[?]	0.14-0.34[?]	7-9	5-7	3.4-5.4[?]
Hays % High	9	6	2	0	0	0	80	0	0
% Adequate	46	28	32	85	22	43	20	96	100
% Deficient	44	66	66	15	88	57	0	4	0
	July 9	**July 28**	**Aug. 13**	**July 9**	**July 28**	**Aug. 13**	**July 9**	**July 28**	**Aug. 13**
Adequate level	1.6-2.4	1.2-1.8	1.0-1.6	0.22-0.62	0.20-0.50	0.16-0.36	7-9	5-7	3.5-5.5
Fincastle % High	0	0	6	51	22	55	76	98	2
% Adequate	14	20	29	45	65	41	24	2	92
% Deficient	86	80	65	4	14	4	0	0	6

[?] Standards were adjusted downward because of the late sampling date and Snowden, a mid-season variety, was nearing maturity.

Petiole Analysis

Potato producers routinely take petiole samples from late June through mid to late August. The samples are tested for nitrate nitrogen (NO_3-N) to help producers maintain consistent nitrogen health or to make corrections for insufficient N by fertigating the entire field. Historically, potato producers did not test for phosphorous or potassium status nor did they make adjustments for insufficient P and K. In the last 3 or 4 years, many have also been analyzing for P, K in addition to NO_3-N.

Nitrate Nitrogen

In 1996, petiole NO_3–N (Table 14) was adequate at most of the sites at the time of the first sampling but, despite fertigation with additional N, it decreased and became deficient at the time of the second and third sampling.

In 1997, petiole N at Hays (Table 14b) was adequate on 45% and deficient on 55% of the sites at the time of the first sampling and deficient on 100% of the sites at the time of the second or third samplings. Soil nitrate N was deficient on 92% of the sites (Table 11) the previous October and 77% of the field had less than 15% clay in the 0.0-0.60 m. The field received from 0.37-0.45 m of rainfall and irrigation from June 23 to September 9 (Fig. 3a). The coarse textured soils permitted leaching of nitrogen below the root zone, which meant there was excess moisture.

In 1997, the Fincastle site was deficient in petiole N (Table 14) on 88% of the field in early July to 62% by August 12. Fincastle received about the same amount of irrigation and rainfall as Hays but over a period one week longer than the Hays site (June 24 to September 18). The Russet Burbank potatoes at Fincastle used more water in the latter part of the season than the earlier maturing Snowden potatoes at Hays.

In 1998, petiole analysis on both Hays and Fincastle indicated that the percent of samples that were deficient decreased from highs of 96 and 76 early in July to 46 and 21 by August 10 or 11 (Table 14c). Total soil nitrogen plus fertilizer nitrogen (Table 3) was higher in 1998 than in 1997 and 1996. This may be the reason that the tissue nitrogen did not decline like it did in 1996 and

1997. In 1999 at the time of the third petiole sampling (Table 14d), both Hays and Fincastle had about 66% of the samples deficient in petiole N.

Petiole analysis for nitrogen in the first week of July was significantly correlated with soil N the previous October in three of the six fields monitored, such as Hays in 1999 (Fig. 11a). This was before uniform applications of nitrogen fertilizer. However, petiole nitrate for all fields was not significantly correlated to soil nitrogen (Fig. 11b) and had an r of 0.95. Petiole nitrate was significantly positively correlated to soil clay per cent (Fig. 11c) with an r of 0.45. This means it would be more useful to base a variable nitrogen fertilizer application on soil clay content than on soil nitrogen. The fields chosen for this project had most of the samples with a clay content between 6% and 32% (Fig. 2). This is a lower range clay content than is typical for agricultural soils but it is typical for potato soils. The variability of texture of the soils used in this project may be higher than is typical of soils used for potato production.

Petiole nitrate N was significantly negatively correlated to tuber yield in early July (r = 0.25) (Fig. 11d) and in late July there was no significant relationship between petiole nitrate N and yield (Fig. 11e). In August (Fig. 11f) petiole nitrate N was significantly positively correlated (r = 0.155) to yield. This suggests nitrogen supply may be excessive early in the growing season and deficient later in the season. The areas with higher clay content could be expected to retain nitrogen late in the season, while those areas lower in clay content are subject to loss of nitrogen by leaching. These same areas with a higher clay content, and therefore a higher exchange capacity could be expected to have less soluble nitrogen early in the season, thus lower petiole N content than areas with a lower clay content.

Phosphorus

Tissue P at Hays in 1996 and 1997 (Fig. 13) was adequate in the first week of July and declined rapidly to become 100% deficient in the August samples (Tables 14a and 14b). This same decline did not occur at the Fincastle site, which had a higher level of available soil P (36% of soil sample sites tested marginal or higher) in 1997 as compared to Hays, which had 8% of soil P marginal or higher (Table 12).

In 1998, both fields were mostly marginal in soil P (Table 12) but received high applications of fertilizer P (119 kg/ha Hays and 153 kg/ha at Fincastle, Table 3). Despite these high applications of fertilizer, available tissue P declined by Aug. 10-11 to become 46% deficient at Hays and 94% deficient at Fincastle (Table 14c).

In 1999, in early July, the tissue P levels in the Hays field were mostly marginal (85 %) with some areas (15%) high (Table 14d). The Fincastle field was 51% high and 45% marginal and 4% low. Petiole P levels were high or adequate in the part of the field that had received hog manure. In the remainder of the field, petiole P levels were adequate on July 9 and declined to become deficient or adequate on July 28 and August 13.

Petiole phosphorus on six fields for July 3-7 was highly significantly positively correlated to soil P (Fig. 14a) (r = 0.57**). On the same six fields, petiole phosphorus content was highly significantly negatively correlated to soil clay content (Fig. 14b) (r = 0.32**). This occurs because soil P is tied up in unavailable forms on clay. However, there was no significant correlation between soil P and clay content. In contrast to soil nitrogen, soil phosphorus content can be used as a basis for variable rate application of phosphorus fertilizers. Petiole P was highly significantly positively correlated to yield at all three sampling times (Fig.14c, 14d and 14e). This indicates petiole P was low for optimum yields on these fields.

Potassium

Tissue K analysis was not done in 1996. In 1997, at both Hays and Fincastle, almost all sites were deficient in the first week of July (Table 14). By July 23 and 24 tissue levels increased and by August 12-13 the Hays field had 67% high levels of K and the Fincastle field had 100% high levels of K (Table 14 and Fig. 15). A similar pattern occurred in 1998. In 1997 mean tissue K at Hays was 6.2% July 3, 6.9% July 23 and 6.0% August 12. In 1997 at Fincastle, mean tissue K was 6.5% July 7, 7.5% July 24 and 6.4% August 13. However, in 1999 both Hays and Fincastle showed most of the field with excess levels of tissue K on July 7 and 9 (Fig. 16a) and this decreased to 0% with excess at Hays and 2% with excess at Fincastle by the 13th of August (Fig.16b).

It is not known why these tissue levels in 1997 and 1998 changed so much, in contrast to the standards, which indicate tissue K levels normally decline during the season. Potassium uptake is reduced by low soil temperature. The standards have been developed in parts of the USA where soil temperatures would usually be higher than in southern Alberta. In southern Alberta, June nights are often quite cool.

Tissue K levels at both sites for three years were not significantly related to yield. Apparently these K levels were not appreciably deficient. In another experiment, in 2000 and 2001, field tests with phosphorus fertilizer and compost at a total of 5 locations showed declining tissue potassium levels throughout the season. This problem of petiole K levels deficiencies needs more study in western Canada where soil K levels are usually high but some of the growing season temperatures are lower than required for maximum growth of potatoes.

Fertilizer Treatments

The N_3 treatment (Table 15) at Hays in 1997 gave the highest yield and the potato crop was worth $116/ha more than the N_2 treatment but required $60/ha more nitrogen fertilizer (N fertilizer cost = $0.66/kg) than the N_2 treatment. This increase in yield and value does not account for changes in quality such as low specific gravity, which may occur on the high N treatment. At Fincastle, the N_2 treatment, which was the farmer's rate, showed the highest yield. This N2 treatment also showed losses in nitrogen below the root zone (Rodvang, 1998). In 1998 the nutrients applied (Table 6) were in addition to the farmer's rate (Table 3).

Table 15. 1997 potato yields (t/ha) and gross value on fertilizer strips.

Treatment	**Hays**		**Fincastle**	
	Yield	**Gross value ($/ha)†**	**Yield**	**Gross value ($/ha)†**
N_1	39.2	4140	39.4	4161
N_2	42.5	4488	42.7	4509
N_3	43.6	4604	42.0	4435

† Value is based on 80% marketable at $132/tonne.

At both sites in 1998 (Table 16), the N treatment yielded less than the check or farmer's rate (-4.4% Hays and –7.7% Fincastle). At both sites the NP treatment yielded similar to the check (-0.3% Hays and +1.1% Fincastle). The P treatment at both sites yielded more than the check

(+2.7% Hays and +5.3% Fincastle). These results indicate the farmers are at an optimum rate with respect to nitrogen. Phosphorus rates on these two fields may be low. Both of these fields had high phosphorus fertilizer applications (Table 3) and petiole P levels declined during the season (Table 12).

Table 16. 1998 potato yields (t/ha) and gross value on fertilizer strips.

Treatment	Hays		Fincastle	
	Yield	Gross value ($/ha)†	Yield	Gross value ($/ha)†
N	34.9	3685	33.2	3506
P	38.6	4076	37.8	3992
NP	37.5	3961	36.6	3865
Check	37.6	3970	35.9	3791

† Value is based on 80% marketable at $132/tonne.

In 1999, six treatments were set out at Hays (Table 7) consisting of two rates of compost, manure and phosphorus fertilizer. Disease counts on the foliage of the plants (Table 17) indicated that the low phosphorus treatment had a greater amount of foliar disease than all other treatments. The three high rate treatments also had a lower incidence of foliar disease than their corresponding low rate treatments, indicating an overall benefit of high rates of P, whatever the form, in terms of foliar disease. Because this field has been used a number of times for growing potatoes in the last 10 years, the level of foliar diseases was quite high. *Rhizoctonia* and scab counts were also made on the tuber surfaces. Variability on tuber disease counts was high and disease occurrence on tubers was low so no conclusions can be made regarding the influence of these treatments on tuber disease.

The 1999 Hays field has a history of developing low P levels in petioles in late July and August despite high rates of P fertilizer being applied. The treatments had no significant effect on tuber yields (Table 17) although compost and manure treatments yielded slightly more than the P treatments. Tuber numbers were also recorded for each treatment.

Table 17. Effect of P, compost and manure on tuber yield and size and disease incidence of potatoes – Hays, 1999.

				% surface infected on 160 tubers		% plants affected
Treatments	**Total tuber Wt (t/ha)**	**Medium Tubers (t/ha)**	**Tubers† /1.2 m**	***Rhizoctonia***	**Scab**	**Disease† on 600 m row**
Low P	34.6	30.2	65	0.68	0.75	9.0
High P	36.5	32.5	70	0.32	0.88	7.1
Low compost	40.0	33.3	95	0.82	1.20	6.6
High compost	38.7	35.2	82	0.36	0.57	5.9
Low manure	37.2	34.0	81	0.68	0.57	7.6
High manure	39.8	36.2	75	0.86	0.73	6.1

† significant at 5% level

Pest Monitoring

Weeds

In most fields, the weeds did not occur in large numbers in any one area so they were not suitable for site specific management. In 1999 on the Hays field, there were patches from 10 m to 50 m in diameter, which were heavily infested with Canada Thistle. In late August prior to harvest, the perimeters of some of these patches were mapped with GPS. It was not possible to identify these patches on remote sensed imagery taken on July 28. If accurately identified, these patches of Canada Thistle could be controlled with spot applications of chemicals such as Lontrel (clopyralid) or Roundup (glyphosate). These chemicals are toxic to potatoes so this is an extreme treatment and the herbicides need to be applied precisely. The potential exists for developing an irrigation system, which will provide site specific applications of herbicides, as well as water (Eberlein, 1999).

Disease

Diseases were monitored each year on all fields. Disease incidence was low and diseased plants were scattered. No attempt was made to map disease. Late blight did occur in varying degrees on the fields prior to harvest and it would have been possible to map this disease but it is difficult to distinguish from vine senescence. Disease surveys were done in the middle of August when the incidence of late blight was low.

Insects

Colorado potato beetles were the only insect pest present at sufficient levels to require insecticide application by the farmers. Colorado potato beetles are native to southern Alberta so the problem of resistance to insecticides is not as important as in areas where it only occurs on potatoes. It is not necessary to retain non resistant populations for reproduction in portions of the fields as described by Weisz et. al.(1996). Flescher et. al.(1999) describes how Colorado potato beetle are most dense near the edge of fields thus making them suitable for site specific management. However, due to farmer vigilance and spray programs, the Colorado potato beetles never became a serious problem in any areas of the fields tested, so were not suitable for site specific management.

Remote Sensing

Potato fields are closely monitored during the growing season for the onset of nutrient deficiencies, disease and pests. With respect to nutrients, typically test areas are established in a field and 40 to 50 petioles from representative plants are collected at each sampling date for determination of primarily N but also P and K content (Schaupmeyer, 1992). This method of petiole sampling provides only limited information regarding spatial variability across the whole field and does not provide information suitable for use with variable rate equipment. Remote sensing data offers one source of spatial information suitable for use in site-specific management systems. Digital imaging systems provide the potential to delineate management zones within a field based upon soil characteristics and the detection of crop stresses both in the short and long term (Brisco et al., 1998, Moran et al., 1997). A number of algorithms have been proposed to measure chlorophyll or N content of plants using remote sensing (Table 18). The close correlation between leaf chlorophyll and N availability suggests that chlorophyll content can be use to characterize N status and vice versa (Filella and Peñuelas, 1994). The majority of the algorithms or indices are based upon reflectance in the green (530-600 nm), red (670-680 nm) or so-called 'red-edge' (690-710 nm) normalized to reflectance in the near-infrared (750-900 nm) range of the electromagnetic spectrum. Reflectance at wavelengths above 735 nm is relatively insensitive to chlorophyll or N levels while reflectance at 550 and 690-710 nm is most sensitive. Sensitivity to N stress at 670-680 nm is variable due to the signal being saturated and reflectance reaching a minimum at relatively low chlorophyll levels (Gitelson et al., 1999). The objective within this study was to test, using airborne remote sensing imagery, the suitability of the reported algorithms to estimate petiole-N content in potatoes and examine the spatial information regarding N status across the field.

Table 18. Published algorithms for chlorophyll/N estimation using remote sensing data.

Index	Formula	Citation	CASI bands
Simple ratio			
SR_{800_670}	(R_{800nm}/R_{670nm})		17, 25
SR_{695_430}	$(R_{695nm}R_{430nm})$	Carter 1994	1, 18
SR_{605_760}	(R_{605nm}/R_{760nm})	Carter 1994	12, 23
SR_{695_760}	(R_{695nm}/R_{760nm})	Carter 1994	18, 23
SR_{695_670}	(R_{695nm}/R_{670nm})	Carter 1994	17, 18
SR_{750_705}	(R_{750nm}/R_{705nm})	Gitelson and Merzlyak 1996, Sims and Gamon 2002	19, 22
SR_{750_550}	(R_{750nm}/R_{550nm})	Gitelson and Merzlyak 1996, Lichtenthaler et al. 1996	9, 22
SR_{667_717}	(R_{667nm}/R_{717nm})	Leblon et al. 2001	17, 20
SR_{550_850}	(R_{550nm}/R_{850nm})	Schepers et al. 1996	9, 28
SR_{710_850}	(R_{710nm}/R_{850nm})	Schepers et al. 1996	19, 28
SR_{800_680}	(R_{800nm}/R_{680nm})	Sims and Gamon 2002	17, 25
SR_{735_700}	(R_{735nm}/R_{700nm})	Gitelson and Merzlyak. 1999	19, 21
Pigment specific simple ratio (PSSR)	(R_{810nm}/R_{676nm})	Blackburn 1998	17, 26
Normalized difference index			
Normalized green difference vegetation index (NGVDI)	$(R_{750nm} - R_{550nm})/(R_{750nm} + R_{550nm})$	Gitelson et al. 1996	9, 22
Photochemical reflectance index (PRI)	$(R_{531nm} - R_{570nm})/(R_{531nm} + R_{570nm})$	Gamon et al. 1992	8, 10
Pigment specific normalized difference (PSND)	$(R_{810nm} - R_{676nm})/(R_{810nm} + R_{676nm})$	Blackburn 1998	17, 26
Normalized difference index (NDI_{750_700})	$(R_{750nm} - R_{700nm})/(R_{750nm} + R_{700nm})$	Gitelson and Merzlyak 1994, Sims and Gamon 2002	19, 22
Normalized difference index (NDI_{800_680})	$(R_{800nm} - R_{680nm})/(R_{800nm} + R_{680nm})$	Sims and Gamon 2002	17, 25
Normalized pigments chlorophyll ratio index (NPCI)	$(R_{680nm} - R_{430nm})/(R_{680nm} + R_{430nm})$	Peñuelas et al. 1994	1, 17
Structure-insensitive pigment index (SIPI)	$(R_{800nm} - R_{445nm})/(R_{800nm} + R_{680nm})$	Peñuelas et al. 1995	2, 17, 25
Others			
Modified simple ratio (mSR_{750_445})	$(R_{750nm} - R_{445nm})/(R_{705nm} - R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Modified normalized ratio (mNR_{750_445})	$(R_{750nm} - R_{705nm})/(R_{750nm} + R_{705nm} - 2*R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Optimized soil adjusted vegetation index (OSAVI)	$(1 + 0.16)*(R_{800nm} - R_{670nm})/(R_{800nm} + R_{670nm} + 0.16)$	Rondeaux et al. 199	17, 25
Modified chlorophyll absorption in reflectance index (MCARI)	$[(R_{700nm} - R_{670nm}) - (0.2*(R_{700nm} - R_{550nm}))*(R_{700nm}/R_{670nm})]$	Daughtry et al. 2000	9, 17, 19
Transformed chlorophyll absorption in reflectance index (TCARI)	$3*[(R_{700nm} - R_{670nm}) - (0.2*(R_{700nm} - R_{550nm}))*(R_{700nm}/R_{670nm})]$	Haboudane et al. 2002	9, 17, 19
Plant senescence reflectance index (PSRI)	$(R_{680nm} - R_{500nm})/(R_{750nm})$	Merzlyak et al. 1999	6, 17, 22
Carotenoids	$[4.145*(S_{760nm}/S_{500nm})*(R_{500nm}/R_{760nm})]-1.171$	Chapelle et al. 1992	5, 23
Chlorophyll b	$2.94*[((S_{675nm}/R_{650nm}*S_{700nm})*(R_{650nm}*R_{700nm}/R_{675nm}))]+0.378$	Chapelle et al. 1992	15, 17, 18
Chlorophyll a	$22.735[=(S_{675nm}/S700_{nm})*(R_{700nm}/R_{675nm})] - 10.407$	Chapelle et al. 1992	17, 18

Nitrogen

On July 28, 1999, Itres acquired digital images over the Hays and Fincastle test fields. The image data were acquired over the spectral range 420-965 nm using a Compact Airborne Spectrographic Imager (CASI) at 2 and 3 m resolution. The spectral bands in which data were acquired varied with the resolution from 36 to 48 nm respectively. The image data were radiometrically corrected and geocoded by Itres.

The data were imported into the ENVI? image analysis software package (Research Systems Inc. Colorado, USA) and converted from spectral radiance units (µW cm^{-2} sr^{-1} nm^{-1}) to surface reflectance (%) using the FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) atmospheric correction model (Anon., 2001). The input parameters used in the model are shown in Table 19.

Table 19. Input parameters for the FLAASH atmospheric correction model.

Parameter	**Input**
Latitude/Longitude	49.9867N, 111.8523W
Sensor altitude	2.286 km
Ground elevation	0.786 km
Atmospheric model	Sub-Artic Summer
Aerosol model	Rural
Visibility	40 km

Images of the various chlorophyll/N indices outlined in Table 18 were created using the band math function in the image analysis software. The spatial patterns of the indices across the sites were visually examined and compared to those in the kriged maps derived from the ground based petiole nitrate N samples. The grid sampling points were overlaid on the imagery and the reflectance values under a 3 x 3-pixel window centered over each grid point were extracted for each band and each chlorophyll/N index. The relationship between the various chlorophyll/N indices and the petiole nitrate N values was assessed using correlation and regression analyses.

True colour images derived from the 2 m resolution airborne imagery for both the Fincastle and Hays sites are shown in Fig. 17. Both the 2 and 3 m resolution images were processed but due to the similarity in the information content only the 2 m data will be discussed. The images show differential "greeness" across the fields, particularly in the Hays field. The spatial patterns tend

to correspond to soil texture, particularly in the northern end of the field at Hays and likely results from poorer growth on the coarse textured soils. Consistent with the observation that many of the proposed indices involve reflectance in similar wavebands, the spatial patterns in the images derived for the various indices were similar (Table 18). Only the images showing the spatial variability in the index SR_{550_850} derived from reflectance at 550 and 850 nm are shown (Fig. 18 and 19). Visual comparison of the petiole-N maps derived in Surfer? using the grid point petiole nitrate N data and the index SR_{550_850} shows similarities in the patterns across both fields. Generally, areas of low petiole nitrate N exhibited high values for the SR_{550_850} index.

Fincastle Site

Correlation analysis showed a strong relationship between most of the chlorophyll/N indices and petiole nitrate N for the Fincastle site (Table 20). The strongest relationships were evident with simple ratios involving either reflectance in the green band (550 nm) or the red-edge (700-710 nm) and the near infrared reflectance (750-850 nm). These observations can be attributed to the greater range of chlorophyll/N content to which reflectance at 550 and 700-710 nm responds. The absorption feature at 660-680 nm saturates at relatively low chlorophyll content and thus relative to 550 or 700-710 nm is insensitive to variation in chlorophyll/N.

Hays Site

At the Hays site, visually there were some similarities between the spatial patterns within the image of the SR_{550_850} index and the kriged map of the ground based sampling. The extent of the N deficient areas in the remote sensing image appeared less than in the kriged map. The imagery may provide a more accurate representation of the spatial variability given that each pixel in the remote sensing image represents information from an area of 2 x 2 m on the ground while the ground data is an interpolation from grid points at greater than 100 m apart. Quantitative analysis showed only a limited number of indices were significantly related to petiole nitrate N. The strength of the relationship was poor compared to that at the Fincastle site. The lack of a strong relationship may reflect uncertainty in the georeferencing of the airborne imagery and the sampling sites and the heterogeneity of the crop reflectance in the areas selected for sampling (Deguise et al., 1998).

Table 20. Relationship between the various proposed indices and petiole nitrate N samples.		
Index	**Fincastle**	**Hays**
Simple ratio		
SR800_680	0.751	NS
SR695_430	-0.734	-0.356
SR605_760	-0.781	NS
SR695_760	-0.748	NS
SR695_670	0.449	-0.318
SR750_705	0.820	NS
SR750_550	0.821	NS
SR677_717	-0.639	NS
SR550_850	-0.832	NS
SR710_850	-0.832	NS
SR735_700	0.821	NS
PSSR	0.764	NS
Normalized difference index		
NGVDI	0.809	NS
PRI	0.770	NS
PSND	0.706	NS
NDI750_700	0.809	NS
NDI750_705	0.696	NS
NDI800_680	0.707	NS
SIPI	-0.660	NS
Other		
mSR750_705	0.821	0.326
mNR750_705	0.813	0.308
OSAVI	0.722	NS
MCARI	0.445	-0.298
TCARI	-0.800	-0.317
PSRI	-0.597	
Carotenoids	0.746	NS
Chlorophyll a	-0.448	0.313
Chlorophyll b	-0.674	NS
PSRI	-0.597	NS
NPCI	-0.702	NS
# of Observations	**N=51**	**N=54**

Summary

The results of the study indicated that potato petiole nitrate N could be estimated from remote sensing imagery at one test site but not the other. At the Fincastle site, visually the spatial patterns in the remote sensing derived maps for N levels and those derived from ground based plant sampling were similar. Errors in the overlay of petiole sampling points on the remote sensing imagery may account for the lack of a significant quantitative relationship at the Hays

site. Further studies are being conducted to determine the ability to estimate plant N content using remote sensing techniques.

Soil Salinity

A soil salinity map was made of the additional Vauxhall potato field in 1999 (Fig. 20). This permitted identifying those areas of the field where problem levels of salinity occurred. Tuber samples in these areas were compared to measurements of electrical conductivity (E.C.) calculated from EM38 readings and a tolerance of potatoes to salinity was developed for this field (Fig. 21a). A 50% yield reduction of potatoes occurred at an E.C. of about 6 dS/m. This method is suitable for precision applications to potato production. A salinity tolerance limit and a salinity map means it is then possible to identify those areas where it is not feasible to grow potatoes. Specific gravity of tubers was found to be higher in saline soils than non-saline soils (Fig. 21b).

CONCLUSIONS

A yield monitor was successfully adapted to two farmers' potato harvesters. Maps of tuber yields were developed based on data collected from the harvester. Difficulties were encountered on parts of fields where soil lumps occurred. These lumps usually occurred on areas with a high clay content and resulted in false high yield readings from the mass-based yield sensor. This will be a major restriction to yield mapping of potatoes unless technology can be developed to separate tubers from soil lumps on the harvester belt.

Yield maps were also developed from grid sampling. These grid samples were used to determine tuber yield, average tuber size and tuber quality as measured by specific gravity, chipping score and French fry score. Uniformity of tuber quality is a major concern of processors. Uniformity of irrigation affected tuber size. No relationship was found between chipping and French fry score and the measured factors of soil or water in the field.

Grid sampling was used to develop numerous maps of irrigation and precipitation, consumptive water use, soil texture and nutrient contents, plant petiole (tissue) nutrient contents and the tuber characteristics just described.

Grid sampling of the fields showed variability in soil texture. Most of the fields contained about 6 to 30% clay with a few sites with as much as 40% clay. The texture was correlated to various soil and plant chemical properties.

When yield mapping with differential GPS using a base station in the corner of the field, accurate topographic maps could be developed. When differential corrections were obtained from a geostationary satellite service, the vertical accuracy was no longer suitable for confident topographical mapping.

Soil levels and fertilizer applications of nitrogen by the farmers were in most cases equal to what a crop of potatoes yielding 50 t/ha would be anticipated to take up. No allowance was made for release of nitrogen from soil organic matter. Tissue nitrate levels were frequently deficient according to standards used by Alberta potato growers. Two of six fields had sufficient variability of soil nitrogen to justify the cost of soil sampling and variable rate application. However, petiole NO_3-N in the first week of July was significantly negatively related to clay content (0.0-0.60 m) and was not significantly related to soil NO_3-N. This means it would be more useful for farmers on these fields to base a site specific nitrogen application on soil clay content than on soil NO_3-N content.

Soil P was significantly positively correlated to petiole P content. Soil P was not significantly correlated to clay content or other easily-measured soil characteristics. Opportunities exist for precision applications of phosphorus particularly on two of the fields that had a history of receiving non-uniform applications of manure. Thus, in the absence of any easily-measured factors that are correlated to P, a strategy of phosphorus fertilizer applications based on grid sampling of soil phosphorus should provide some improvement in efficiency of uptake of phosphorus.

Potassium levels in the soil from 1997 to 1999 were marginal to adequate on most grid sample sites. In 1997 and 1998 petiole K levels were deficient in the first week of July but became adequate to high in two later samplings. The reason for this is not known. It may be due to lower soil temperatures in early July restricting uptake, rather than the higher soil temperatures in the USA where the standards were developed. There is a need for research that will develop local standards for petiole K levels.

Diseases and insect pests were examined but their occurrence was very infrequent and highly variable, thus not predictable or manageable with site specific technologies. Weeds were carefully managed by farmers thus fields were too weed-free to allow for examination of the usefulness of site specific management for weed control. The sites used in the trials, like most potato fields, were extremely flat, which eliminated the opportunity for relating landscape position to potato yield.

Economic analysis indicated that grid sampling and site specific applications of P and K, on a field that received uneven manure applications, would have realized significant savings.

Remote sensing imagery was successful correlated to plant petiole NO3-N at one test site but not the other. Errors in the overlay of petiole sampling points on the remote sensing imagery may account for the lack of a significant quantitative relationship at the Hays site.

Piezometers were used to measure groundwater depth movement and soil NO_3-N content at the Hays (1997) and Fincastle (1997, 1998) sites. Overall, nitrate levels were low at depth but this may have been due to reducing conditions, causing denitrification. At the Hays site, flow of groundwater occurred from the irrigated field outward to an unirrigated rangeland. Irrigation has caused water table mounding below the sites and water tables rose during the summer at the Hays site.

FIGURES

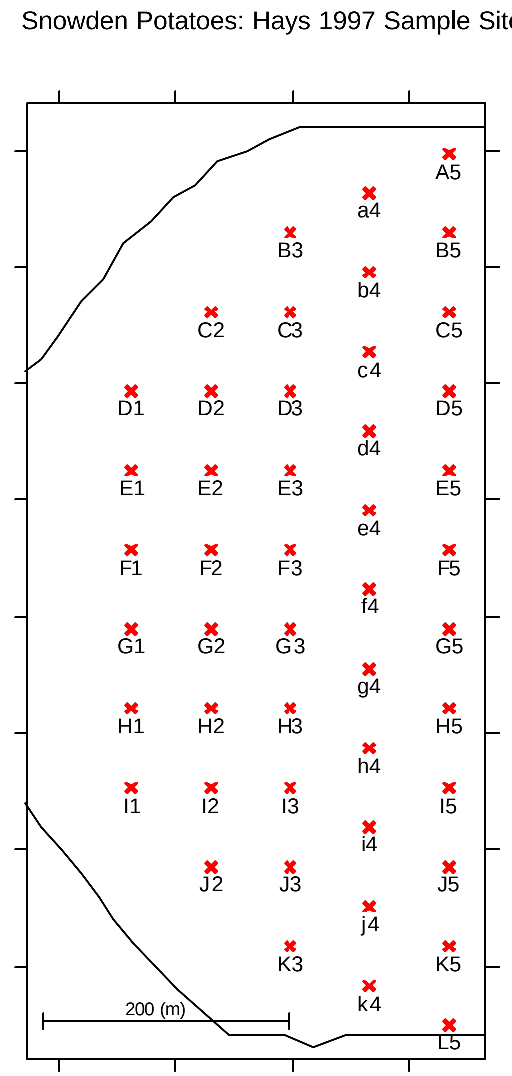

Figure 1. Sampling grid for yield, petioles, water and soil samples for Snowden potatoes grown at Hays in 1997.

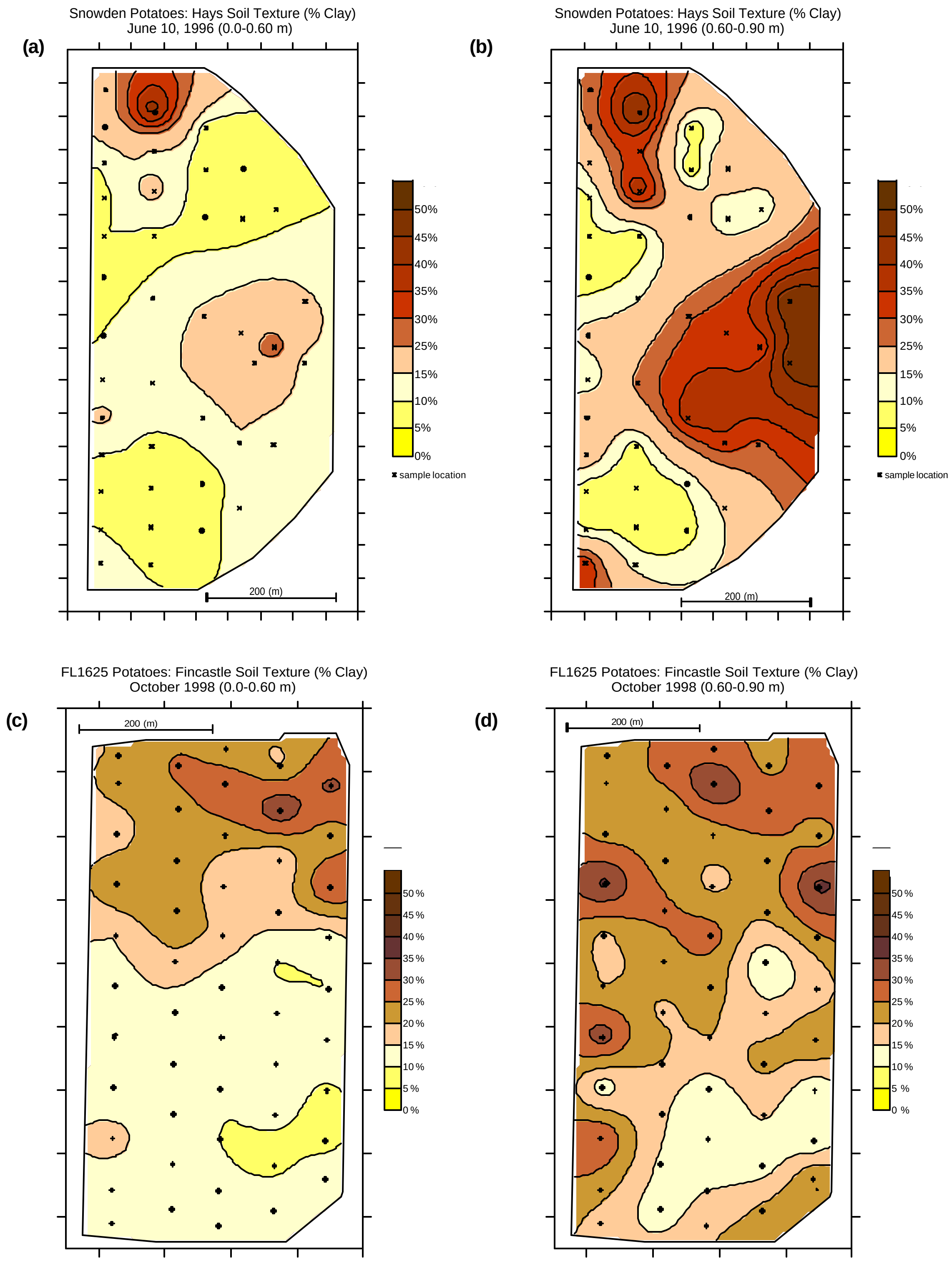

Figure 2. Soil texture maps of Hays 1996 (a and b) and Fincastle 1999 (c and d) fields for two soil depths 0.0-0.60 m and 0.60-0.90 m.

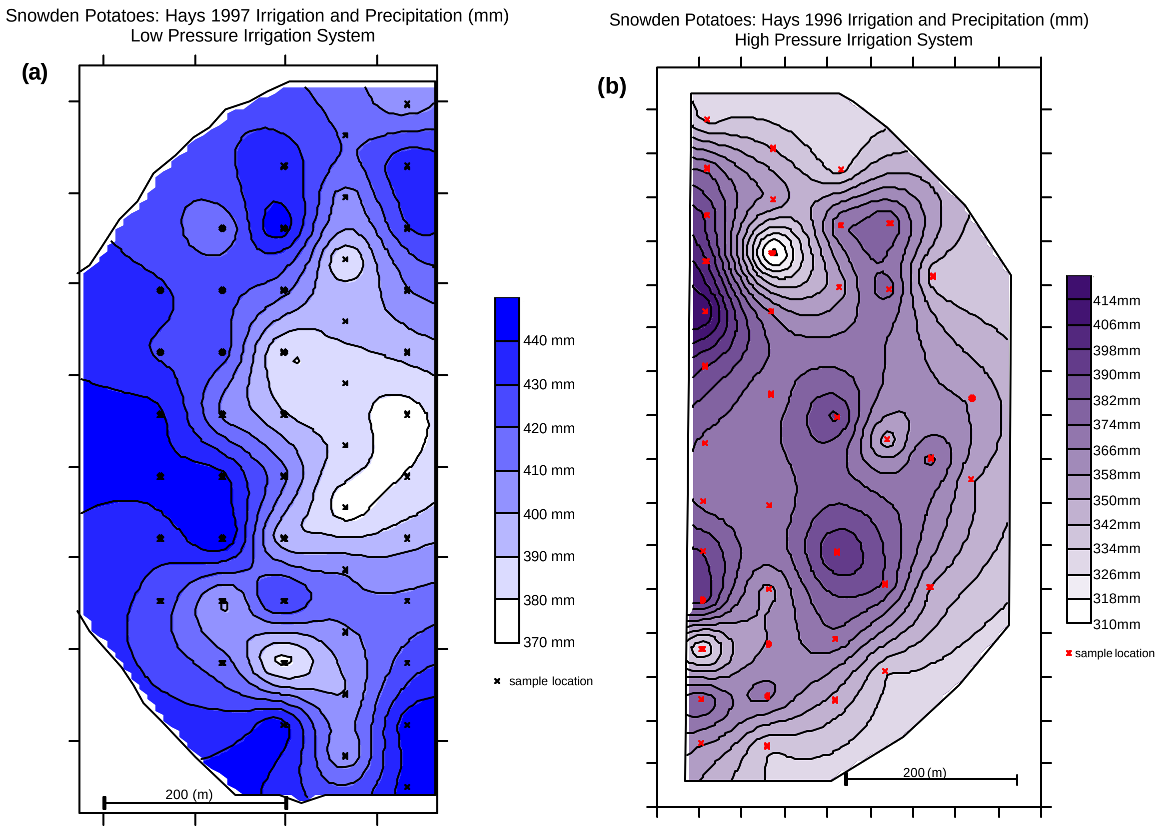

Figure 3. Change of sprinkler design causing contrasting distribution of irrigation and preciptation at Hays in 1997 west (a) and 1996 east (b).

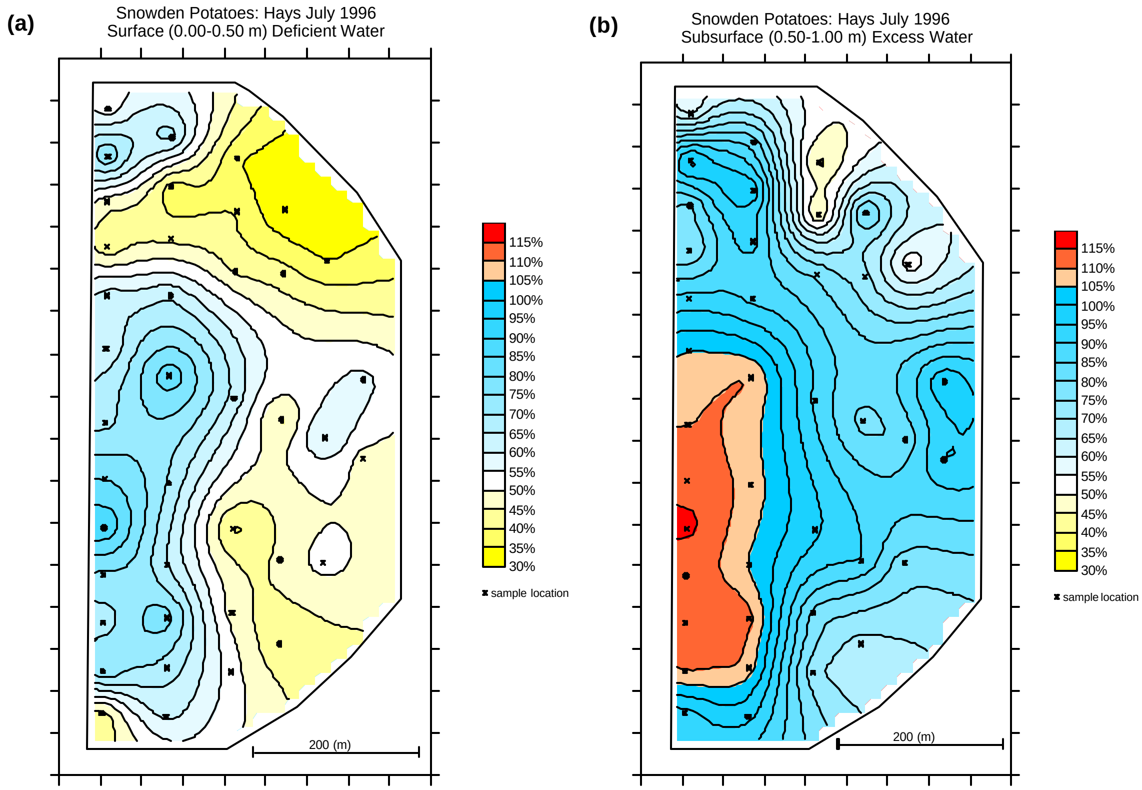

Figure 4. Percent of available moisture (100% = field capacity) in 1996 at Hays for (a) 0.0-0.50 m and (b) 0.50-1.00 m.

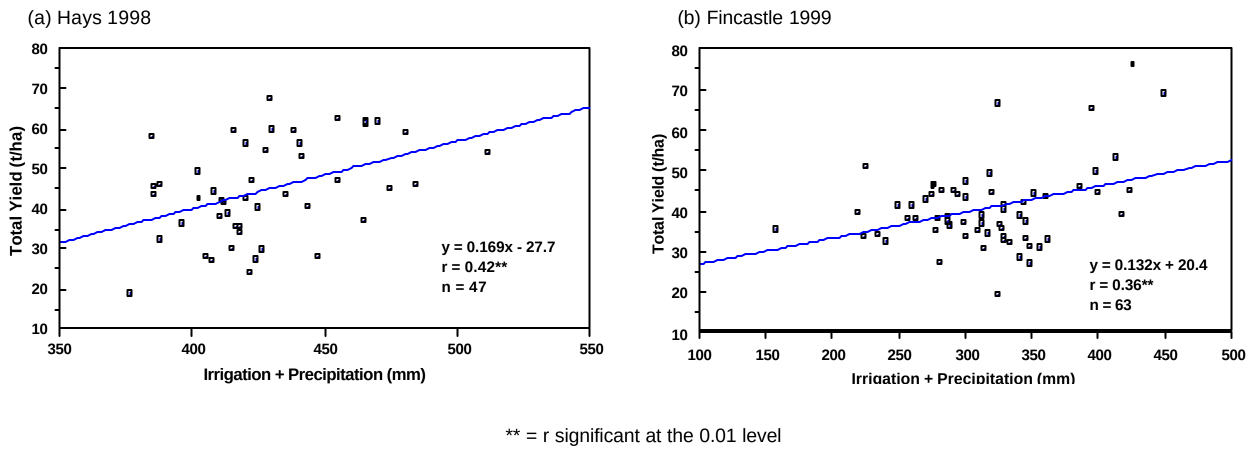

Figure 5. Correlation between total potato yield and total added water (irrigation + precipitation) at (a)Hays 1998 and (b)Fincastle 1999.

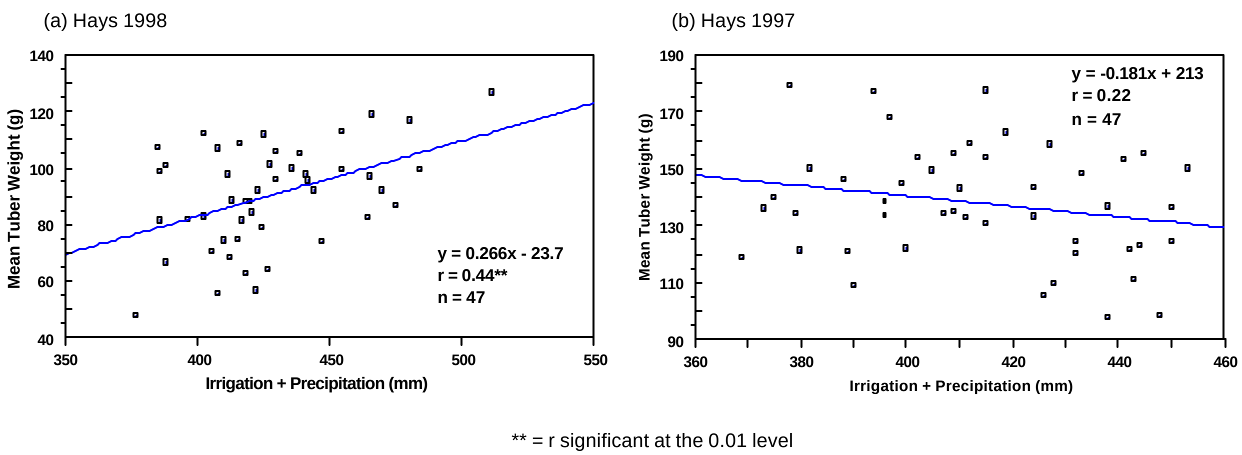

Figure 6. Correlation between mean tuber weight and total added water (irrigation + precipitation) at (a)Hays 1998 and (b)Hays 1997.

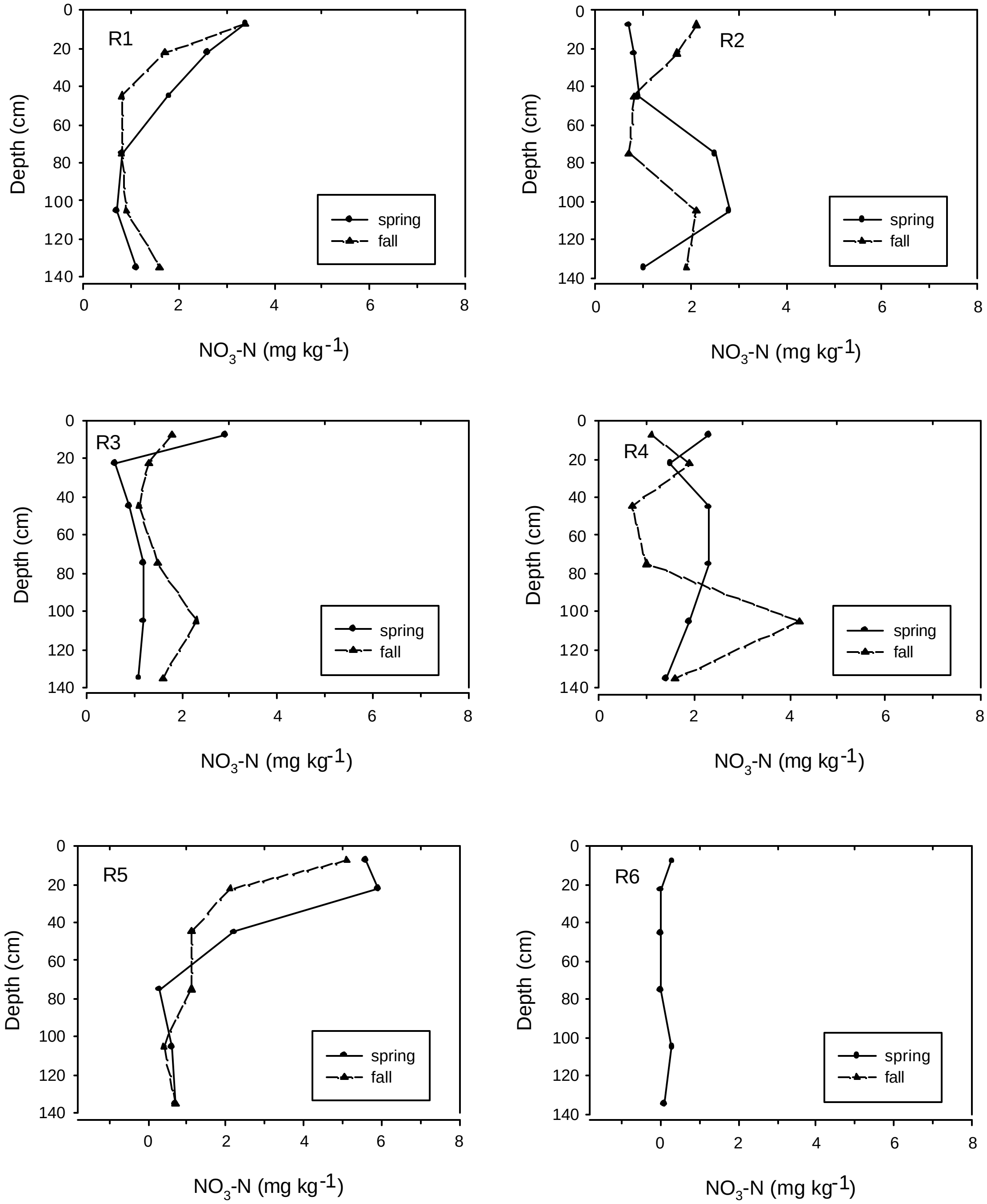

Figure 7. Soil NO_3-N at piezometer sites from 1997 at Hays.

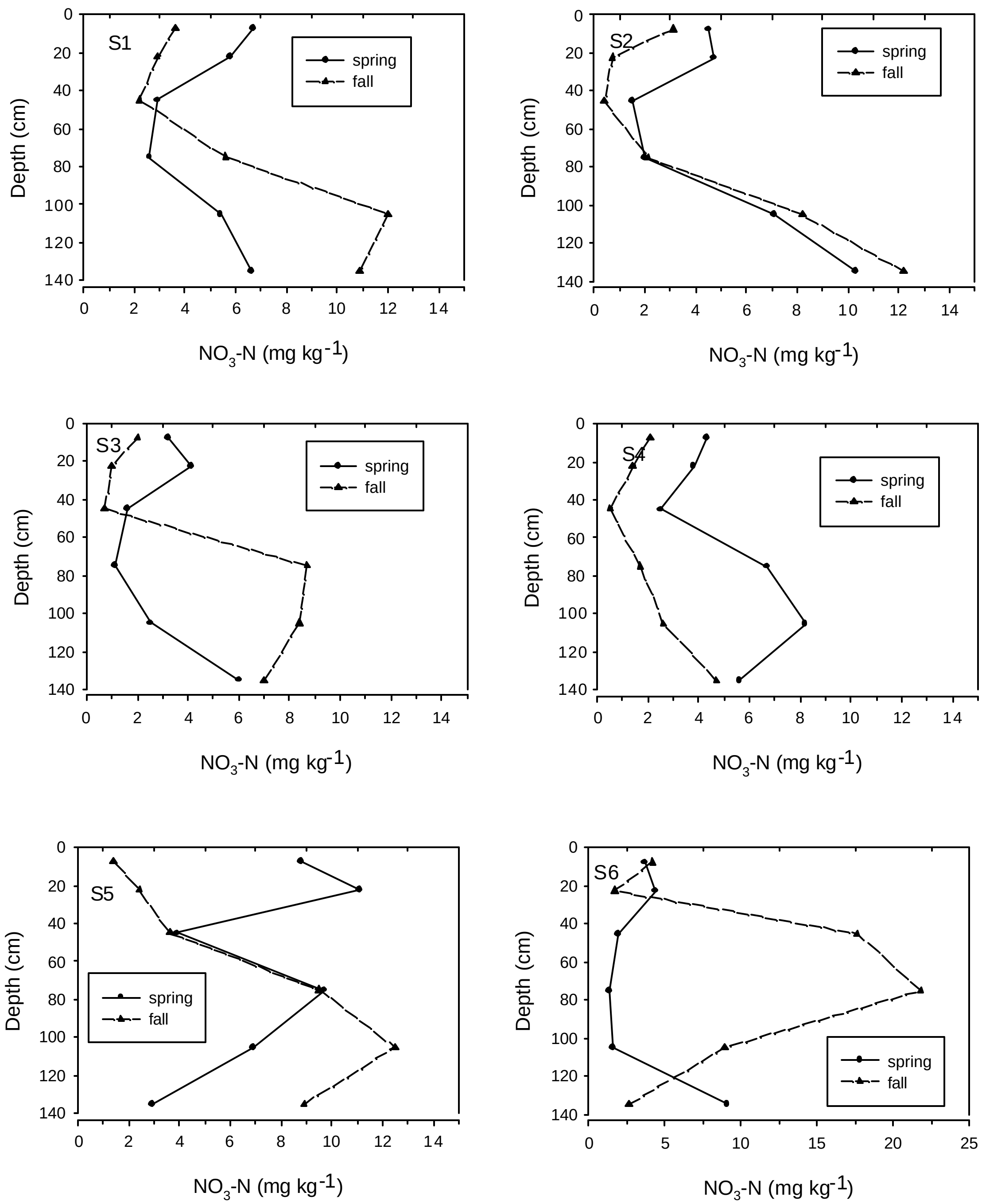

Figure 8. Soil NO_3-N levels at piezometer sites from 1997 at Fincastle.

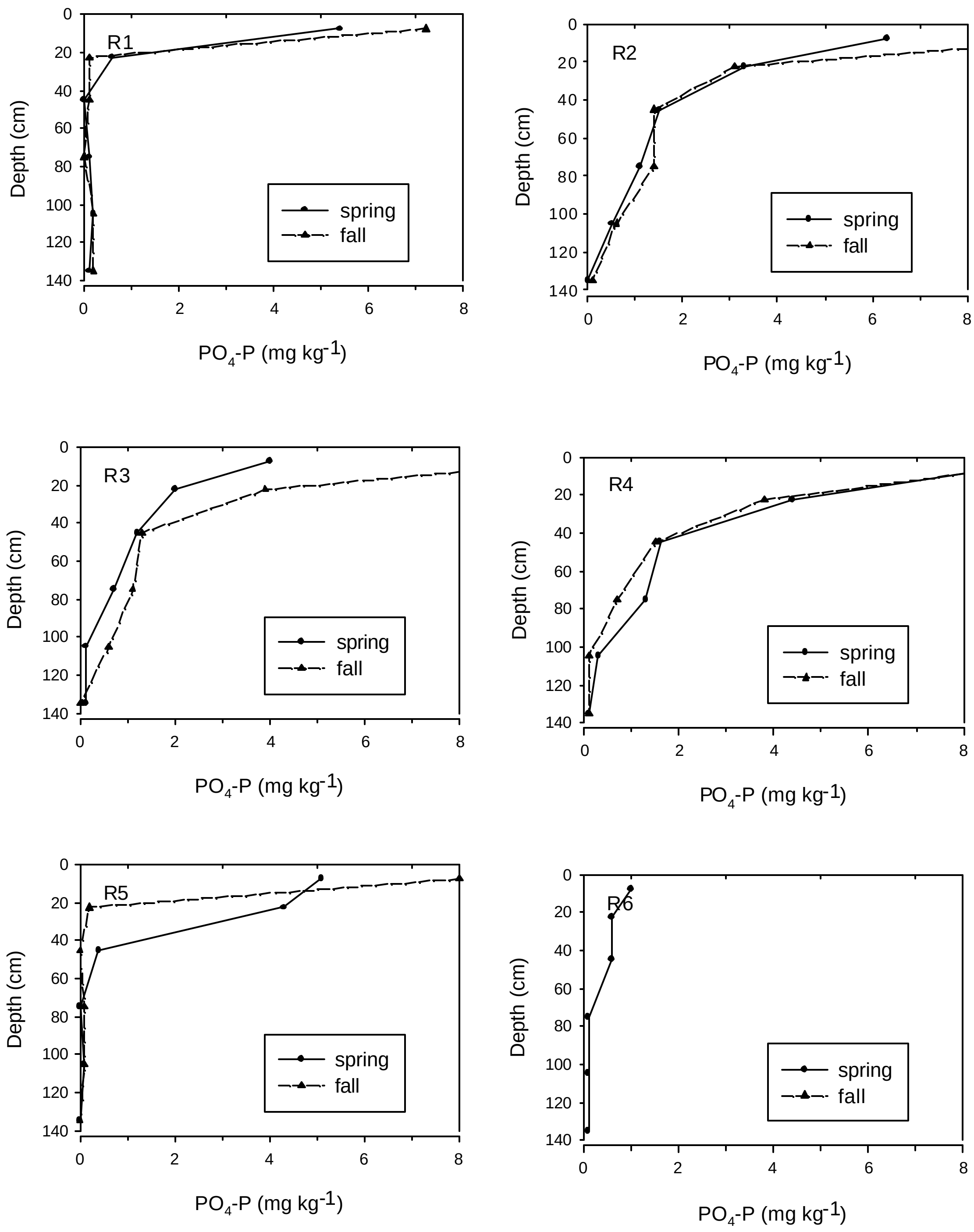

Figure 9. Soil PO_4-P at piezometer sites from 1997 at Hays.

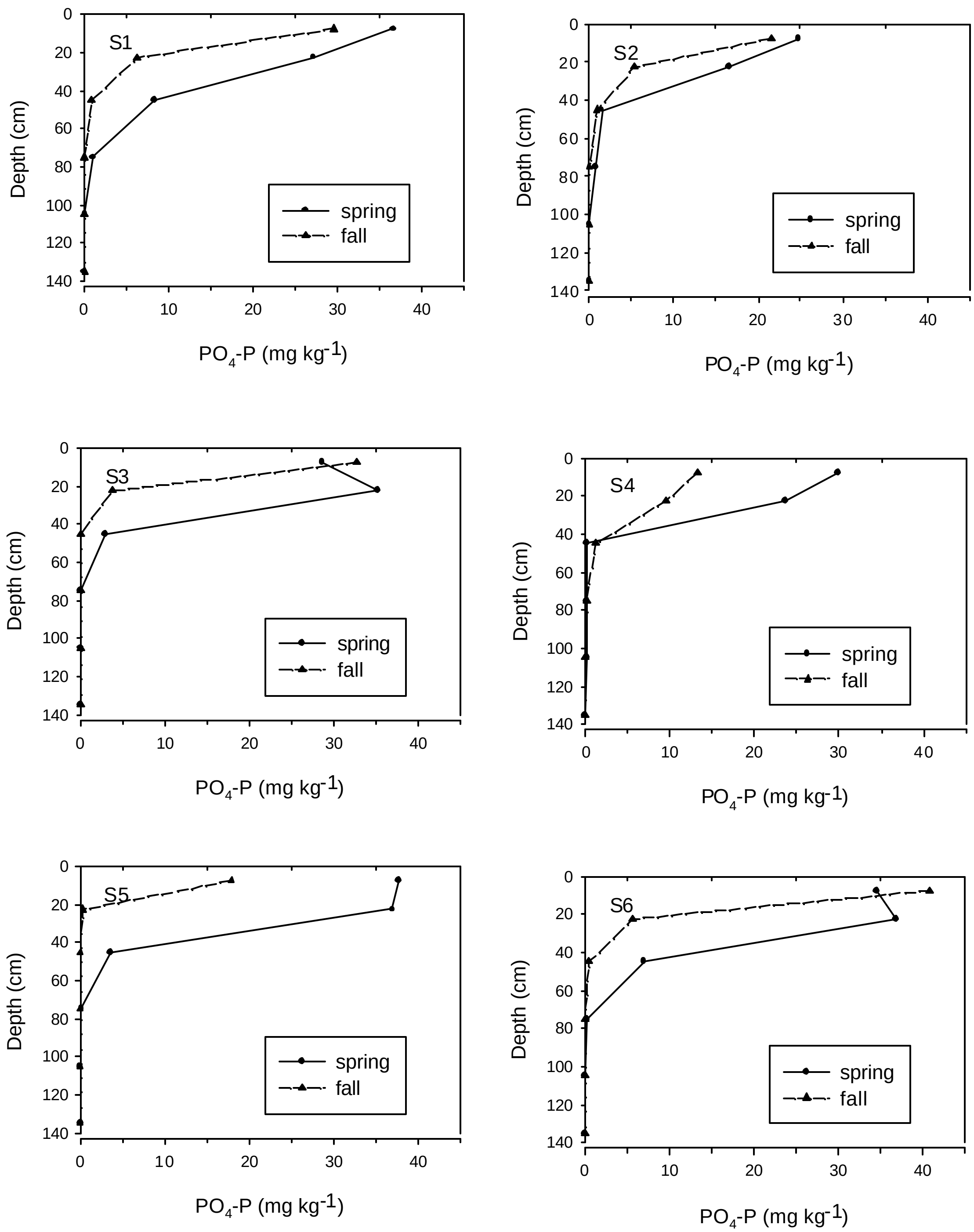

Figure 10. Soil PO_4-P at piezometer sites from 1997 at Fincastle.

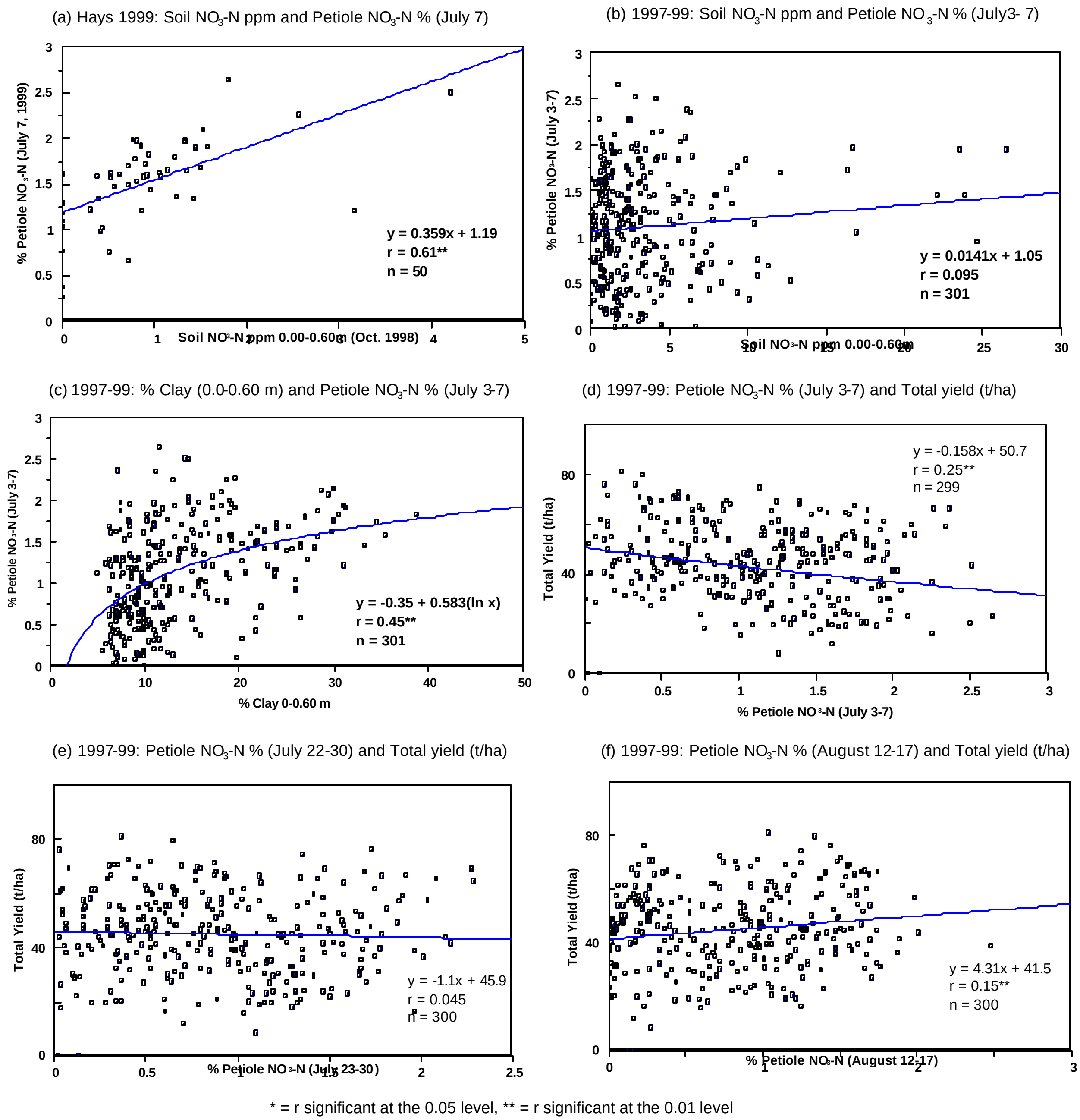

Figure 11. Correlation between potato petiole NO_3-N and (a) soil NO_3-N for Hays 1999 and (b) soil NO_3-N, (c) soil clay and (d, e and f) total yield for Fincastle and Hays potatoes 1997-1999.

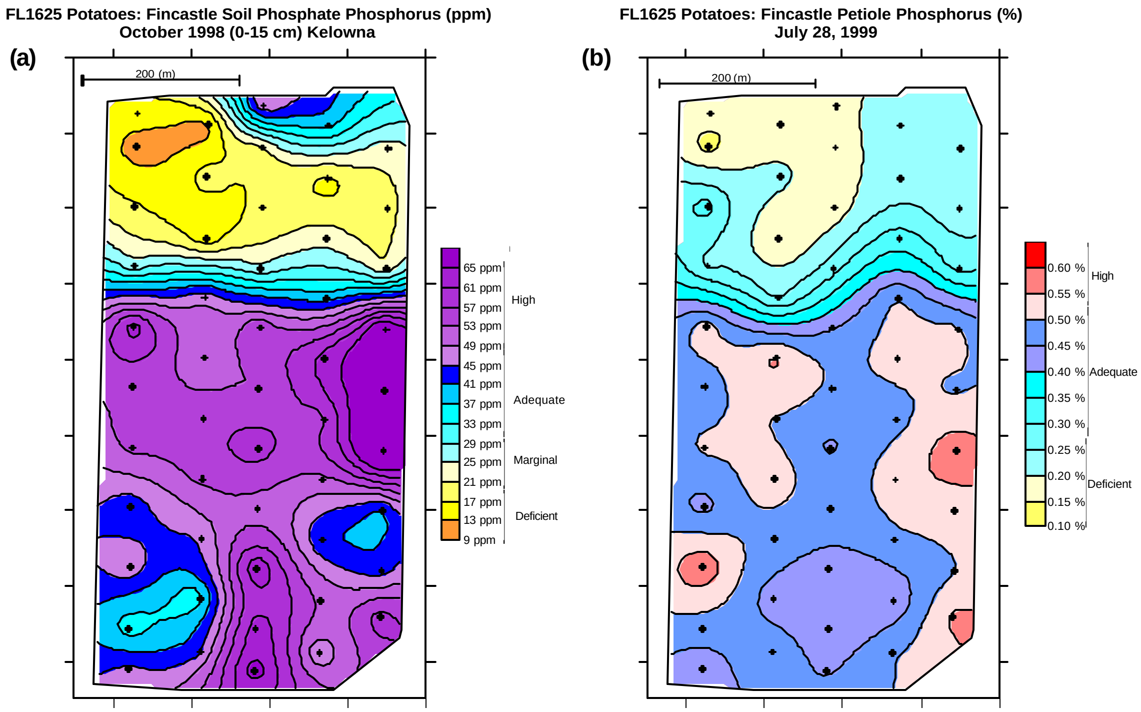

Figure 12. Fincastle (a) soil PO_4-P (October 1998, 0.00-0.15 m) and (b) petiole P (July 28, 1999) for a field which was partially fertilized with hog manure October 1997.

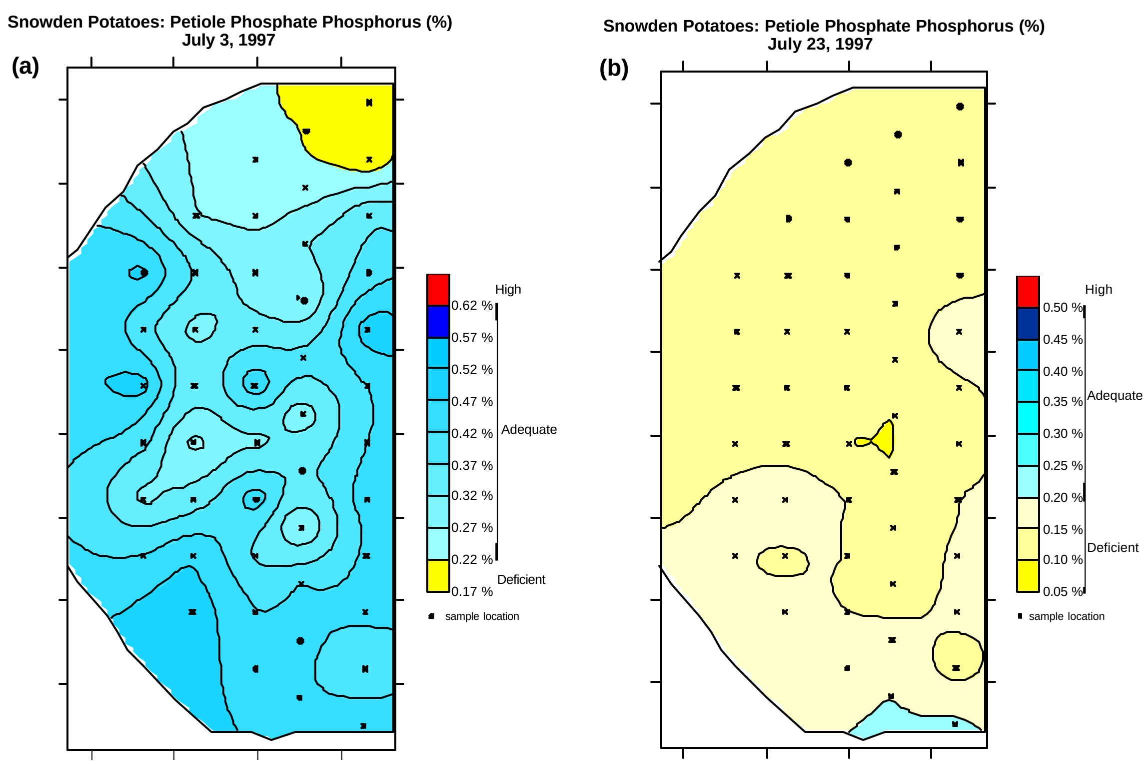

Figure 13. Petiole P levels at Hays (July 1998) showing rapid decline of petiole P from (a) July 3 to (b) July 23, 1997.

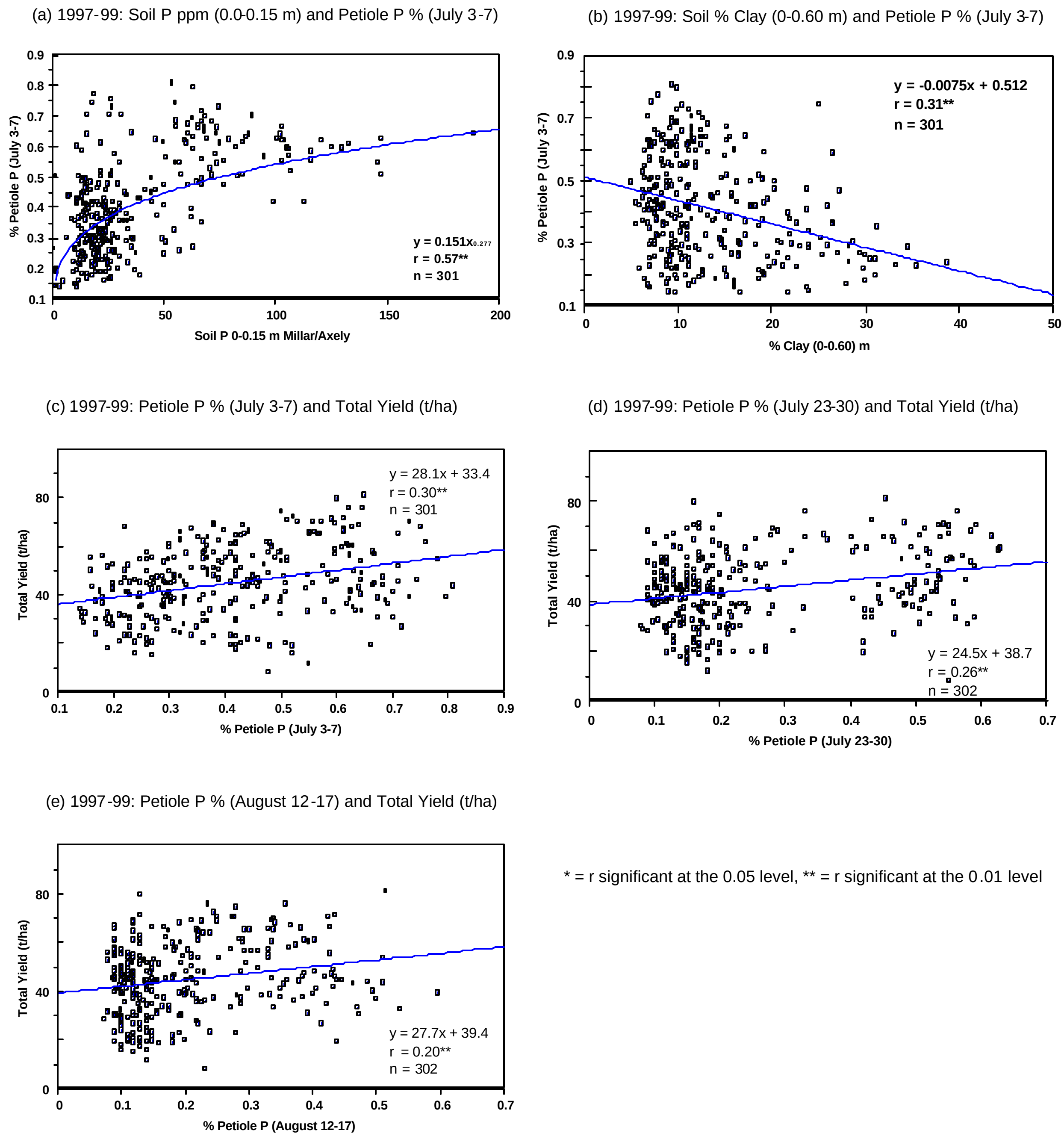

Figure 14. Correlation between potato petiole P and (a) soil PO_4-P, (b) soil clay and (c, d and e) total yield for 3 sampling dates at Hays and Fincastle for 1997-1999.

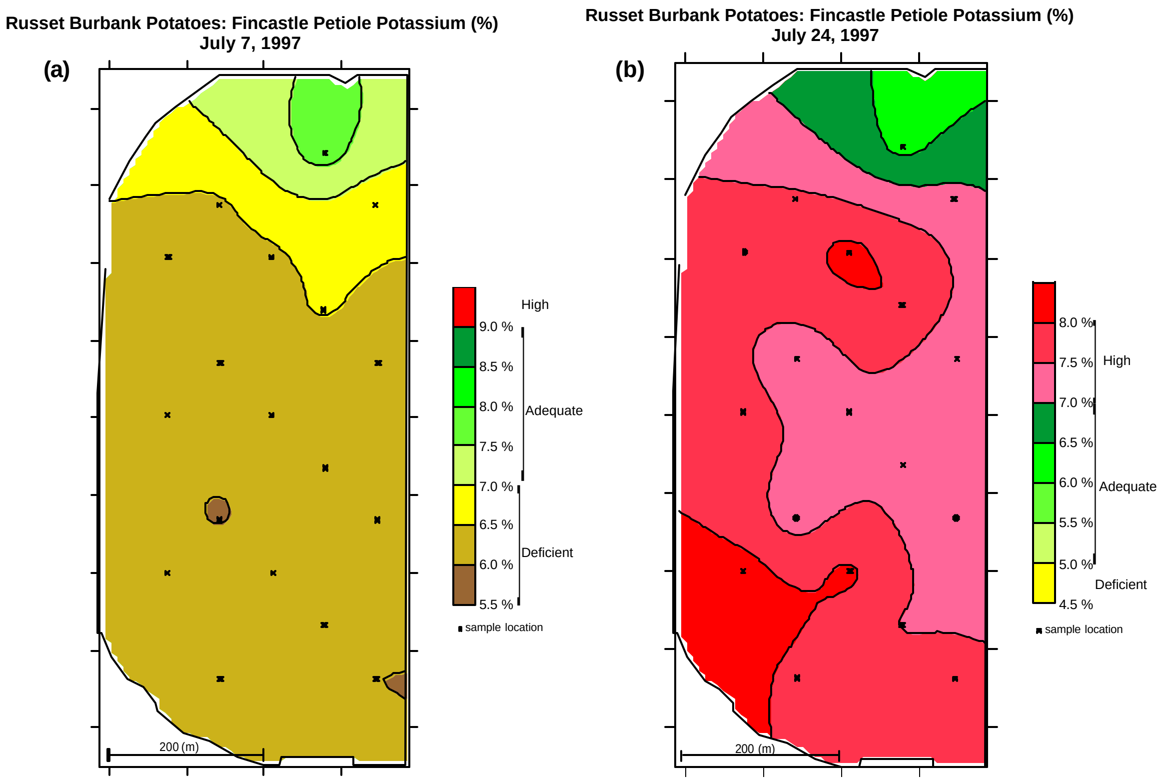

Figure 15. Petiole potassium showing an increase of percent K from (a) July 7, 1997 to (b) July 24, 1997 at Fincastle.

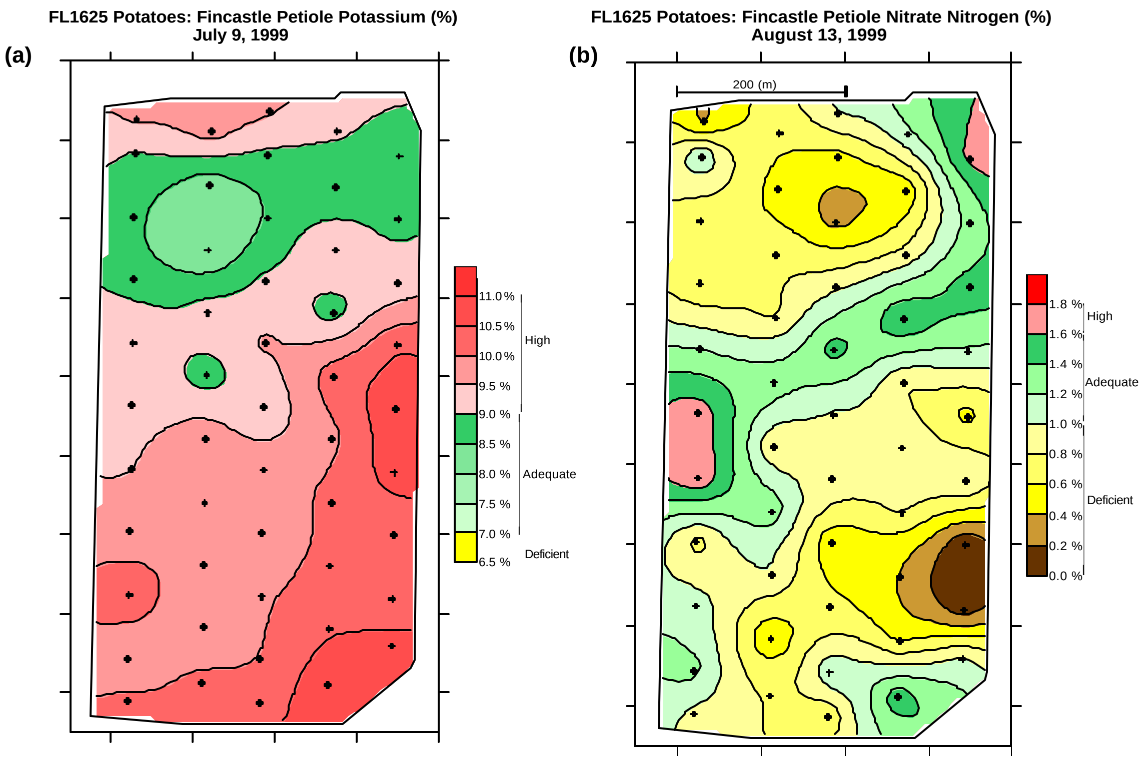

Figure 16. Petiole potassium showing a slight decrease of percent K from (a) July 9, 1999 to (b) August 13, 1999 at Fincastle.

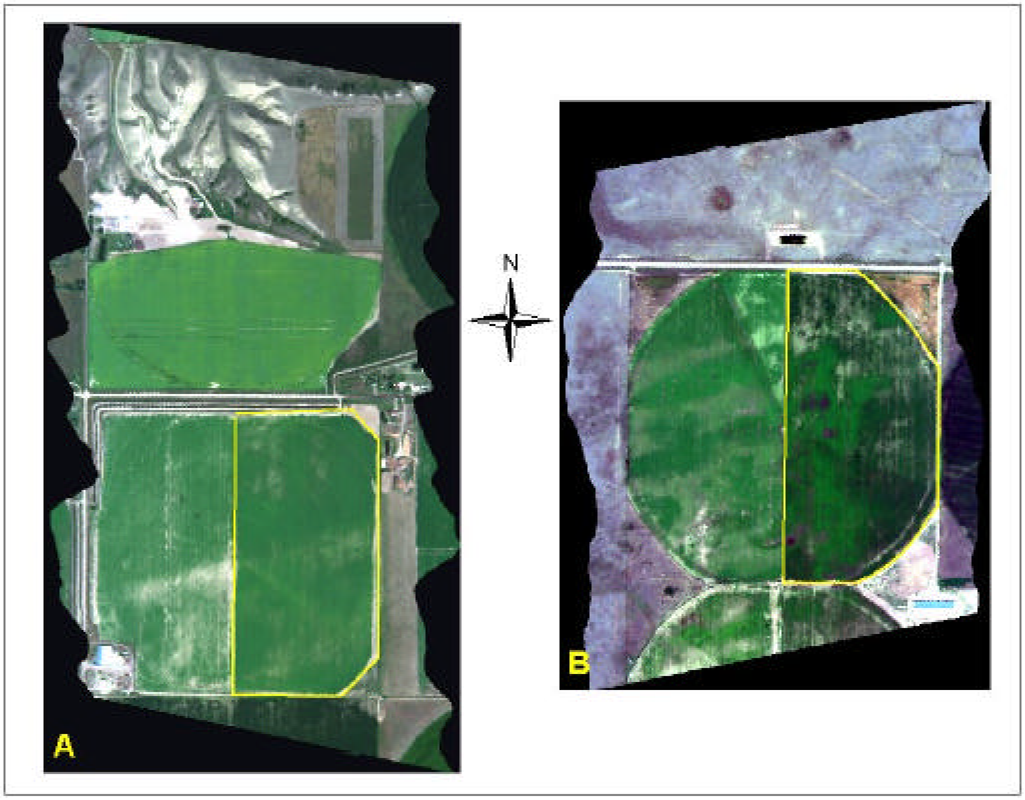

Figure 17. True colour composite images acquired July 28, 1999 at the (a) Fincastle and (b) Hays sites.

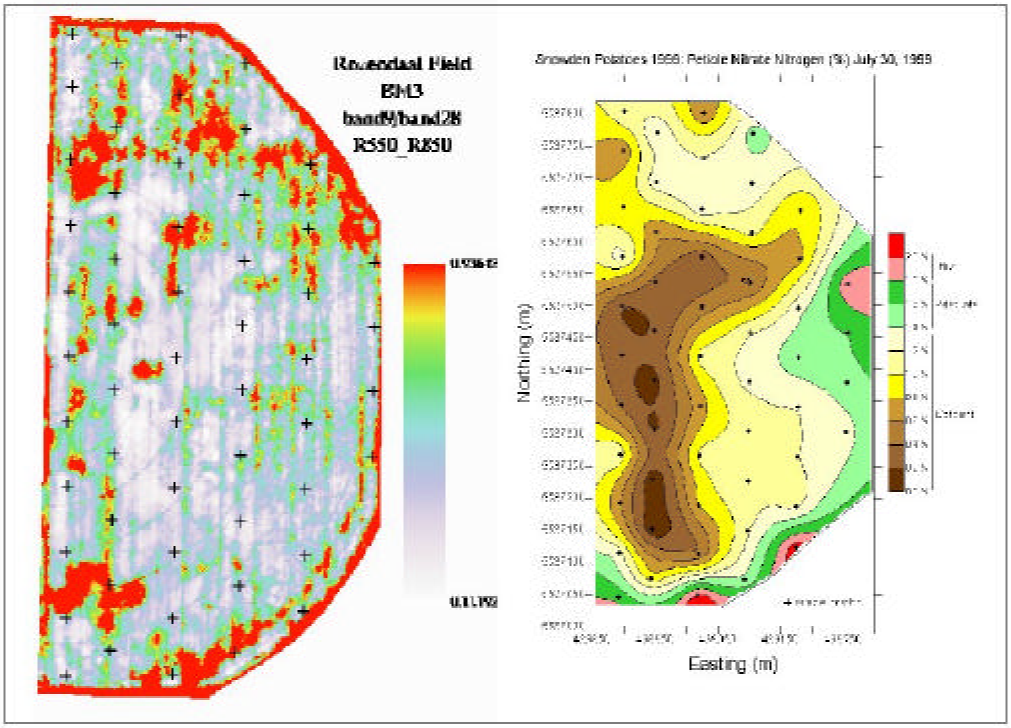

Figure 18. Fincastle site SR_{550_850} index image and petiole N map (July 28, 1999) derived from ground-based sampling.

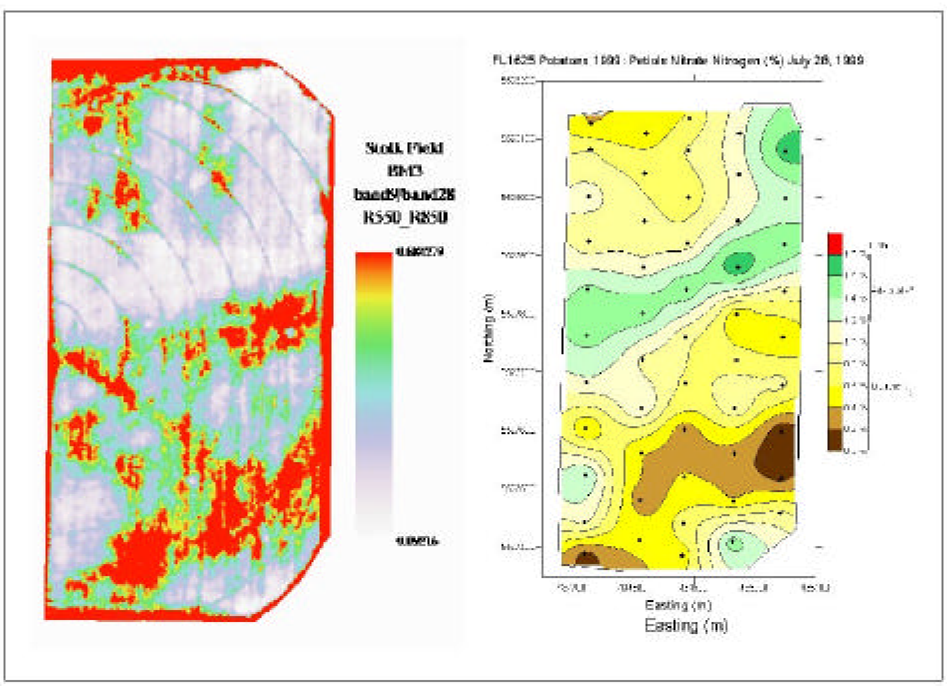

Figure 19. Hays site SR_{550_850} index image and petiole N map (July 30, 1999) derived from ground-based sampling.

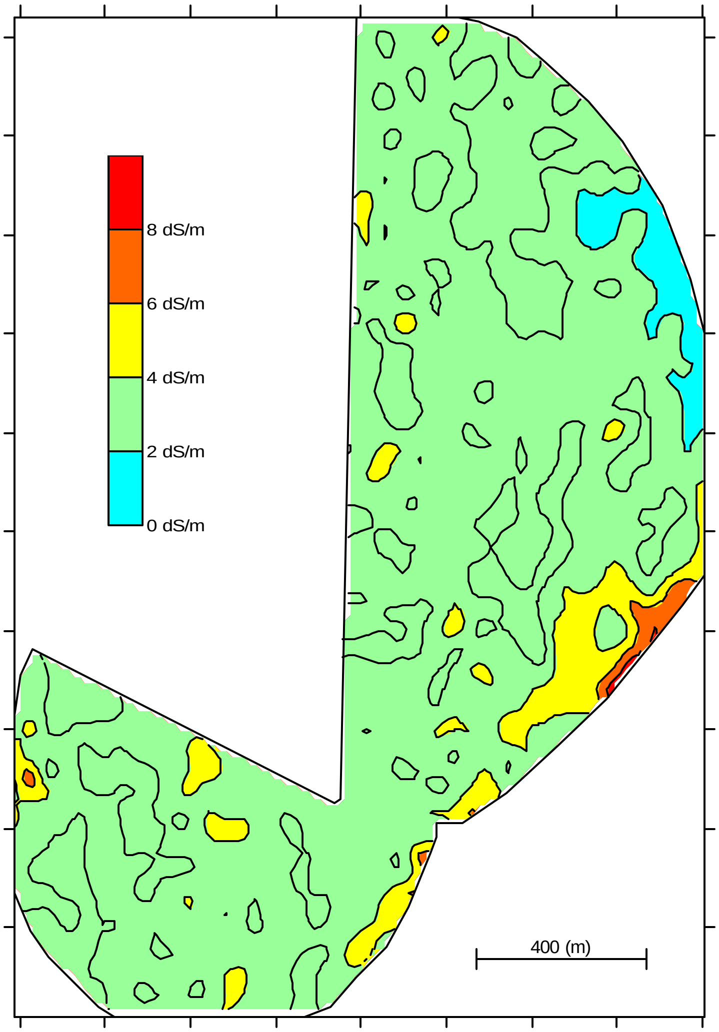

Figure 20. Soil salinity map (E.C. dS/m) for Vauxhall potatoes, April 1999.

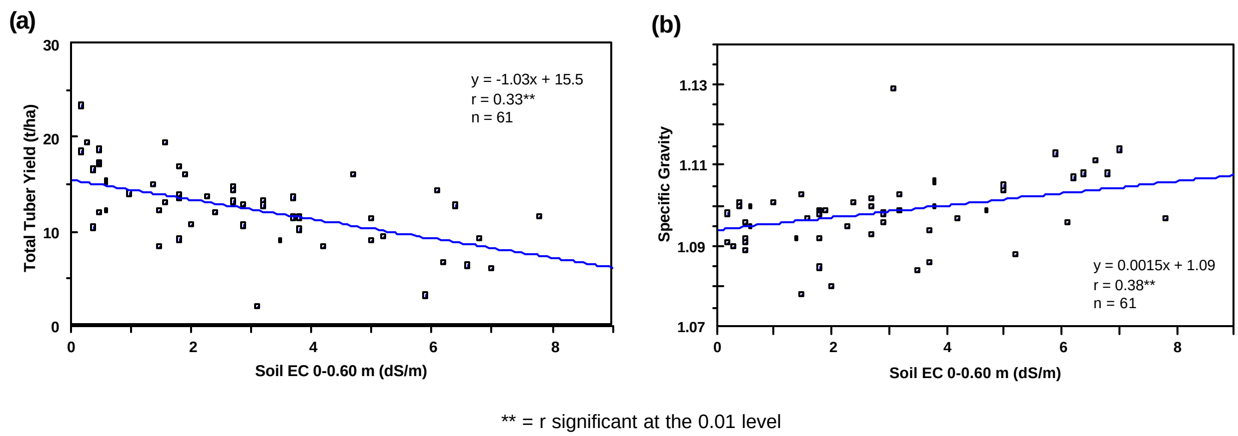

Figure 21. The effect of soil salinity on (a) tuber yield and (b) tuber specific gravity for Vauxhall potatoes 1999.

IMPLICATIONS OF THE STUDY WITH REGARD TO THE IMPROVEMENT OF ALBERTA'S AGRICULTURAL AND FOOD INDUSTRY AND ADVANCEMENT OF AGRICULTURAL KNOWLEDGE

This project showed the difficulties using current yield monitoring equipment on many commercial fields. When soil variability is present, there are areas, which contain a high percentage of clay and form lumps on the harvester. The yield monitor weighs the material on the harvester belt and does not distinguish between potatoes and other material. Yield monitors usually work satisfactorily on fields, which do not contain medium or fine textured areas. Upper limits of currently used potato petiole nutrient sufficiency standards for phosphorus were found to be high. Subsequent experiments with rates of phosphorus on potatoes have confirmed this.

Petiole nutrient contents of potassium were shown to be unreliable as an indication of potassium deficiency. Research needs to be done to determine what are critical levels for yield or quality and what factors influence the potassium of petioles when grown under conditions with cold night temperatures like those of southern Alberta.

Field variability and lack of uniformity of output of irrigation water were found to be factors, which influence the growth and quality of potatoes. Farmers would do well to measure the output and uniformity of their irrigation systems.

Soil salinity was shown to be a measurable characteristic, which can be used to select portions of potential fields, which are not suitable for growing potatoes.

Site specific monitoring and yield mapping of a potato field, which is sampled by grid is a useful research technique to identify factors, which may be influencing yield and quality of potatoes.

ACKNOWLEDGEMENTS

Support for this project was received from the Alberta Agriculture Research Institute, Potato Growers of Alberta, Cargill, Potash and Phosphate Institute of Canada, Southern Agri Services, Westco and The Snack Food Association of Canada. Laboratory analysis was provided by the AAFRD Soil and Crop Diagnostic Centre, Edmonton. Two farm operations – one at Hays, the other Fincastle – allowed access to their fields and their potato and grain harvesters.

J. Rodvang monitored ground water at a series of piezometer nests in 1997 and 1998 and prepared the related portion of this document, including the text and Figures 7-10.

A. Smith of Agriculture and Agri-Food Canada, Lethbridge interpreted the 1999 CASI data and prepared the related portion of this document, including the text, Tables.18-20 and Figure 17-19. A. Smith's full report also appears as an appendix in this document.

L. Hingley, technologist for the Soil and Water Agronomy Program, conducted yield monitoring, sample collection and data organization and he prepared the figures and appendices for this document.

The Precision Agriculture Project with Potatoes was operated by an Alberta Agriculture, Food and Rural Development (AAFRD) team. Soil moisture budgets were determined by R. Hohm and T. Harms. D. McKenzie, R. Skretting, B. winter, T. Dell, A. Harms, H. Harms and L. Wenger collected and processed samples. J. Panford organized measurement of tuber chipping and French fry scores. M. Eliason and D. McKay assisted with setting up yield monitoring equipment. C. Murray proofread the manuscript. Word processing of the manuscript was done by S. Day and M. Bunney.

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APPENDICES

Appendices I to VIII list the raw data collected from the grid sample sites, including soil characteristics, plant tissue nutrients, rain gauge readings and hand-dug tuber sample attributes. Appendix IX provides the data from the 1999 Vauxhall soil salinity site. Appendix X is the remote sensing document provided by A. Smith.

I. 1996 Fincastle Grid Sample Data

1996 Fincastle Site (FL1625)																		
	Position Data		**Moisture**		**Soil Characteristics**			**Petiole Nutrient Contents**										
Site	Easting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Clay (%)		pH	NO_3-N (%)			P (%)			Ca (%)				
Info			DR					DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]
Depth (cm)				(0-50)	(0-60)	(60-90)	(0-90)									
1	434777.637	5527480.426	298	350	11	14	7.4	0.96	0.20	0.18	0.48	0.16	0.11	1.36	1.49	1.78
2	434781.031	5527683.803	321	352	13	18	7.6	0.08	0.03	0.06	0.54	0.34	0.18	0.87	1.08	1.55
3	434783.654	5527839.738	328	379	17.5	25	7.7	0.53	0.25	0.00	0.53	0.31	0.11	1.03	1.10	1.21
4	434786.785	5528039.644	306	379	23	23	8.2	1.29	0.34	0.01	0.27	0.12	0.06	1.43	1.22	1.27
5	434973.944	5528031.152	295	333	23	28	7.7	1.48	0.38	0.12	0.56	0.22	0.12	1.16	1.02	1.21
6	434971.236	5527835.103	307	389	12.5	19	7.4	1.15	0.59	0.14	0.51	0.23	0.13	1.23	1.59	1.59
7	434969.571	5527672.749	289	344	11	17	7.3	0.98	0.31	0.07	0.49	0.15	0.13	1.34	1.71	1.73
8	434965.784	5527471.701	315	379	9	10	7.3	0.90	0.01	0.02	0.52	0.22	0.18	1.09	1.22	1.49
Means			**307**	**363**	**15**	**19**	**7.6**	**0.92**	**0.26**	**0.08**	**0.49**	**0.22**	**0.13**	**1.19**	**1.30**	**1.48**

Additional Information, as follows.

DR – June 28 – August 16, 1996

DT[1] – July 4, 1996
DT[2] – July 30, 1996
DT[3] – August 20, 1996

II. 1996 Hays Grid Sample Data

1996 Hays Site (Snowden)																
	Position Data		**Moisture**		**Soil Characteristics**			**Petiole Nutrient Contents**								
Site	Easting (m)	Northing (m)	Irrigation + Precip. (mm)	Consumptive Use (mm)	Clay (%)		PH	NO_3-N (%)			P (%)			Ca (%)		
Info			DR					DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]
Depth (cm)				(0-100)	(0-60)	(60-90)	(0-30)									
1	438902.045	5537073.788	359	356	12	35	5.6		1.19	0.34	0.38	0.19	0.07	0.9	1.0	1.2
2	438902.672	5537123.641	384	392	10	9	6.6	2.00	0.59	0.06	0.41	0.17	0.07	0.9	1.1	1.8
3	438903.484	5537181.997	321	331	8	7	6.6	2.09	0.37	0.05	0.44	0.18	0.06	0.9	1.2	2.0
4	438904.003	5537237.907	398	384	10	21	6.2	2.38	1.47	0.35	0.46	0.23	0.07	1.0	1.1	1.4
5	438904.662	5537293.805	391	383	17	23	6.5	2.32	1.75	0.71	0.42	0.22	0.07	0.8	0.9	1.4
6	438905.223	5537351.503	371	375	11	10	7.2	2.48	1.56	0.43	0.50	0.21	0.07	0.8	0.9	1.5
7	438906.604	5537417.929	372	383	10	17	6.3	1.86	0.95	0.33	0.44	0.13	0.07	1.0	1.2	1.7
8	438907.019	5537506.409	390	406	9	7	7.1	1.48	0.71	0.08	0.44	0.10	0.07	1.0	1.4	1.7
9	438907.631	5537568.681	423	446	10	9	6.4	1.55	0.67	0.14	0.39	0.11	0.07	0.9	1.3	1.7
10	438908.385	5537626.645	401	390	9	9	6.3	1.59	0.66	0.12	0.44	0.12	0.07	1.0	1.3	1.6
11	438908.782	5537679.863	390	398	11	17	6.6	1.96	1.04	0.40	0.43	0.12	0.08	1.0	1.2	1.5
12	438909.163	5537733.54	373	386	36	48	7.5	2.35	1.25		0.30	0.16		1.1	1.1	
13	438909.557	5537789.555	331	373	20	26	7.6	2.07	1.08	0.32	0.25	0.13	0.06	1.1	1.5	1.8
14	438986.812	5537755.953	342	352	44	47	7.8	2.13	1.24	0.84	0.35	0.14	0.07	1.0	1.3	1.8
15	438986.256	5537697.291	358	383	14	31	7.2	2.02	0.88	0.38	0.48	0.16	0.08	1.0	1.2	1.5
16	438985.613	5537636.566	302	344	18	40	7.2	2.26	1.35	0.47	0.49	0.19	0.07	0.9	1.1	1.6
17	438984.958	5537568.789	366	363	9	7	7.2	1.70	0.97	0.37	0.50	0.16	0.08	0.8	1.1	1.7
18	438983.743	5537474.191	368	354	11	14	7.1	1.76	0.69	0.16	0.47	0.12	0.08	0.7	1.1	1.5
19	438982.247	5537346.354	365	374	14	26	7.1	2.07	0.00	0.41	0.50	0.00	0.08	0.9	0.0	1.5
20	438981.503	5537250.395	354	381	9	8	7.3	2.02	0.64	0.35	0.49	0.19	0.07	0.9	1.1	1.5
21	438980.989	5537187.362	358	363	9	7	7.8	1.53	0.23	0.03	0.34	0.13	0.07	0.9	1.2	1.6
22	438980.163	5537128.009	370	384	8	6	8	1.62	0.49	0.19	0.35	0.13	0.06	0.9	1.0	1.6
23	438979.531	5537070.395	334	355	10	13	6.2	1.80	1.30	0.40	0.39	0.20	0.07	1.0	0.8	1.5
24	439058.761	5537122.957	348	387	9	8	6.1	2.01	0.75	0.27	0.38	0.11	0.06	0.9	1.2	1.7
25	439059.473	5537193.538	373	376	7	11	5.9	2.33	0.75	0.11	0.45	0.15	0.07	1.2	1.4	1.7
26	439060.845	5537292.797	399	404	13	38	5.9	2.08	0.84	0.29	0.44	0.13	0.06	0.9	1.3	1.7
27	439061.772	5537447.533	393	402	16	29	6.7	2.16	1.19	0.71	0.48	0.14	0.08	1.0	1.0	1.5
28	439063.901	5537597.375	353	379	8	23	7	2.09	1.24	0.30	0.41	0.12	0.07	0.9	1.3	1.6
29	439065.186	5537668.442	373	415	7	6	6.9	2.09	0.84	0.22	0.41	0.10	0.08	1.0	1.2	1.7
30	439066.187	5537731.877	330	362	8	7	6.4	2.34	1.51	0.29	0.49	0.15	0.07	1.0	1.3	1.7
31	439123.012	5537670.624	382	400	5	25	6.7	1.82	0.70	0.10	0.45	0.12	0.07	1.0	1.2	1.6
32	439121.895	5537594.491	378	410	7	10	6.5	1.92	0.69	0.17	0.42	0.09	0.07	1.0	1.3	1.5
33	439119.689	5537422.167	344	410	19	34	6.4	2.20	1.07	0.52	0.43	0.10	0.07	0.9	1.2	1.7
34	439117.792	5537256.015	382	438	15	34	6.6	1.92	0.89	0.31	0.46	0.13	0.07	0.9	1.2	1.6
35	439117.272	5537156.568	335	353	12	16	6.8	2.06	1.19	0.38	0.39	0.12	0.06	0.8	1.1	1.7
36	439169.852	5537252.858	350	378	12	29	6.3	2.31	1.02	0.48	0.38	0.10	0.06	0.8	1.4	1.6
37	439171.477	5537400.514	378	395	29	30	7.6	2.09	0.99	0.53	0.31	0.17	0.07	1.0	1.1	1.5
38	439174.2	5537609.394	336	373	9	10	6.8	2.32	1.30	0.45	0.45	0.11	0.06	1.0	1.4	1.9
39	439218.719	5537469.349	357	385	16	50	6.1	2.21	1.23	0.75	0.35	0.12	0.07	1.0	1.2	1.5
40	439218.169	5537376.241	351	391	13	48	6.7	2.42	1.04	0.70	0.42	0.14	0.07	1.0	1.2	1.5
Means			**365**	**383**	**13**	**21**	**6.8**	**2.04**	**0.96**	**0.35**	**0.42**	**0.14**	**0.07**	**0.9**	**1.2**	**1.6**

Additional Information, as follows.

DR – June 17 – September 09, 1996
DT[1] – July 3, 1996
DT[2] – July 30, 1996
DT[3] – August 20, 1996

III. 1997 Fincastle Grid Sample Data

1997 Fincastle Site (Russet Burbank)																											
	Position Data		**Moisture**		**Soil Characteristics**							**Petiole Nutrient Contents**									**Hand-Sampled Tuber Data**				
Site	Easting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Clay (%)		CaCO$_3$ (%)	NO$_3$-N (ppm)		PO$_4$-P (ppm)	K (ppm)	NO$_3$-N (%)			P (%)			K (%)			Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity	Chipping Score
Info ☛			DR							Kel	Kel	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]					
Depth (cm)				(0-100)	(0-60)	(60-90)	(0-30)	(0-60)	(60-90)	(0-15)	(0-30)														
B1	430474.374	5523475.42	388	457.8	10			3.5			164.0	1.00	0.90	0.21	0.27	0.15	0.10				47	40	153.9	1.084	6.5
C1	430474.374	5523407.42	511	616.2	17		1.85	4.9			330.5	0.87	0.41	0.06	0.26	0.18	0.08	6.3	7.7	6.6	32	28	122.2	1.080	6.0
D1	430474.374	5523339.42	429	609	24			22.1		99	250.0	1.43	1.73	0.98	0.29	0.25	0.15				48	43	124.4	1.087	7.5
E1	430474.374	5523271.42	346	467.5	9			3.3			144.0	0.70	0.53	0.26	0.37	0.31	0.19				60	40	140.6	1.086	6.5
F1	430474.374	5523203.42	421	530.2	10			7.7			167.0	0.89	0.93	1.69	0.55	0.46	0.29	6.2	7.7	6.9	66	57	194.8	1.089	7.5
G1	430474.374	5523135.42	463	578.1	9			12.8			239.0	0.51	0.69	1.11	0.60	0.48	0.29				57	50	127.7	1.086	6.0
H1	430474.374	5523067.42	449	548.4	8			2.2			186.0	0.36	0.20	0.17	0.66	0.57	0.36				58	36	109.7	1.087	6.5
I1	430474.374	5522999.42	374	456	8			5.7			243.5	1.21	0.81	0.72	0.62	0.52	0.34	6.4	8.1	7.3	61	47	198.7	1.083	8.0
J1	430474.374	5522931.42	372	432.5	9			16.8		152	257.5	1.95	1.58	0.87	0.55	0.50	0.29				49	30	157.1	1.077	7.5
A2	430542.374	5523543.42	408	496.1	7	7		2.9	2.6		186.0	1.26	1.12	0.15	0.41	0.17	0.18				57	35	221.3	1.086	7.5
B2	430542.374	5523475.42	435	573.5	8			4.8		101	290.0	0.69	0.45	0.30	0.57	0.45	0.30	6.4	7.6	6.5	66	46	144.3	1.088	7.5
C2	430542.374	5523407.42	518	602.2	20			4.2			329.5	1.26	1.10	0.28	0.48	0.55	0.23				8	4	40.4	1.021	6.0
D2	430542.374	5523339.42	420	572	12			7.2			227.0	0.69	1.35	1.40	0.56	0.54	0.33				66	41	124.9	1.081	5.0
E2	430542.374	5523271.42	354	485	10			7.4			181.5	0.83	0.66	1.67	0.48	0.40	0.29	6.3	7.1	6.2	60	48	120.1	1.078	5.5
F2	430542.374	5523203.42	441	538.5	8			8.9		66	185.5	0.71	0.85	1.61	0.48	0.55	0.33				58	32	118.7	1.084	6.5
G2	430542.374	5523135.42	446	595.1	9			10.7			188.5	0.75	0.88	1.66	0.61	0.55	0.37				67	44	135.4	1.085	6.5
H2	430542.374	5523067.42	428	525.9	7			9.4		57	150.5	0.37	0.29	0.19	0.57	0.40	0.22	6.0	7.2	6.5	66	41	143.5	1.086	7.0
I2	430542.374	5522999.42	420	554.8	8			24.7			330.5	0.94	0.89	0.83	0.63	0.59	0.34				68	45	105.6	1.084	6.5
J2	430542.374	5522931.42	375	460.1	9			7.8			199.5	1.30	1.38	1.34	0.62	0.55	0.30				57	47	140.4	1.081	8.0
K2	430542.374	5522863.42	402	492.6	7			6.2			204.0	2.36	1.78	1.74	0.61	0.5	0.43	6.5	7.8	7.3	66	47	169.2	1.074	6.0
A3	430610.374	5523543.42	367	496.9	9	20		12.2	20.6	107	429.0	1.69	2.28	1.53	0.42	0.36	0.22				65	44	228.8	1.081	8.0
B3	430610.374	5523475.42	417	563.3	8	8		3.5	4.3		210.5	0.72	0.57	0.10	0.51	0.52	0.25				54	29	129.7	1.083	6.5
C3	430610.374	5523407.42	461	608.8	19	34		6.6	3.3		356.5	1.07	1.45	1.00	0.50	0.52	0.39	6.4	8.1	7.0	48	33	115.2	1.078	7.0
D3	430610.374	5523339.42	470	620.9	18	24		6.6	3.6		304.5	0.78	1.75	1.17	0.42	0.41	0.29				62	43	158.3	1.082	6.0
E3	430610.374	5523271.42	382	475.4	7	9		3.1	1.8	78	171.5	0.61	1.03	0.67	0.47	0.49	0.28				62	45	153.7	1.087	6.5
F3	430610.374	5523203.42	453	561.3	8	10		1.7	1.7		182.5	0.39	0.31	0.39	0.40	0.36	0.15	6.1	7.4	5.8	67	49	171.5	1.090	6.5
G3	430610.374	5523135.42	452	536.7	9	8		7.7	3.2		255.0	0.43	0.47	0.74	0.56	0.55	0.34				70	46	120.9	1.087	7.0
H3	430610.374	5523067.42	453	542.4	7	8		8.3	5.1		238.5	0.50	0.08	0.20	0.60	0.51	0.34				69	55	133.2	1.093	7.0
I3	430610.374	5522999.42	402	503.8	9	10		7.9	7.8		258.5	1.16	0.56	0.47	0.67	0.56	0.31	6.4	8.0	6.2	57	53	135.6	1.087	7.5
J3	430610.374	5522931.42	456	578.8	13	14		26.6	6.9		169.5	1.93	1.59	1.24	0.59	0.53	0.34				46	27	149.6	1.075	6.5
K3	430610.374	5522863.42	453	530.3	11	11		6.4	9.0	152	244.0	2.35	1.90	1.61	0.60	0.52	0.37				59	37	120.4	1.077	5.5
A4	430678.374	5523543.42	431	535.3	7	8		3.5	3.3		205.5	0.86	0.71	0.53	0.51	0.59	0.43		7.1	6.3	56	41	122.3	1.090	7.5
B4	430678.374	5523475.42	434	539.5	6	6		3.1	2.8		196.0	0.62	0.35	0.27	0.53	0.59	0.42				71	54	129.8	1.090	8.5
C4	430678.374	5523407.42	441	556.8	11	10		16.4	13.3	98	267.0	1.70	1.58	1.37	0.35	0.47	0.23				64	47	145.2	1.081	7.0
D4	430678.374	5523339.42	424	553.2	10	17		4.6	4.6		269.5	0.76	1.12	1.41	0.55	0.62	0.38	6.5	8.0	6.5	66	58	143.3	1.087	6.0
E4	430678.374	5523271.42	384	490.5	7	7		3.0	2.8		271.5	0.37	0.33	0.29	0.51	0.54	0.27				71	55	138.7	1.086	5.5
F4	430678.374	5523203.42	412	530.2	7	7		4.6	3.6		246.0	0.54	0.97	0.92	0.63	0.62	0.39				61	44	95.7	1.085	6.0
G4	430678.374	5523135.42	414	515.6	8	9		11.3	13.6		367.0	0.67	0.70	0.83	0.57	0.53	0.28	6.4	7.4	6.1	70	60	114.6	1.091	7.0
H4	430678.374	5523067.42	458	558.2	9	10		5.2	6.1		259.5	0.60	0.40	0.73	0.52	0.43	0.25				73	52	100.7	1.087	7.0
I4	430678.374	5522999.42	468	570.1	7	7	0.2	6.9	5.1	78	256.0	0.63	0.70	0.69	0.58	0.53	0.30				52	39	87.1	1.080	5.5
J4	430678.374	5522931.42	438	555.6	11	10		6.4	2.7		156.5	1.34	0.85	1.06	0.29	0.23	0.12	6.4	7.4	6.4	39	33	128.1	1.087	6.5
K4	430678.374	5522863.42	448	562.1	16	42		9.1	22.1		193.0	1.34	2.03	1.56	0.50	0.50	0.27				58	45	112.8	1.087	8.5
A5	430746.374	5523543.42	369	464.4	7	6		3.4	3.8	94	208.5	0.67	0.49	0.11	0.63	0.54	0.32				50	33	75.0	1.081	7.5
B5	430746.374	5523475.42	425	527.6	10	16	0	4.3	18.0		229.5	0.87	0.66	1.51	0.62	0.42	0.39	6.6	6.8	6.3	61	46	109.2	1.092	6.5
C5	430746.374	5523407.42	429	559.4	14	11		6.5	8.8		261.5	1.41	1.32	1.05	0.40	0.30	0.21				56	39	132.8	1.088	7.5
D5	430746.374	5523339.42	429	573.6	10	28		3.2	7.4		168.0	0.15	0.52	1.50	0.61	0.48	0.44				72	60	116.0	1.090	7.0
E5	430746.374	5523271.42	424	552.3	8	21		2.0	4.5		173.5	0.24	0.36	1.03	0.65	0.45	0.51	6.3	6.7	7.0	81	65	100.7	1.089	6.5
F5	430746.374	5523203.42	481	647.8	12	30		10.1	12.2	205	454.5	0.32	0.07	0.03	0.64	0.54	0.43				49	21	65.6	1.084	6.5
G5	430746.374	5523135.42	429	568.7	26	36		17.0	30.7		145.5	1.04	0.85	1.12	0.42	0.24	0.20				48	35	116.4	1.082	6.5
H5	430746.374	5523067.42	469	557.7	13	16		3.6	2.3		250.5	0.13	0.05	0.07	0.64	0.59	0.51	6.0	7.1	6.3	54	32	81.5	1.090	6.5
I5	430746.374	5522999.42	462	553.3	13	15		3.3	2.6		188.0	0.15	0.04	0.18	0.62	0.63	0.40				61	42	91.3	1.084	7.0
J5	430746.374	5522931.42	437	553.1	10	15		1.7	2.3	115	172.5	0.13	0.03	0.23	0.62	0.56	0.36				76	60	133.0	1.087	5.5
K5	430746.374	5522863.42	382	546.1	10	22	0.1	2.2	2.6		300.5	0.67	0.67	0.90	0.59	0.58	0.40	6.0	7.2		48	35	109.1	1.087	7.0
Means			**427**	**541.2**	**11**	**15**	**0.54**	**7.5**	**7.2**	**108**	**236.1**	**0.89**	**0.85**	**0.82**	**0.53**	**0.47**	**0.31**	**6**	**7.5**	**6**	**59**	**43**	**129.4**	**1.084**	**6.7**

☛ **Additional Information, as follows.**

DR – June 24 – September 18, 1997

Kel – Kelowna method

DT[1] – July 7, 1997

DT[2] – July 24, 1997

DT[3] – August 13, 1997

IV. 1997 Hays Grid Sample Data

1998 Hays Site (Snowden)																											
	Position Data		**Moisture**		**Soil Characteristics**								**Petiole Nutrient Contents**									**Hand-Sampled Tuber Data**					
Site	Easting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Clay (%)		$CaCO_3$ (%)	NO_3-N (ppm)		PO_4-P (ppm)	K (ppm)		NO_3-N (%)			P (%)			K (%)			Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity	Chipping Score
Info☗			DR							Kel	AA	Kel	DT^1	DT^2	DT^3	DT^1	DT^2	DT^3	DT^1	DT^2	DT^3					
Depth (cm)				(0-100)	(0-60)	(60-90)	(0-30)	(0-60)	(60-90)	(0-15)	(0-30)	(0-30)														
D1	438562.2	5537593.3	432	525	8	5		3.8	2.5	17	176.9	119	1.25	0.21	0.06	0.48	0.13	0.09	6.2	7.3		61	61	120.4	1.085	50.5
E1	438562.2	5537525.3	428	599	22	42		3.9	1.7	20	243.8	155	1.69	0.81	0.26	0.38	0.12	0.09			6.6	48	47	109.8	1.084	44.5
F1	438562.2	5537457.3	443	562	11	28		4.1	2.9	13	123.6	74	1.45	0.83	0.13	0.49	0.12	0.10				56	55	111.2	1.088	44.5
G1	438562.2	5537389.3	442	577	13	35		5.0	1.7	15	136.1	87	1.56	0.29	0.25	0.39	0.13	0.10				51	50	121.8	1.084	44
H1	438562.2	5537321.3	433	574	17	30		2.5	2.3	17	127.5	81	1.70	0.51	0.10	0.31	0.15	0.10	6.1	6.9	5.8	48	47	148.3	1.085	52
I1	438562.2	5537253.3	426	525	8	25		3.6	2.2	15	127.5	76	1.52	0.87	0.22	0.42	0.15	0.11				54	53	105.8	1.084	48
C2	438630.2	5537661.3	411	559	30	29		6.1	1.4	10	163.5	91	2.07	0.63	0.34	0.27	0.11	0.09				56	55	132.7	1.090	50.5
D2	438630.2	5537593.3	424	545	6	14	0.05	8.9	3.9	13	172.5	111	1.70	0.99	0.18	0.37	0.12	0.10				56	52	143.7	1.082	51.5
E2	438630.2	5537525.3	427	569	18	38		3.5	1.5	16	335.4	206	1.94	0.51	0.27	0.30	0.14	0.09	6.5	8.4	7.4	61	59	158.6	1.083	52
F2	438630.2	5537457.3	407	528	22	41	0	8.7	1.5	13	151.9	99	1.50	0.98	0.19	0.33	0.12	0.10				44	44	134.2	1.089	54.5
G2	438630.2	5537389.3	444	596	31	43		4.2	1.5	12	136.6	85	1.83	0.76	0.37	0.25	0.12	0.09				45	45	123.1	1.088	43.5
H2	438630.2	5537321.3	453	583	15	36		3.1	1.1	12	123.5	69	1.82	1.17	0.27	0.34	0.20	0.11	6.4	7.5	5.1	52	51	150.1	1.085	46
I2	438630.2	5537253.3	396	480	6	4	0	6.5	4.7	16	105.4	60	0.92	0.15	0.02	0.47	0.14	0.12				37	36	133.7	1.083	43.5
J2	438630.2	5537185.3	415	498	5	4	0	5.4	1.3	15	102.6	64	1.12	0.21	0.01	0.50	0.18	0.12				39	39	130.6	1.083	39.5
B3	438698.2	5537729.3	438	574	33	40	1.35	3.3	1.8	14	178.0	90	1.47	0.52	0.14	0.23	0.11	0.10				40	38	97.8	1.091	51.5
C3	438698.2	5537661.3	450	547	11	37		5.3	2.2	14	137.5	76	1.36	0.46	0.19	0.25	0.10	0.09	6.3	7.0	6.1	55	54	124.5	1.088	46
D3	438698.2	5537593.3	415	559	21	45		3.2	1.5	13	132.4	72	1.15	0.61	0.21	0.31	0.11	0.09				56	52	177.5	1.085	50
E3	438698.2	5537525.3	378	497	10	20	0	9.4	1.6	18	298.6	176	1.75	0.93	0.15	0.34	0.13	0.09				68	61	179.5	1.082	44
F3	438698.2	5537457.3	390	485	7	5		4.6	2.2	20	109.9	65	0.35	0.06	0.01	0.46	0.14	0.10	6.2	6.6	6.3	47	46	109.2	1.087	45.5
G3	438698.2	5537389.3	415	501	8	8		2.7	0.5	15	111.8	75	1.07	0.16	0.03	0.31	0.10	0.11				49	48	154	1.087	45.5
H3	438698.2	5537321.3	389	506	6	7		3.4	7.1	16	130.5	93	1.29	0.29	0.06	0.45	0.15	0.10				47	45	121.2	1.084	41.5
I3	438698.2	5537253.3	438	564	27	32		2.1	1.4	9	130.6	78	1.45	0.71	0.20	0.36	0.15	0.10	6.3	5.8	4.2	58	57	136.6	1.088	47
J3	438698.2	5537185.3	369	504	6	6	0.85	2.7	1.9	24	131.4	83	1.23	0.36	0.09	0.42	0.15	0.11				50	50	118.8	1.080	49.5
K3	438698.2	5537117.3	450	587	14	43		5.4	3.8	13	86.5	59	1.41	0.51	0.26	0.45	0.17	0.11				56	55	136.3	1.088	50
a4	438766.2	5537763.3	419	551	15	31	1.2	3.4	1.4	12	159.6	97	1.64	0.55	0.27	0.22	0.11	0.10				50	47	162.7	1.091	47
b4	438766.2	5537695.3	405	548	28	29		4.8	1.2	15	210.4	111	1.87	0.90	0.32	0.24	0.10	0.09	6.1	6.8	7.0	46	40	149.7	1.085	45
c4	438766.2	5537627.3	379	522	15	44		2.4	1.5	15	110.1	72	1.53	0.94	0.35	0.32	0.12	0.09				66	65	134.2	1.090	47.5
d4	438766.2	5537559.3	397	541	20	40		3.0	1.5	13	191.1	107	1.92	1.02	0.25	0.26	0.11	0.09				58	52	168	1.087	47
e4	438766.2	5537491.3	382	467	8	18		2.4	1.6	13	125.1	85	1.31	0.16	0.05	0.38	0.12	0.09	6.1	7.3	6.9	58	57	150.2	1.085	42
f4	438766.2	5537423.3	388	479	11	24		4.3	1.0	15	292.5	155	1.85	0.89	0.01	0.29	0.10	0.11				46	43	146.4	1.086	46.5
g4	438766.2	5537355.3	373	529	23	39		3.8	1.7	12	100.9	67	1.42	0.56	0.09	0.37	0.11	0.10				49	48	136.1	1.086	39.5
h4	438766.2	5537287.3	409	597	30	43		2.3	1.5	10	132.8	77	1.75	1.06	0.35	0.26	0.10	0.09	6.1	7.1	5.5	55	53	135.2	1.090	50.5
i4	438766.2	5537219.3	409	524	8	18		3.3	1.5	11	133.9	88	1.76	0.61	0.42	0.42	0.12	0.12				55	55	155.2	1.085	44.5
j4	438766.2	5537151.3	399	513	7	11		2.4	0.7	8	81.8	52	1.29	0.46	0.04	0.44	0.17	0.12				46	44	145.1	1.084	44
k4	438766.2	5537083.3	400	510	8	7		6.6	2.1	12	94.5	57	1.86	0.89	0.28	0.43	0.20	0.13	6.2	6.2	4.6	51	50	122	1.083	47
A5	438834.2	5537797.3	402	516	19	27		2.7	2.4	11	232.2	127	1.97	0.61	0.22	0.20	0.13	0.08				53	53	154.1	1.086	46
B5	438834.2	5537729.3	441	568	30	37		4.5	1.8	16	216.7	122	2.13	0.92	0.25	0.18	0.11	0.08				56	55	153.3	1.089	48
C5	438834.2	5537661.3	432	555	9	12		5.1	1.7	15	136.2	87	1.17	0.14	0.02	0.36	0.12	0.09	6.3	7.2	7.0	40	40	124.5	1.082	48
D5	438834.2	5537593.3	410	539	15	45	0.7	3.2	2.8	14	154.9	92	1.60	0.16	0.03	0.39	0.13	0.11				47	46	143.1	1.084	48
E5	438834.2	5537525.3	394	478	10	12		5.6	3.0	12	106.4	64	1.83	0.16	0.07	0.5	0.19	0.12				54	54	177.1	1.086	46.5
F5	438834.2	5537457.3	375	489	11	38		9.9	2.8	14	112.0	68	1.83	0.23	0.11	0.42	0.14	0.12	6.2	6.8	6.3	61	55	140.1	1.087	38.5
G5	438834.2	5537389.3	380	546	18	40		2.6	2.8	11	121.5	71	1.55	0.40	0.10	0.42	0.13	0.12				48	48	121.4	1.082	45.5
H5	438834.2	5537321.3	396	516	12	36	0	6.1	2.7	14	134.0	82	1.49	0.65	0.27	0.45	0.15	0.14				48	46	138.6	1.086	42.5
I5	438834.2	5537253.3	412	573	19	38	0	3.1	1.9	11	103.1	69	1.58	0.77	0.45	0.43	0.16	0.12	6.2	7.0	4.9	65	59	159.1	1.085	39.5
J5	438834.2	5537185.3	424	535	8	25		2.6	2.1	13	113.1	71	1.13	0.25	0.05	0.44	0.16	0.12				44	43	133.5	1.090	46
K5	438834.2	5537117.3	448	590	19	32		2.8	3.0	10	107.4	67	1.13	0.53	0.02	0.36	0.13	0.13				32	31	98.5	1.086	47
L5	438834.2	5537049.3	445	591	27	45		2.7	1.7	15	226.0	120	1.29	0.91	0.31	0.47	0.22	0.13	6.4	7.6	6.1	53	50	155.5	1.082	43.5
Means			**412**	**539**	**15**	**28**	**0.4**	**4.3**	**2.1**	**14**	**150**	**90**	**1.52**	**0.58**	**0.18**	**0.36**	**0.14**	**0.10**	**6.2**	**7.0**	**6.0**	**51**	**50**	**137.9**	**1.086**	**46.3**

☗ **Additional Information, as follows.**

DR – June 23 – September 4, 1997
Kel – Kelowna method
AA – Ammonium Acetate method
DT^1 – July 3, 1997
DT^2 – July 23, 1997
DT^3 – August 12, 1997

V. 1998 Fincastle Grid Sample Data

1998 Fincastle Site (Russet Burbank)																												
	Position Data		**Moisture**				**Soil Characteristics**								**Petiole Nutrient Contents**										**Hand-Sampled Tuber Data**			
Site	Easting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Available Water (%)		Clay (%)		$CaCO_3$ (%)	NO_3-N (ppm)		PO_4-P (ppm)	K (ppm)		NO_3-N (%)			P (%)			K (%)			Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity	French Fry Score
Info☕			DR									Kel	AA	Kel	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]					
Depth (cm)				(0-100)	(0-60)	(60-100)	(0-60)	(60-90)	(0-30)	(0-60)	(60-90)	(0-15)	(0-30)	(0-30)														
A1	430812.375	5523543.126	361	363.2	34	64	10	11	0.20	1.8	1.1	32.5	125.5	148.6	0.86	1.36	1.57	0.30	0.19	0.13	6.5	6.6	5.3	39	27	141.0	1.066	9.3
B1	430811.632	5523475.175	379	391.4	31	52	10	28		1.4	5.3	20.8		152.4		1.05	0.95		0.13	0.09		6.4	4.8	42	27	96.1	1.071	9.3
C1	430810.417	5523407.056	382	395.3	122	88	12	8		2.2	1.0	40.9		258.8	1.26	1.71	1.21	0.28	0.21	0.14	7.4	8.2	8.5	42	30	139.4	1.074	9.5
D1	430809.695	5523339.225	382	376.7	68	177	6	7		0.9	1.5	34.0		129.4	0.19	0.40	0.22	0.43	0.19	0.12	5.7	5.2	3.4	44	33	105.8	1.075	8.8
E1	430808.867	5523271.117	389	387.5	83	170	8	8		7.1	3.5	39.8		163.6	0.61	1.66	1.57	0.46	0.27	0.21	6.7	7.1	6.0	46	34	134.7	1.084	9.3
F1	430807.816	5523203.228	573	531.3	165	203	10	21		1.1	0.9	34.8		105.4	0.51	0.62	0.52	0.19	0.12	0.10	6.0	5.1	4.6	30	22	110.4	1.068	9.0
G1	430806.907	5523135.176	396	360.2	63	111	8	7	2.90	0.9	1.2	39.3	92.5	121.0	0.62	1.11	1.28	0.20	0.13	0.15	6.0	4.6	5.3	45	31	128.1	1.075	8.5
H1	430806.02	5523067.21	421	425.9	56	63	11	12		1.4	1.7	22.8		116.8	0.86	1.04	1.22	0.17	0.14	0.17	6.2	4.7		37	24	138.1	1.078	8.8
I1	430805.056	5522999.311	432	436.0	78	114	9	8		4.2	9.4	47.0		94.6	0.58	0.36	0.65	0.25	0.13	0.13	5.9	5.3	5.3	35	20	112.5	1.067	8.3
J1	430804.199	5522931.362	447	448.3	110	191	10	17		1.2	4.3	57.8		114.0	0.44	0.98	0.92	0.33	0.19	0.20	6.2	5.4	6.5	39	35	175.8	1.073	6.8
K1	430803.338	5522863.337	434	461.5	95	108	24	27		2.7	3.9	62.0		157.8	1.67	1.82	1.63	0.30	0.26	0.20	6.5	7.5	7.1	55	47	171.1	1.083	7.8
A2	430885.597	5523576.237	289	306.5	-4	37	13	10		2.4	3.0	19.7		131.2	2.26	2.02	1.87	0.33	0.17	0.13	7.0	5.7	6.0	37	32	172.6	1.074	8.3
B2	430884.757	5523508.167	400	463.9	28	11	11	44		1.8	6.6	21.1		80.0	1.45	1.97	2.48	0.33	0.22	0.20	6.0	5.2	4.3	39	34	130.7	1.083	9.0
C2	430883.885	5523440.255	361	415.0	74	114	21	23	8.65	10.5	30.5	33.8	163.5	132.8	1.14	1.23	1.66	0.27	0.21	0.20	5.9	6.7	7.2	31	17	113.1	1.074	8.5
D2	430883.145	5523372.328	364	393.0	81	51	9	6		2.4	3.0	31.6		229.4	1.75	1.88	1.99	0.33	0.21	0.21	7.1	7.9	8.1	57	42	137.0	1.079	9.3
E2	430882.246	5523304.386	373	407.9	130	150	10	10		1.1	3.0	32.7		195.4	1.30	1.50	1.65	0.22	0.16	0.18	7.6	6.2	7.5	47	39	206.0	1.077	9.0
F2	430881.387	5523236.416	360	418.0	95	168	10	9	6.95	2.7	4.2	13.3	87.0	178.6	1.07	1.67	1.25	0.14	0.15	0.19	6.6	5.0	6.1	31	26	171.1	1.076	9.5
G2	430880.517	5523168.414	356	402.0	71	115	9	9		2.2	5.6	26.4		184.0	1.28	1.67	1.65	0.19	0.11	0.19	8.0	5.2	7.2	52	50	198.5	1.080	7.8
H2	430879.658	5523100.519	528	533.6	74	114	9	8		1.0	1.5	23.7		101.2	1.16	1.69	0.92	0.24	0.17	0.19	6.9	6.0	7.4	40	34	156.4	1.074	9.0
I2	430878.826	5523032.568	402	417.8	80	217	10	9		0.8	1.1	20.4		154.4	1.02	1.58	1.70	0.22	0.15	0.20	6.8	4.8	6.7	41	32	130.3	1.070	8.8
J2	430877.991	5522964.592	373	391.8	92	135	11	10	0.40	0.8	0.8	32.1	119.0	166.6	1.16	1.47	1.39	0.36	0.17	0.19	7.0	5.8	6.0	58	43	163.3	1.077	7.8
K2	430877.172	5522896.629	388	462.7	37	108	14	16		2.6	4.4	46.2		167.6	1.27	1.79	1.75	0.45	0.28	0.21	7.4	6.4	6.4	45	31	142.0	1.079	9.7
L2	430876.273	5522828.614	313	351.0	87	109	14	20		2.9	3.9	39.1		148.8	2.51	2.15	2.01	0.46	0.20	0.22	7.2	5.3	6.7	44	34	131.8	1.074	9.0
A3	430958.199	5523541.139	314	313.9	65	128	13	13		1.0	3.2	27.9		174.6	0.88	1.07	1.30	0.21	0.10	0.08	7.3	5.3	4.1	32	16	77.1	1.061	9.0
B3	430957.419	5523473.105	370	351.4	60	100	8	8		0.6	1.4	20.3		102.0	0.66	0.84	0.99	0.33	0.11	0.09	8.5	6.1	5.0	46	26	92.9	1.074	8.0
C3	430956.612	5523405.18	380	360.2	132	177	17	31	0.55	0.7	0.6	43.1	286.0	310.0	1.60	1.57	1.50	0.30	0.16	0.10	9.0	9.0	9.0	50	41	145.5	1.075	9.3
D3	430955.742	5523337.179	415	405.3	73	117	12	14		0.2	1.4	20.1		138.0	1.26	1.78	1.62	0.18	0.10	0.10	7.1	5.0	3.7	40	28	105.1	1.076	8.8
E3	430954.96	5523269.237	408	408.6	91	187	12	15		0.3	0.7	11.8		100.0	1.07	1.68	1.74	0.19	0.11	0.10	7.4	4.3	3.9	33	23	106.5	1.075	9.3
F3	430954.204	5523201.266	414	407.6	40	76	9	9		0.0	0.0	11.9		59.6	0.08	0.12	0.12	0.15	0.08	0.07	6.6	5.2	5.0	29	15	86.6	1.065	7.5
G3	430953.393	5523133.326	398	399.6	72	119	10	15		0.3	1.7	9.14		57.8	0.48	0.73	0.81	0.23	0.09	0.09	6.7	4.0	3.2	41	31	116.5	1.076	7.8
H3	430952.655	5523065.387	488	462.0	139	137	15	13	8.15	8.1	13.2	16.3	91.5	109.0	1.44	1.36	0.89	0.20	0.12	0.09	7.7	5.6	5.4	31	22	127.4	1.070	8.5
I3	430951.737	5522997.333	456	442.1	108	108	11	15		2.8	8.1	21.0		122.6	0.91	0.97	0.97	0.25	0.10	0.10	8.1	6.0	3.8	39	29	116.7	1.069	8.3
J3	430951.063	5522929.518	408	417.2	74	99	14	12		1.5	4.4	21.8		92.2	1.71	1.67	1.38	0.19	0.12	0.12	7.5	5.0	6.5	30	22	137.7	1.075	8.5
K3	430950.116	5522861.567	320	340.8	46	137	15	36		5.8	23.9	42.4		257.4	2.03	2.17	1.89	0.30	0.10	0.11	8.5	7.2	7.5	42	36	156.8	1.064	8.5
B4	431030.577	5523506.315	285	324.8	51	91	10	10	0.25	1.1	1.3	24.6	84.0	168.6	0.91	1.36	1.48	0.29	0.17	0.11	5.0	5.2	3.9	36	29	111.4	1.070	8.5
C4	431029.8	5523438.124	391	455.2	101	151	23	31		1.4	2.6	34.7		583.2	1.64	1.47	1.46	0.23	0.18	0.12	6.4	6.2	5.5	52	31	128.5	1.068	8.3
D4	431029.115	5523370.278	395	442.3	79	109	19	24		0.9	1.1	24.7		212.2	1.11	1.30	1.09	0.22	0.17	0.11	6.5		5.8	45	28	133.5	1.075	9.5
E4	431028.422	5523302.245	418	435.5	102	120	16	30		1.2	2.0	29.3		143.8	1.01	1.35	1.48	0.27	0.18	0.14	6.4	5.3	4.8	45	35	141.2	1.084	9.8
F4	431027.637	5523234.197	427	451.9	45	114	16	35	1.10	1.0	1.6	15.8	65.0	73.0	1.04	1.24	1.42	0.16	0.16	0.11	5.8		3.6	44	35	117.8	1.076	7.5
G4	431027.011	5523166.323	418	443.4	107	198	9	9		0.8	1.7	23.9		451.8	0.80	0.95	1.18	0.28	0.19	0.12	5.9	5.3	4.4	47	29	109.4	1.074	8.8
H4	431026.258	5523098.333	422	422.3	103	181	10	14		0.8	0.8	27.5		180.4	0.46	0.25	0.42	0.20	0.14	0.10	6.1	7.5	6.5	42	25	85.3	1.066	9.0
I4	431025.488	5523030.342	398	390.9	63	79	9	10		1.0	1.0	38.6		117.6	1.08	1.53	1.36	0.18	0.20	0.12	6.1	6.8	5.7	42	34	119.0	1.076	8.2
J4	431024.776	5522962.35	433	429.6	63	98	17	14		1.2	2.9	12.0		260.0	0.82	1.29	1.17	0.14	0.14	0.13	5.4	4.9	4.0	33	25	107.0	1.070	8.5
K4	431023.95	5522894.345	316	347.2	-2	9	13	14	0.45	1.0	1.4	35.6	196.5	429.2	1.35	1.56	1.01	0.20	0.16	0.14	6.7	6.5	6.6	53	36	117.1	1.074	9.0
B5	431100.839	5523472.144	319	348.5	21	9	9	7		1.8	2.9	30.6		94.8	1.07	1.88	1.49	0.48	0.21	0.15	5.8	5.7	3.8	49	32	80.9	1.080	8.5
C5	431100.222	5523403.549	320	349.0	35	18	10	10		1.0	1.2	40.8		128.8	0.96	1.25	1.53	0.27	0.14	0.11	6.0	5.3	2.6	45	27	92.6	1.080	8.5
D5	431099.213	5523334.033	400	424.6	122	144	21	25	6.15	2.3	9.6	25.5	134.0	240.8	1.41	1.23	0.88	0.30	0.20	0.16	6.6	6.5	6.4	45	37	191.5	1.083	8.5
E5	431098.364	5523267.723	396	425.4	108	165	16	31		1.9	6.9	31.1		213.8	1.22	2.09	1.20	0.43	0.26	0.17	6.9	7.4	6.6	65	54	123.4	1.085	9.5
F5	431097.599	5523200.61	413	416.1	101	181	9	25		2.6	2.5	31.5		145.6	0.78	1.65	0.89	0.39	0.26	0.15	6.6	6.4	4.8	53	42	109.7	1.083	8.5
G5	431096.721	5523133.014	426	432.1	68	134	9	9	0.00	1.5	3.1	39.2	43.5	156.2	0.33	1.73	1.44	0.65	0.33	0.24	6.9	6.4	5.7	76	52	118.6	1.084	8.7
H5	431095.435	5523062.111	399	427.5	36	68	9	9		1.0	2.7	38.3		201.8	0.15	0.63	0.40	0.26	0.12	0.09	7.1	6.7	7.0	50	38	124.7	1.076	8.6
I5	431093.623	5522995.354	449	496.2	104	135	11	28		1.3	2.1	31.2		283.6	1.26	2.28	1.15	0.43	0.28	0.23	6.9	7.5	7.8	69	59	167.8	1.084	8.5
J5	431092.706	5522928.4	324	357.5	52	113	20	28		0.5	1.3	32.7		222.4	2.27	1.93	1.64	0.44	0.28	0.17	6.8	7.4	7.4	67	55	147.2	1.082	9.8
Means			**393**	**408.9**	**76**	**116**	**12**	**16**	**2.98**	**1.9**	**3.9**	**29.9**	**124**	**174.8**	**1.09**	**1.39**	**1.28**	**0.28**	**0.17**	**0.14**	**6.7**	**6.0**	**5.7**	**44**	**33**	**130.2**	**1.075**	**8.7**

☕ **Additional Information, as follows.**

DR – June 19 – September 16, 1998
Kel – Kelowna method
AA – Ammonium Acetate method
DT[1] – July 7, 1998
DT[2] – July 23, 1998
DT[3] – August 11, 1998

VI. 1998 Hays Grid Sample Data

1998 Hays Site (Snowden)																													
	Position Data		**Moisture**				**Soil Characteristics**								**Petiole Nutrient Contents**									**Hand-Sampled Tuber Data**					
Site	Easting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Available Water (%)		Clay (%)		$CaCO_3$ (%)	NO_3-N (ppm)		PO_4-P (ppm)	K (ppm)		NO_3-N (%)			P (%)			K (%)			Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity	French Fry Score	Chipping Score
Info			DR									Kel	AA	Kel	DT^{1}	DT^{2}	DT^{3}	DT^{1}	DT^{2}	DT^{3}	DT^{1}	DT^{2}	DT^{3}						
Depth (cm)				(0-100)	(0-60)	(60-100)	(0-60)	(60-90)	(0-30)	(0-60)	(60-90)	(0-15)	(0-30)	(0-30)															
D1	438531.588	5536799.196	421	475	76	100	26	29		5.7	2.7	21		135	1.42	0.46	1.05	0.26	0.11	0.11	6.6	6.0		50	43	84	1.086		56.5
E1	438530.645	5536731.164	475	520	109	125	24	28		2.5	0.6	5		165	1.17	0.30	1.07	0.16	0.09	0.11	7.2	6.9	5.9	56	45	87	1.086		59.8
F1	438529.643	5536663.144	396	442	79	122	19	16	5.15	0.6	0.0	2	159	174	1.40	0.99	1.36	0.20	0.11	0.15	7.5	6.8	6.8	43	36	82	1.087		60.3
G1	438528.756	5536595.036	414	442	89	182	8	16		0.7	5.7	21		103	0.65	0.32	1.26	0.26	0.15	0.36	6.7	6.8	6.9	45	39	89	1.082		59.0
H1	438527.841	5536527.115	465	502	187	255	9	12		3.4	2.0	22		157	0.82	0.55	1.28	0.23	0.09	0.18	8.0	9.0	8.4	45	37	83	1.080		59.0
I1	438526.875	5536459.222	423	453	95	145	10	10	0	3.7	3.0	26	224	249	0.94	0.53	1.70	0.39	0.15	0.33	8.2	8.6	9.4	54	47	92	1.079		61.0
B2	438606.003	5536900.103	430	493	80	97	12	10		3.2	0.6	31		255	1.84	1.44	1.60	0.71	0.33	0.34	8.4	8.6	8.2	66	60	96	1.078		62.0
C2	438605.04	5536832.07	385	428	86	154	11	25		7.7	2.7	32		211	0.71	0.65	0.93	0.36	0.13	0.17	7.9	8.0	6.8	62	58	107	1.081		59.0
D2	438604.228	5536764.072	455	491	115	174	14	31	0	5.8	1.9	29	193	230	0.93	0.78	1.25	0.38	0.15	0.21	7.8	7.4	7.6	70	63	113	1.072		58.8
E2	438603.286	5536696.175	388	412	99	171	11	13		6.4	1.6	34		181	0.30	0.16	0.53	0.36	0.15	0.15	7.7	7.8	6.7	52	46	101	1.080		53.8
F2	438602.362	5536628.131	402	458	104	191	6	18		1.6	1.9	22		109	0.18	0.36	1.18	0.36	0.23	0.33	6.9	6.8	6.8	55	50	112	1.079		56.0
G2	438601.431	5536560.217	386	407	110	164	7	27		1.8	8.0	20		84	0.41	0.38	0.61	0.42	0.24	0.21	6.8	7.1	5.7	54	46	81	1.081		60.3
H2	438600.605	5536492.16	420	468	113	189	10	33		5.0	2.8	28		164	0.48	0.58	1.04	0.39	0.20	0.22	7.5	6.9	6.1	63	56	88	1.079		63.8
I2	438599.74	5536424.228	408	423	114	205	7	11	0	2.3	3.4	26	158	136	0.42	0.37	1.05	0.37	0.19	0.22	7.7	7.1	7.3	49	44	107	1.077		57.3
J2	438598.797	5536356.45	425	493	72	101	7	17		0.7	1.7	19		160	0.44	0.50	0.75	0.31	0.18	0.15	7.7	7.2	6.6	46	40	112	1.083		61.8
B3	438679.351	5536933.121	466	498	86	144	13	34		4.1	1.0	24		190	0.90	0.77	0.93	0.22	0.09	0.12	7.6	7.9	6.2	68	61	97	1.086		62.0
C3	438678.595	5536865.14	416	443	97	183	11	28		3.7	1.8	21		177	0.43	0.50	1.06	0.32	0.10	0.13	7.7	7.8	7.2	63	60	109	1.082		55.0
D3	438677.665	5536797.213	412	399	100	184	7	9		1.8	2.3	23		124	0.29	0.23	0.70	0.41	0.10	0.17	7.3	6.9	6.6	46	42	98	1.085		60.0
E3	438676.925	5536729.388	386	395	129	180	10	29		6.9	10.7	27		154	0.68	0.49	0.86	0.38	0.10	0.16	7.4	6.9	6.6	52	44	99	1.078		61.5
F3	438676.024	5536661.359	388	428	154	205	8	33	0	1.6	2.8	24	96	92	0.35	0.48	0.37	0.38	0.14	0.14	7.0	5.9	6.0	41	32	67	1.077		61.3
G3	438675.042	5536593.392	377	387	257	284	7	6		1.6	2.0	25		158	0.01	0.11	0.42	0.17	0.08	0.12	5.8	7.2	7.4	30	19	48	1.061		64.8
H3	438674.216	5536525.461	408	426	244	273	7	7		4.5	2.4	37		131	0.04	0.06	0.18	0.25	0.09	0.15	4.9	7.1	7.2	40	27	56	1.072		61.8
I3	438673.328	5536457.421	411	399	202	242	7	13		2.4	1.8	2		128	0.59	0.31	0.62	0.51	0.14	0.14	7.1	7.8	7.3	45	38	74	1.079		62.3
J3	438672.503	5536389.524	419	422	94	118	10	15	0	1.8	2.4	24	161	146	1.03	0.66	0.70	0.31	0.10	0.13	7.3	7.4	7.6	39	34	88	1.078		55.3
K3	438671.534	5536321.514	417	413	93	112	10	10		6.9	2.9	28		172	0.63	0.41	1.05	0.27	0.09	0.14	7.4	8.0	6.9	42	36	82	1.075		61.8
A4	438752.834	5536966.219	442	495	76	81	9	8		3.8	2.3	26		166	0.85	0.92	1.10	0.50	0.19	0.17	7.1	7.4	5.4	58	53	96	1.078		61.3
B4	438752.263	5536898.3	436	497	82	136	14	40		2.4	0.7	18		213	1.39	1.21	1.32	0.37	0.15	0.21	7.4	7.4	7.3	50	44	100	1.080		59.3
C4	438751.451	5536830.325	470	518	115	181	16	38	0	2.5	0.7	16	190	205	1.40	1.48	1.57	0.38	0.19	0.25	7.5	7.1	7.2	69	62	92	1.082		62.5
D4	438750.56	5536762.421	441	479	137	201	8	17		1.8	4.6	16		97	0.61	0.67	1.08	0.41	0.24	0.22	6.9	6.9	5.4	61	56	98	1.081		55.5
E4	438749.75	5536694.55	430	487	144	202	9	15		2.2	1.7	22		176	1.14	1.36	1.25	0.50	0.20	0.28	7.5	7.4	7.5	75	68	106	1.078		63.0
F4	438748.917	5536626.513	422	495	233	218	10	31		2.6	5.9	18		144	0.13	0.27	0.47	0.29	0.14	0.20	5.7	6.8	6.3	41	24	57	1.082		64.0
G4	438748.016	5536558.501	418	468	232	288	8	8		4.1	1.9	24		308	0.28	0.56	0.93	0.32	0.17	0.23	6.6	7.9	6.9	48	36	63	1.073		58.5
H4	438747.285	5536490.606	412	490	167	220	15	30		3.5	3.5	23		184	0.57	0.05	0.72	0.29	0.18	0.22	6.3	7.4	7.8	54	42	69	1.076		53.3
I4	438746.373	5536422.601	439	507	94	144	27	32	0	1.1	0.7	20	187	178	1.48	1.13	1.38	0.37	0.19	0.24	7.4	6.7	7.5	64	60	105	1.080		61.0
J4	438745.465	5536354.681	428	493	110	168	29	38		4.0	0.0	12		247	2.13	1.42	1.03	0.30	0.17	0.18	7.7	7.1	7.5	60	55	102	1.084		57.5
K4	438744.374	5536286.5	416	506	72	134	8	30		1.7	1.5	14		90	0.80	0.35	0.96	0.42	0.16	0.32	7.0	6.7	6.1	38	30	75	1.079		59.5
A5	438826.358	5536999.112	512	554	61	80	25	45		5.6	1.5	18		176	1.40	1.70	1.55	0.75	0.29	0.19	7.5	7.2	7.9	68	54	127	1.077	9.0	
B5	438825.46	5536931.216	481	514	48	84	27	29	0	1.3	0.0	13	190	185	0.59	0.88	0.97	0.59	0.17	0.13	7.8	7.1	7.9	71	59	117	1.076	8.3	
C5	438824.708	5536863.288	484	504	70	95	16	37		2.6	1.5	16		160	0.43	0.80	1.56	0.64	0.17	0.12	7.8	7.0	7.0	69	46	100	1.077	8.8	
D5	438823.788	5536795.26	466	486	92	108	16	37		1.9	1.3	11		113	0.38	0.65	1.34	0.60	0.16	0.13	7.8	6.7	6.6	80	62	119	1.078	7.5	
E5	438822.922	5536727.377	447	451	191	213	8	10	0	3.1	3.1	19	166	181	0.08	0.17	0.86	0.78	0.27	0.13	7.7	7.5	6.9	55	28	74	1.067	8.3	
F5	438822.052	5536659.395	427	443	173	214	7	11		3.4	1.4	26		215	0.11	0.05	0.70	0.76	0.21	0.13	7.6	7.3	7.3	62	30	65	1.068	9.0	
G5	438821.264	5536591.318	406	429	197	217	7	17		6.8	7.3	26		112	0.03	0.05	0.33	0.71	0.23	0.14	7.2	6.4	6.4	52	28	70	1.072	8.0	
H5	438820.662	5536523.294	423	475	160	148	10	31	0	2.2	1.3	24	147	139	0.02	0.13	0.12	0.46	0.17	0.12	6.5	7.7	7.4	0					
I5	438819.477	5536455.622	450	469	147	121	20	35		1.7	1.7	13		278	0.10	0.02	0.15	0.23	0.09	0.08	6.3	7.4	8.0	0					
J5	438818.753	5536387.448	444	410	129	246	7	8		1.8	1.0	22		156	0.15	0.54	1.16	0.61	0.21	0.13	7.6	7.0	7.6	60	41	92	1.074	7.8	
K5	438817.96	5536319.488	424	449	75	129	7	11	0.05	0.7	1.8	15	109	91	0.23	0.39	1.00	0.71	0.14	0.18	7.4	7.1	6.6	46	27	79	1.068	8.3	
L5	438817.128	5536251.791	455	489	83	138	10	25		2.4	1.8	27		128	0.58	0.30	1.49	0.73	0.16	0.25	7.3	7.7	6.5	71	47	100	1.075	8.0	
Means			**428**	**463**	**122**	**168**	**12**	**22**	**0.43**	**3.1**	**2.4**	**21**	**165**	**165**	**0.67**	**0.57**	**0.97**	**0.42**	**0.16**	**0.19**	**7.2**	**7.3**	**7.0**	**53**	**45**	**90**	**1.078**	**8.3**	**59.7**

Additional Information, as follows.

DR – June 19 – September 9, 1998
Kel – Kelowna method
AA – Ammonium Acetate method
DT^{1} – July 6, 1998
DT^{2} – July 22, 1998
DT^{3} – August 10, 1998

VII. 1999 Fincastle Grid Sample Data

1999 Fincastle Site (FL1625)																											
	Position Data		**Moisture**				**Soil Characteristics**								**Petiole Nutrient Contents**									**Hand-Sampled Tuber Data**			
Site	Easting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Avaliable Water %		Clay (%)		$CaCO_3$ (%)	NO_3-N (ppm)		PO_4-P (ppm)	K (ppm)		NO_3-N (%)			P (%)			K (%)			Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity
Info			DR									Kel	AA	Kel	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]				
Depth (cm)				(0-100)	(0-60)	(60-100)	(0-60)	(60-90)	(0-30)	(0-60)	(60-90)	(0-15)	(0-30)	(0-30)													
A1	434730.679	5528125.947	334	341	105	89	20	21	3.6	1.7	2.3	16	231	143	0.33	0.38	0.34	0.50	0.17	0.16	9.6	8.0	5.4	32	28	117.8	1.107
B1	434729.205	5528082.462	317	321	81	76	22	22	3.4	0.6	0.0	12	180	110	0.42	0.79	1.16	0.14	0.14	0.14	9.0	7.3	5.3	35	32	140.0	1.104
C1	434727.815	5528002.959	342	347	68	19	17	23	1.1	0.0	0.0	18	165	90	1.22	1.09	0.62	0.33	0.31	0.22	8.6	8.2	5.3	28	23	129.4	1.104
D1	434727.121	5527924.325	313	323	76	42	24	36	2.0	0.3	0.0	27	140	80	1.12	0.85	0.61	0.41	0.24	0.22	8.8	7.8	5.3	37	32	137.6	1.105
E1	434726.007	5527843.383	310		70	56	15	19	1.0	0.5	0.0	63	164	95	1.35	1.45	1.19	0.63	0.52	0.42	9.4	8.7	5.3	35	31	145.5	1.097
F1	434724.132	5527763.290	348	335	108	102	12	20	0.6	0.4	0.0	54	136	83	0.43	1.49	1.71	0.72	0.47	0.41	9.3	7.8	5.4	27	26	131.6	1.098
G1	434723.837	5527683.163	349	329	109	152	15	33	0.4	0.5	0.5	54	168	108	0.85	1.16	1.77	0.67	0.51	0.39	9.5	8.7	5.3	31	29	148.0	1.097
H1	434722.733	5527603.904	346	295	58	19	11	12	0.7	0.2	0.5	43	161	105	0.51	0.38	0.72	0.55	0.43	0.34	9.7	8.4	5.3	33	28	177.2	1.100
I1	434721.204	5527523.984	329	341	40	13	17	31	0.6	0.6	0.0	48	145	92	2.06	1.46	1.10	0.65	0.59	0.47	10.4	9.3	5.2	34	31	132.4	1.099
J1	434720.141	5527442.917	344	343	67	63	12	22	0.4	0.2	0.0	35	106	67	0.72	1.07	1.27	0.62	0.48	0.43	9.6	8.2	5.3	42	31	167.6	1.097
K1	434720.093	5527389.989	301	391	41	55	12	18	0.6	1.7	3.9	46	203	133	0.20	0.12	0.95	0.63	0.42	0.27	10.1	9.2	5.3	34	31	117.7	1.103
A2	434821.375	5528111.025	356	352	159	147	26	28	4.6	1.4	0.7	12	196	118	0.93	0.48	0.66	0.29	0.17	0.16	9.8	8.1	5.3	31	28	121.5	1.105
B2	434819.845	5528041.725	327	350	98	35	23	20	6.3	0.4	0.0	19	138	78	1.22	0.74	0.52	0.29	0.21	0.23	8.2	7.4	5.7	36	26	145.6	1.111
C2	434818.367	5527960.253	330	342	28	19	24	22	9.8	0.2	0.0	14	118	64	1.16	0.91	0.80	0.15	0.16	0.17	8.0	6.7	4.9	33	28	132.1	1.110
D2	434817.490	5527881.581	312	336	40	10	24	26	6.4	1.1	0.8	48	129	71	1.08	1.04	0.78	0.47	0.24	0.21	9.2	8.0	5.0	39	29	188.4	1.100
E2	434816.193	5527802.046	362	343	52	32	19	22	2.7	1.1	0.6	48	122	67	1.53	1.54	1.30	0.59	0.56	0.54	8.8	7.8	5.3	33	28	144.8	1.097
F2	434815.005	5527721.508	277	293	51	46	13	19	0.8	0.8	4.7	56	152	87	0.56	0.94	0.80	0.64	0.50	0.39	9.9	8.4	5.0	47	33	179.0	1.097
G2	434813.753	5527640.814	301	298	56	55	13	20	1.5	0.6	13.4	54	169	100	0.57	1.24	1.33	0.68	0.53	0.43	10.0	8.9	5.3	47	34	185.5	1.099
H2	434812.930	5527561.976	287	307	39	48	11	16	1.0	0.8	7.1	46	131	80	0.37	0.41	0.99	0.62	0.48	0.28	9.8	8.6	5.0	39	34	148.9	1.102
I2	434811.710	5527482.351	326	332	47	30	11	14	1.3	0.2	0.0	35	103	55	0.31	0.25	0.40	0.62	0.42	0.23	9.6	8.1	5.3	37	31	156.8	1.113
J2	434810.697	5527412.397	341	368	14	-15	12	12	1.0	0.2	0.7	44	121	70	0.76	0.49	0.78	0.68	0.49	0.33	10.1	8.5	5.3	39	33	140.0	1.104
A3	434892.218	5528136.163	224	209	112	100	22	26	4.2	10.7	1.7	50	247	157	0.58	0.62	1.01	0.40	0.19	0.18	9.6	8.2	5.4	34	27	98.3	1.101
B3	434891.082	5528081.190	424	400	143	209	28	36	2.7	0.4	0.0	20	178	95	1.57	0.83	0.53	0.29	0.19	0.20	8.9	7.9	4.0	45	35	143.5	1.103
C3	434890.411	5528001.030	346	352	78	31	22	22	3.1	0.3	0.0	18	125	73	0.72	0.66	0.34	0.30	0.17	0.25	8.5	7.4	4.0	37	33	119.2	1.105
D3	434888.758	5527920.383	278	268	58	19	16	19	1.2	0.2	0.0	26	155	85	0.97	0.89	0.95	0.45	0.28	0.29	9.1	8.2	3.9	35	30	122.3	1.100
E3	434887.428	5527842.011	329	343	68	133	19	28	1.9	3.0	1.8	56	143	76	2.00	1.57	1.47	0.51	0.44	0.41	9.6	7.8	4.0	42	36	147.6	1.090
F3	434886.304	5527761.250	291		34	2	11	23	0.6	1.0	14.3	53	120	70	0.20	0.85	0.98	0.56	0.49	0.45	9.1	7.8	4.0	45	32	150.4	1.095
G3	434885.096	5527681.959	276	253	63	14	12	20	0.8	1.3	11.7	59	153	92	0.52	0.77	0.93	0.60	0.44	0.44	9.7	8.2	3.9	47	38	159.6	1.098
H3	434884.016	5527601.598	352	333	63	121	10	12	0.6	0.8	4.9	52	138	88	0.44	0.28	0.43	0.68	0.46	0.38	9.6	8.0	4.0	44	37	135.8	1.100
I3	434882.794	5527522.059	289	282	57	99	10	10	0.6	0.8	2.8	65	137	92	0.64	0.42	0.68	0.69	0.43	0.37	9.9	8.5	4.0	36	32	169.1	1.100
J3	434881.429	5527441.844	324	307	82	90	11	15	0.5	1.7	13.0	63	159	108	1.23	0.71	1.15	0.66	0.42	0.44	10.0	8.7	3.7	20	17	149.8	1.090
K3	434880.339	5527386.710	418		61	115	10	19	0.5	1.4	7.0	67	199	141	0.18	0.46	0.64	0.80	0.45	0.40	10.3	8.9	3.6	39	34	136.4	1.102
A4	434975.144	5528110.152	235	208	57	92	19	23	0.8	0.7	0.0	39	233	129	1.86	1.14	1.16	0.37	0.22	0.16	9.1	8.4	3.9	34	27	117.1	1.096
B4	434974.128	5528040.093	263	289	131	110	35	29	4.2	0.9	0.6	16	139	75	1.74	1.09	0.45	0.29	0.22	0.16	8.5	7.8	3.9	38	29	126.8	1.106
C4	434972.866	5527960.541	287	302	63	61	15	22	0.7	1.9	2.8	24	174	102	1.14	1.14	0.86	0.58	0.33	0.29	9.6	8.5	4.3	37	32	132.3	1.102
D4	434971.754	5527880.276	299	321	50	31	18	21	1.0	1.1	0.8	39	146	85	1.77	1.83	1.58	0.50	0.50	0.50	8.8	8.2	3.7	37	32	131.6	1.090
E4	434970.519	5527800.434	250	282	33	6	10	10	0.5	1.9	14.3	63	137	86	1.12	0.44	0.80	0.63	0.51	0.35	10.3	9.3	3.8	42	39	128.4	1.106
F4	434969.323	5527720.352	270	283	24	38	12	16	0.6	3.0	10.4	56	157	98	0.95	0.72	0.97	0.55	0.48	0.35	9.8	8.7	3.6	43	26	177.5	1.094
G4	434967.996	5527640.531	275	258	31	58	13	22	0.7	1.3	20.7	52	144	85	0.85	0.99	0.82	0.66	0.53	0.48	10.2	8.7	3.6	44	30	123.2	1.097
H4	434966.619	5527560.295	387	353	52	62	11	16	0.8	0.9	4.6	42	139	87	0.55	0.33	0.40	0.74	0.49	0.42	10.2	8.5	3.8	46	43	113.5	1.099
I4	434965.319	5527480.535	261	253	32	46	10	12	0.5	4.7	12.4	53	169	113	0.64	0.41	0.56	0.70	0.40	0.30	10.4	8.6	3.7	41	37	149.0	1.099
J4	434963.881	5527410.613	283	267	37	93	12	21	1.0	8.0	29.8	46	169	106	1.45	1.50	1.51	0.67	0.49	0.44	10.8	8.8	3.9	45	41	127.4	1.088
B5	435050.858	5528079.374	158	166	66	102	31	30	4.3	23.6	8.3	23	188	111	1.94	1.72	1.68	0.25	0.24	0.22	8.6	8.1	4.0	36	32	144.8	1.103
C5	435050.299	5527999.572	281	316	47	1	22	22	13.2	1.4	1.3	20	146	93	1.49	1.22	1.27	0.25	0.21	0.22	8.8	8.3	3.7	27	26	126.4	1.106
D5	435049.829	5527919.449	257	248	67	67	31	37	1.1	1.9	1.2	22	205	119	1.92	1.57	1.48	0.35	0.28	0.35	9.1	8.6	3.5	38	29	139.0	1.093
E5	435048.239	5527839.823	329	329	-10	41	13	24	0.8	4.5	18.4	72	150	92	0.50	0.92	1.17	0.64	0.51	0.49	10.4	8.5	3.7	40	31	173.4	1.099
F5	435046.776	5527759.335	301	308	30	39	10	17	1.0	2.0	4.6	70	193	120	1.01	0.42	0.53	0.64	0.49	0.46	10.8	9.8	3.6	43	36	153.2	1.098
G5	435045.437	5527678.991	314	306	57	81	13	25	0.8	2.1	12.1	78	256	168	0.96	0.87	1.02	0.70	0.58	0.47	10.7	9.8	3.4	31	28	110.9	1.098
H5	435044.123	5527599.538	360	380	28	31	10	11	1.1	2.1	13.5	40	214	146	0.54	0.03	0.03	0.81	0.53	0.51	10.1	8.9	3.8	44	36	148.0	1.106
I5	435042.906	5527519.281	279	317	9	9	10	11	0.9	6.4	22.0	43	384	278	0.46	0.12	0.07	0.69	0.50	0.38	10.1	9.5	3.5	38	34	112.0	1.101
J5	435041.392	5527458.930	219	204	28	35	11	25	1.0	23.9	52.1	59	293	201	1.45	0.86	1.03	0.73	0.56	0.60	10.7	9.8	3.1	40	39	142.6	1.099
Means			**308**	**309**	**60**	**59**	**16**	**21**	**2.0**	**2.5**	**6.3**	**43**	**168**	**103**	**0.96**	**0.86**	**0.91**	**0.54**	**0.39**	**0.34**	**9.6**	**8.4**	**4.4**	**38**	**31**	**141.1**	**1.100**

Additional Information, as follows.

DR – July 2 – September 3, 1999
Kel – Kelowna method
AA – Ammonium Acetate method
DT[1] – July 9, 1999
DT[2] – July 28, 1999
DT[3] – August 13, 1999

VIII. 1999 Hays Grid Sample Data

1999 Hays Site (Snowden)																												
	Position Data		**Moisture**				**Soil Characteristics**								**Petiole Nutrient Contents**									**Hand-Sampled Tuber Data**				
Site	Easting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Avaliable Water %		Clay (%)		$CaCO_3$ (%)	NO_3-N (ppm)		PO_4-P (ppm)	K (ppm)		NO_3-N (%)			P (%)			K (%)			Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Opacity	Specific Gravity
Info			DR									Kel	AA	Kel	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]					
Depth (cm)				(0-100)	(0-60)	(60-100)	(0-60)	(60-90)	(0-30)	(0-60)	(60-90)	(0-15)	(0-30)	(0-30)														
A1	438901.353	5537802.739	202	287	94	75	36	42	1.6	0.39	0.00	24	485	282	1.59	1.15	0.27	0.23	0.14	0.09	9.6	5.4	4.8	30	26	114.5	59.70	1.097
B1	438900.519	5537742.303	198	319	49	76	31	32	1.4	0.88	0.00	19	237	168	1.22	0.64	0.71	0.20	0.12	0.10	9.0	5.3	4.6	28	26	93.9	60.50	1.098
C1	438899.251	5537654.886	202	302	12	19	6	5	2.1	0.00	0.00	22	157	196	0.27	0.85	0.04	0.22	0.14	0.12	9.4	5.4	4.7	31	30	105.0	61.48	1.100
D1	438898.355	5537577.275	202	286	139	94	8	18	2.8	1.34	2.98	25	258	204	1.98	1.32	1.09	0.30	0.22	0.19	10.8	5.1	4.6	30	25	91.8	59.96	1.099
E1	438897.233	5537499.906	207	294	162	198	7	14	1.3	0.72	7.06	18	185	118	0.66	0.19	0.18	0.30	0.12	0.12	10.1	5.3	4.4	41	35	116.3	59.96	1.102
F1	438896.412	5537422.836	190	312	145	185	7	10	0.9	0.52	12.70	19	117	91	0.76	0.31	0.01	0.23	0.42	0.24	8.9	5.3	4.6	24	21	84.4	58.99	1.110
G1	438895.245	5537345.214	191	223	198	204	7	12	1.1	0.31	0.51	21	148	95	1.22	0.37	0.38	0.19	0.09	0.14	10.6	5.3	4.7	28	21	62.0	60.56	1.094
H1	438894.223	5537268.288	225	302	115	136	7	14	0.8	0.00	0.00	21	121	151	1.30	1.19	0.90	0.16	0.12	0.10	8.3	5.3	4.6	50	45	100.9	61.78	1.090
I1	438893.407	5537190.871	235	292	140	117	11	31	1.2	3.17	1.25	30	261	160	1.21	0.62	0.06	0.20	0.19	0.09	10.3	5.3	4.7	45	40	91.5	60.52	1.094
J1	438892.435	5537113.489	214	343	131	218	11	28	0.5	0.00	0.67	21	120	122	0.38	1.31	0.00	0.23	0.20	0.10	9.7	5.3	4.7	30	27	97.6	60.16	1.110
K1	438891.946	5537045.230	221	308	98	162	16	19	0.4	0.53	0.00	21	155	187	1.59	1.75	1.39	0.18	0.20	0.13	9.7	5.3	4.8	37	32	107.8	60.69	1.091
C2	438953.123	5537770.223	208	266	106	108	28	50	0.8	0.95	0.00	25	262	206	1.43	1.37	0.95	0.17	0.13	0.10	8.3	5.3	4.3	24	35	175.9	61.10	1.101
D2	438952.023	5537693.018	205	284	65	91	19	40	1.0	0.00	0.00	23	189	189	0.78	1.30	0.65	0.19	0.14	0.10	9.3	4.9	4.7	18	17	79.0	60.63	1.109
E2	438951.139	5537615.713	219	315	46	96	20	31	0.7	0.57	0.79	28	211	199	1.48	0.61	0.23	0.24	0.15	0.10	10.4	5.2	4.7	16	35	88.5	55.57	1.097
F2	438950.097	5537538.058	200	294	66	99	9	9	0.6	1.44	8.44	34	207	162	1.34	0.34	0.02	0.36	0.15	0.11	10.6	2.7	4.7	20	37	111.6	56.35	1.095
G2	438949.070	5537461.360	191	232.5	131	137	11	9	0.5	0.43	0.91	26	128	107	0.99	0.21	0.00	0.26	0.12	0.09	10.6	2.6	4.7	19	33	117.3	59.68	1.101
H2	438947.981	5537383.411	190	239	198	234	14	11	0.8	0.00	1.03	29	97	91	1.30	0.12	0.00	0.26	0.17	0.11	10.3	2.5	4.8	22	33	125.9	57.55	1.095
I2	438947.748	5537306.217	183	270.5	127	144	12	25	0.5	0.00	1.08	18	129	91	1.04	0.14	0.01	0.28	0.16	0.10	9.7	2.4	4.7	29	40	152.9	60.06	1.098
J2	438946.142	5537228.829	183	217	178	181	8	9	0.7	0.00	2.02	19	112	106	1.19	0.04	0.00	0.28	0.13	0.10	10.5	2.6	4.8	26	38	92.4	61.43	1.100
K2	438945.078	5537151.613	187	217.5	186	164	18	24	1.1	0.82	0.97	18	149	119	1.53	0.04	0.00	0.42	0.15	0.13	10.4	2.7	5.6	18	12	41.4	57.08	1.108
L2	438944.151	5537074.166	197	283	106	119	19	22	1.9	1.08	1.10	18	136	184	1.58	0.89	0.27	0.21	0.15	0.12	8.4	2.6	4.7	21	36	88.4	58.01	1.092
A3	439028.024	5537801.346	184	214	90	80	27	38	0.4	1.23	0.00	21	302	217	1.79	0.60	1.06	0.27	0.16	0.13	9.5	2.6	4.6	21	36	95.1	61.69	1.093
B3	439026.928	5537730.751	230	288	34	93	11	14	0.8	0.40	0.00	23	222	175	1.34	1.20	0.56	0.36	0.17	0.11	9.4	5.7	4.7	29	32	112.9	59.76	1.101
C3	439025.803	5537651.912	204	280	78	111	39	41	0.8	0.94	0.00	22	220	139	1.83	1.35	1.20	0.24	0.13	0.11	8.8	5.3	4.2	21	30	101.9	57.27	1.093
D3	439024.693	5537576.041	206	290.5	30	112	7	11	0.7	0.00	0.00	20	140	114	1.09	0.28	0.02	0.42	0.22	0.13	9.3	5.8	4.7	20	30	98.9	62.61	1.099
E3	439023.847	5537498.624	224	316.5	107	221	7	17	0.8	0.00	1.21	21	149	189	1.62	0.49	0.04	0.35	0.17	0.13	8.9	5.7	4.7	27	46	116.0	61.21	1.099
F3	439022.916	5537421.286	183	225	213	127	12	21	0.3	1.80	0.98	29	349	183	2.65	1.08	1.14	0.38	0.20	0.28	10.8	5.9	3.6	23	35	82.2	60.96	1.089
G3	439021.796	5537343.987	184	275	134	128	11	19	0.7	1.35	0.94	18	153	95	1.65	0.69	0.19	0.42	0.21	0.15	10.0	5.8	4.7	30	46	135.4	60.49	1.095
H3	439020.753	5537266.777	192	275.5	162	243	15	43	0.4	0.77	0.57	24	129	91	1.99	1.07	0.44	0.31	0.16	0.14	9.7	5.8	4.6	25	43	90.7	57.59	1.095
I3	439019.930	5537189.617	197	234.5	186	241	11	20	1.0	3.25	9.33	27	117	114	2.81	0.85	0.41	0.43	0.20	0.17	10.1	5.8	4.7	22	34	142.4	58.22	1.095
J3	439019.162	5537111.949	196	246.5	192	200	11	15	1.0	0.55	2.23	29	146	186	2.85	0.38	0.61	0.43	0.16	0.17	10.6	5.8	4.4	24	39	92.3	61.38	1.098
K3	439018.309	5537046.828	136	220.5	135	176	25	36	0.9	2.92	2.42	29	237	178	2.77	2.14	1.51	0.52	0.28	0.20	11.0	5.7	3.9	20	34	92.1	59.26	1.096
B4	439105.437	5537768.650	254	299.5	101	175	30	46	1.1	1.06	0.00	17	172	114	1.63	1.47	1.06	0.22	0.13	0.09	8.4	5.6	4.4	24	22	110.8	62.16	1.101
C4	439104.332	5537691.258	236	283	105	196	11	32	0.5	1.33	0.86	21	141	88	1.97	1.36	0.73	0.42	0.23	0.14	9.0	5.6	4.7	30	29	103.0	60.76	1.096
D4	439103.144	5537613.871	204	275	49	168	9	25	0.6	0.88	0.66	31	96	75	1.58	1.07	0.19	0.43	0.25	0.15	9.0	5.6	4.5	20	19	93.7	62.31	1.103
E4	439102.189	5537536.393	213	247	148	150	15	23	0.4	4.21	8.48	21	119	83	2.50	0.37	0.05	0.51	0.27	0.20	10.7	5.9	4.4	20	16	63.8	60.59	1.095
F4	439101.235	5537459.127	211	296	94	135	21	37	0.4	0.93	0.00	15	132	73	1.60	1.18	0.66	0.23	0.17	0.12	8.7	5.8	4.6	27	26	111.4	61.43	1.098
G4	439100.034	5537381.661	202	263	23	59	12	32	0.5	1.24	0.53	5	125	60	1.36	1.26	0.80	0.44	0.27	0.18	9.4	5.9	4.4	22	20	137.9	61.49	1.095
H4	439099.090	5537304.598	191	247	30	140	17	39	0.6	0.43	0.00	12	90	85	1.02	1.04	0.60	0.27	0.15	0.12	8.2	5.4	3.6	16	14	78.4	60.83	1.106
I4	439098.094	5537227.026	193	279	35	88	12	32	0.4	1.58	1.54	25	170	138	1.91	1.17	0.69	0.29	0.20	0.15	8.9	5.8	4.4	35	29	154.8	59.53	1.093
J4	439097.389	5537149.713	198	276	73	125	11	28	0.5	0.73	0.75	16	225	153	1.49	1.16	0.61	0.25	0.17	0.12	9.4	5.9	4.4	23	23	135.0	59.85	1.094
K4	439092.546	5537072.361	181	242	60	162	17	39	0.6	0.87	0.53	21	191	108	1.92	1.42	0.84	0.37	0.18	0.15	9.8	5.9	4.4	30	29	124.5	61.55	1.100
C5	439181.201	5537649.607	207	302.5	-13	50	8	30	0.3	1.15	0.00	14	104	82	1.65	0.79	0.43	0.48	0.17	0.16	9.4	5.8	4.1	19	19	104.7	63.54	1.106
D5	439179.149	5537574.110	213	267	17	76	7	8	0.8	0.52	0.00	20	140	83	1.61	0.71	0.17	0.55	0.18	0.14	9.9	5.9	4.4	12	11	109.6	58.89	1.108
E5	439178.921	5537496.708	203	204	18	77	24	47	0.4	0.91	0.54	15	112	98	1.72	1.32	0.93	0.34	0.16	0.14	8.5	5.4	3.6	24	16	127.0	60.26	1.097
F5	439178.087	5537419.385	189	181	56	132	25	44	0.7	1.50	0.61	19	159	108	1.69	1.52	1.04	0.32	0.16	0.13	8.8	5.5	3.8	25	24	127.1	58.50	1.097
G5	439177.265	5537342.207	202	241	59	136	13	36	0.0	0.80	0.60	13	150	93	1.78	1.20	0.85	0.41	0.19	0.15	9.6	5.7	4.3	24	22	106.4	58.45	1.098
H5	439176.047	5537264.613	213	329.5	41	113	10	36	0.4	0.64	0.64	16	123	87	1.61	1.19	0.52	0.41	0.20	0.14	9.0	5.5	4.0	19	16	91.1	58.39	1.101
I5	439174.920	5537187.333	128	357	2	0	11	36	0.3	0.71	0.83	17	144	85	1.70	1.12	0.59	0.48	0.20	0.18	9.9	5.6	4.4	19	18	56.3	58.16	1.100
E6	439256.758	5537534.400	155	191	1	44	19	40	1.0	2.57	8.63	19	124	96	2.26	1.97	1.25	0.52	0.18	0.14	9.4	5.4	4.0	16	16	101.3	62.44	1.110
F6	439256.500	5537457.460	167	266	45	90	18	52	0.2	1.53	0.87	19	153	96	2.10	1.60	1.40	0.42	0.20	0.19	9.6	5.5	4.4	23	23	119.0	60.68	1.104
G6	439255.838	5537379.924	193	287	35	67	16	46	0.5	0.82	0.55	13	124	81	1.98	1.51	0.90	0.46	0.18	0.15	9.6	5.5	4.4	22	21	157.4	61.18	1.107
H6	439254.010	5537302.641	146	215.5	3	64	15	40	0.4	1.44	2.19	18	126	144	1.90	1.33	1.22	0.52	0.17	0.12	9.2	5.6	4.2	19	18	110.0	60.60	1.106
Means			**198**	**269.8**	**91**	**129**	**15**	**28**	**0.8**	**0.99**	**1.66**	**21**	**169**	**131**	**1.59**	**0.96**	**0.56**	**0.33**	**0.18**	**0.14**	**9.6**	**5.1**	**4.5**	**25**	**26**	**106.1**	**60.1**	**1.099**

Additional Information, as follows.

DR – July 7 – September 3, 1999
Kel – Kelowna method
AA – Ammonium Acetate method
DT[1] – July 7, 1999
DT[2] – July 30, 1999
DT[3] – August 17, 1999

IX. 1999 Vauxhall Grid Sample Data

	Position Data		**EM38 Soil Salinity Data**		**Hand-Sampled Tuber Data**			
Site	Easting (m)	Northing (m)	E.C. Horizontal (dS/m)	E.C. Vertical (dS/m)	Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity
Depth (cm)			(0-60)	(0-120)				
2	417803.452	5545198.060	5.0	5.7	27	21	99.2	1.105
3	417802.606	5545208.771	0.5	4.3	36	27	98.4	1.091
4	417803.706	5545217.884	3.7	4.7	34	24	95.8	1.086
5	417802.545	5545231.981	3.7	5.4	40	34	122.8	1.094
6	417804.655	5545250.974	3.2	5.0	40	35	114.5	1.103
7	417804.179	5545258.717	2.7	4.6	44	31	103.5	1.102
8	417806.070	5545284.676	2.7	4.7	43	35	105.0	1.100
9	417806.324	5545311.932	3.8	5.7	30	25	131.4	1.106
10	417807.379	5545353.228	0.3	0.1	49	40	101.6	1.110
11	417807.760	5545368.950	0.3	0.2	46	38	107.9	1.105
12	417805.729	5545433.224	0.3	0.2	35	28	104.9	1.089
13	417734.776	5545134.595	4.2	3.9	25	14	103.0	1.097
14	417732.885	5545139.708	3.8	4.1	34	29	118.9	1.100
15	417734.047	5545146.255	2.9	3.9	38	30	108.1	1.096
16	417735.376	5545160.364	1.8	3.2	41	36	106.0	1.098
17	417735.460	5545160.352	2.7	3.7	39	32	112.6	1.093
18	417735.746	5545177.626	3.2	4.8	38	32	103.8	1.099
19	417735.340	5545186.596	0.3	3.8	44	34	114.2	1.100
20	417735.547	5545201.099	4.7	5.3	48	35	91.3	1.099
21	417735.846	5545227.155	2.3	4.4	41	34	101.8	1.095
22	417736.294	5545240.162	1.8	3.8	40	29	95.8	1.099
23	417737.002	5545292.974	1.6	3.3	39	29	82.9	1.097
24	417742.783	5545420.668	0.6	2.1	36	29	105.3	1.095
25	417741.043	5545425.065	0.4	1.7	31	20	93.3	1.100
26	417742.753	5545437.498	0.3	0.8	47	37	105.4	1.087
27	417743.677	5545453.048	0.3	0.9	40	36	127.3	1.089
28	417744.943	5545473.627	0.3	1.2	27	18	80.6	1.085
29	416599.690	5545133.444	6.4	6.0	38	31	118.3	1.108
30	416601.295	5545137.559	6.8	6.1	28	20	125.4	1.108
31	416604.731	5545132.820	6.6	6.1	20	14	115.6	1.111
32	416611.542	5545131.133	7.0	6.1	18	14	101.4	1.114
33	416624.477	5545146.228	6.2	6.0	20	16	108.2	1.107
34	416628.008	5545148.094	5.0	5.5	34	27	134.4	1.104
35	416633.429	5545150.672	1.8	3.4	50	40	124.9	1.092
36	416637.308	5545159.760	0.5	2.2	56	48	148.9	1.096
37	416643.724	5545165.115	2.9	4.2	32	21	119.5	1.098
38	416652.716	5545157.126	1.9	3.4	48	40	138.4	1.099
39	416663.907	5545183.050	1.0	2.5	46	41	134.2	1.101
40	416671.818	5545173.875	0.4	1.6	49	43	147.6	1.101
41	416677.985	5545170.589	0.6	2.2	46	38	153.3	1.100
42	416684.811	5545190.281	0.4	1.8	49	37	157.0	1.101
43	416689.479	5545197.304	0.2	1.6	55	50	142.5	1.098
44	416704.301	5545206.294	0.3	1.2	44	37	147.9	1.097
45	416712.669	5545218.766	0.3	1.2	52	47	154.4	1.103
46	417011.817	5545102.675	5.9	7.3	10	4	86.2	1.113
47	417009.936	5545087.434	6.1	6.7	43	17	81.7	1.096
48	417011.213	5545067.675	7.8	8.5	27	12	117.2	1.097
49	416989.494	5545069.341	2.0	3.2	32	10	60.1	1.080
50	416990.820	5545052.866	1.5	2.6	25	13	78.9	1.078
51	416988.397	5545040.775	1.8	2.7	27	8	37.6	1.085
52	417010.838	5545041.948	5.2	5.5	28	13	89.6	1.088
53	417014.113	5545023.477	3.5	4.6	27	17	79.9	1.084
54	417012.063	5545009.248	3.1	4.6	6	3	19.4	1.129
55	417010.002	5544984.904	1.6	3.0	58	48	172.1	1.097
56	417011.943	5544966.075	1.4	2.7	45	38	186.5	1.092
57	417011.061	5544955.561	0.5	1.9	51	48	224.0	1.089
58	417014.215	5544939.563	2.4	4.0	36	32	179.8	1.101
59	417020.608	5544932.424	1.5	3.4	37	33	140.2	1.103
60	417020.454	5544919.843	0.2	1.7	49	44	157.8	1.091
61	417010.756	5544922.446	0.3	1.7	58	52	176.1	1.090
62	417025.447	5544919.278	0.5	1.9	51	46	150.4	1.092
Means			**2.5**	**3.6**	**38**	**30**	**117.1**	**1.098**

ESTIMATING POTATO PETIOLE NITRATE NITROGEN USING REMOTE SENSING TECHNIQUES

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Introduction

Potato, a high value crop in southern Alberta, requires large amounts of fertilizers, pesticides and irrigation water. With respect to nitrogen (N), a balance between supply and utilization is required to optimize crop growth and economic return as well as minimize environmental impact. Application of excess N results in delayed maturity, reduced tuber set and dry matter yield, and increased incidence of hollow heart. Thus, too much nitrogen leads to a reduction in net returns and potentially ground water contamination due to leaching. Conversely, too little N reduces profitability due to a reduction in yield and an increase in susceptibility to blight (Schaupmeyer 1992). Early detection of N deficiency in crops such as potatoes allows producers an opportunity to more closely match their application rates to the real time N requirements of the crop thereby optimizing returns and alleviating concerns about environmental contamination.

Potato fields are closely monitored during the growing season for the onset of nutrient deficiencies, disease and pests. With respect to nutrients, typically test areas are established in a field and 40 to 50 petioles from representative plants are collected at each sampling date for determination of primarily N but also P and K content. In Alberta in mid-July, the target range for petiole nitrate N for potatoes under irrigation is 1.0 to 2.0%; below 1.0% the plants are considered to be deficient in N. Based upon the petiole sampling, N can be applied through fertigation. This method of petiole sampling provides only limited information regarding spatial variability across the whole field and does not provide information suitable for use with variable rate equipment.

Remote sensing data offers one source of spatial information suitable for use in site-specific management systems. Digital imaging systems provide the potential to delineate management zones within a field based upon soil characteristics and the detection of crop stresses both in the short and long term (Brisco et al. 1998, Moran et al. 1997). A number of algorithms have been proposed to measure chlorophyll or N content of plants using remote sensing (Table 1). The close correlation between leaf chlorophyll and N availability suggests that chlorophyll content can be use to characterize N status and vice versa (Filella and Peñuelas 1994). The majority of the algorithms or indices are based upon reflectance in the green (530-600 nm), red (670-680 nm) or so-called 'red-edge' (690-710 nm) normalized to reflectance in the near-infrared (750-900 nm) range of the electromagnetic spectrum. Reflectance at wavelengths above 735 nm is relatively insensitive to chlorophyll or N levels while reflectance at 550 and 690-710 nm is most sensitive. Sensitivity to N stress at 670-680 nm is variable due to the signal being saturated and reflectance reaching a minimum at relatively low chlorophyll levels (Gitelson et al. 1999). The objective within this study was to test, using airborne remote sensing imagery, the suitability of the reported algorithms to estimate petiole-N content in potatoes and examine the spatial information regarding N status across the field.

Materials and Methods

Fields Sites

Two field sites were identified one near Fincastle and the other at Hays, Alberta. The producers used their normal methods for seeding, cultivation, irrigation, pest control and harvesting of the potato crop. The characteristics of the sites and fertilizer applications are given in Table 2.

Petiole Sampling

A sampling grid was set up in each field in the fall of 1998; the grid sampling points were located with differential GPS methods. Petiole samples were collected at each grid sampling point at Fincastle on July 9, July 28 and August 13 and at Hays on July 7, July 30 and August 17, 1999. Within 5 m of each grid sampling point, 45 to 70 petioles were taken from the fourth leaf of representative plants. The tissues were analyzed to determine nitrate N and total N as well as a number of other elements (McKenzie et al. 2002). The N levels in the tissues were compared to sufficiency limits used by various Alberta and USA soils laboratories. The geographic coordinates of the grid points together with their associated petiole nitrate N values were imported into the grid-based graphics program Surfer? (Golden Software Inc, Colorado, USA). The data between the grid points were interpolated using kriging to produce a map delineating petiole nitrate N levels across each of the test fields.

Remote sensing data

On July 28, 1999, Itres acquired digital images over the test fields. The image data were acquired over the spectral range 420-965 nm using a Compact Airborne Spectrographic Imager at 2 and 3-m resolution. The spectral bands in which data were acquired varied with the resolution from 36 to 48 respectively. The image data were radiometrically corrected and geocoded by Itres.

The data were imported into the ENVI? image analysis software package (Research Systems Inc. Colorado, USA) and converted from spectral radiance units (µW cm^{-2} sr^{-1} nm^{-1}) to surface reflectance (%) using the FLAASH (Fast Line-of-sight

Atmospheric Analysis of Spectral Hypercubes) atmospheric correction model (Anon 2001). The input parameters used in the model are shown in Table 3.

Images of the various chlorophyll/N indices outlined in Table 1 were created using the band math function in the image analysis software. The spatial patterns of the indices across the sites were visually examined and compared to those in the kriged maps derived from the ground based petiole nitrate N samples. The grid sampling points were overlaid on the imagery and the reflectance values under a 3 x 3-pixel window centered over each grid point were extracted for each band and each chlorophyll/N index. The relationship between the various chlorophyll/N indices and the petiole nitrate N values was assessed using correlation and regression analyses.

Results & Discussion

True colour images derived from the 2-m resolution airborne imagery for both the Fincastle and Hays sites are shown in Figure 1. Both the 2 and 3-m resolution images were processed but due to the similarity in the information content only the 2-m data will be discussed. The images show differential "greeness" across the fields, particularly in the Hays field. The spatial patterns tend to correspond to soil texture, particularly in the northern end of the field at Hays and likely results from poorer growth on the coarse textured soils. Consistent with the observation that many of the proposed indices involve reflectance in similar wavebands, the spatial patterns in the images derived for the various indices were similar (Table 1). Only the images showing the spatial variability in the index SR_{550_850} derived from reflectance at 550 and 850 nm are shown (Figures 2 and 3). Visual comparison of the petiole-N maps derived in Surfer? using the grid point petiole nitrate N data and the index SR_{550_850} shows similarities in the patterns across both fields. Generally, areas of low petiole nitrate N exhibited high values for the SR_{550_850} index. Correlation analysis showed a strong relationship between most of the chlorophyll/N indices and petiole nitrate N for the Fincastle site (Table 4). The strongest relationships were evident with simple ratios involving either reflectance in the green band (550 nm) or the red-edge (700-710 nm) and the near infrared reflectance (750-850 nm). These observations can be attributed to the greater range of chlorophyll/N content to which reflectance at 550 and 700-710 nm responds. The absorption feature at 660-680 nm saturates at relatively low chlorophyll content and thus relative to 550 or 700-710 nm is insensitive to variation in chlorophyll/N.

At the Hays site, visually there were some similarities between the spatial patterns within the image of the SR_{550_850} index and the kriged map of the ground based sampling. The extent of the N deficient areas in the remote sensing image appeared less than in the kriged map. The imagery may provide a more accurate representation of the spatial variability given that each pixel in the remote sensing image represents information from an area of 2 x 2 m on the ground while the ground data is an interpolation from grid points at greater than 100 m apart. Quantitative analysis showed only a limited number of indices were significantly related to petiole nitrate N. The strength of the relationship was poor compared to that at the Fincastle site. The lack of a strong relationship may reflect uncertainty in the georeferencing of the airborne imagery and the sampling sites and the heterogeneity of the crop reflectance in the areas selected for sampling. (Deguise et al. 1998).

Conclusions

The results of the study indicated that potato petiole nitrate N could be estimated from remote sensing imagery at one test site but not the other. At the second site, visually the spatial patterns in the remote sensing derived maps for N levels and those derived from ground based plant sampling were similar. Errors in the overlay of petiole sampling points on the remote sensing imagery may account for the lack of a significant quantitative relationship at the second site. Further studies are being conducted to determine the ability to estimate plant N content using remote sensing techniques.

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TABLE 2. PUBLISHED ALGORITHMS FOR CHLOROPHYLL/N ESTIMATION USING REMOTE SENSING DATA

Index	Formula	Citation	CASI bands
Simple ratio			
SR_{800_670}	(R_{800nm}/R_{670nm})		17, 25
SR_{695_430}	$(R_{695nm}R_{430nm})$	Carter 1994	1, 18
SR_{605_760}	(R_{605nm}/R_{760nm})	Carter 1994	12, 23
SR_{695_760}	(R_{695nm}/R_{760nm})	Carter 1994	18, 23
SR_{695_670}	(R_{695nm}/R_{670nm})	Carter 1994	17, 18
SR_{750_705}	(R_{750nm}/R_{705nm})	Gitelson and Merzlyak 1996, Sims and Gamon 2002	19, 22
SR_{750_550}	(R_{750nm}/R_{550nm})	Gitelson and Merzlyak 1996, Lichtenthaler et al. 1996	9, 22
SR_{667_717}	(R_{667nm}/R_{717nm})	Leblon et al. 2001	17, 20
SR_{550_850}	(R_{550nm}/R_{850nm})	Schepers et al. 1996	9, 28
SR_{710_850}	(R_{710nm}/R_{850nm})	Schepers et al. 1996	19, 28
SR_{800_680}	(R_{800nm}/R_{680nm})	Sims and Gamon 2002	17, 25
SR_{735_700}	(R_{735nm}/R_{700nm})	Gitelson and Merzlyak. 1999	19, 21
Pigment specific simple ratio (PSSR)	(R_{810nm}/R_{676nm})	Blackburn 1998	17, 26
Normalized difference index			
Normalized green difference vegetation index (NGVDI)	$(R_{750nm} - R_{550nm})/(R_{750nm} + R_{550nm})$	Gitelson et al. 1996	9, 22
Photochemical reflectance index (PRI)	$(R_{531nm} - R_{570nm})/(R_{531nm} + R_{570nm})$	Gamon et al. 1992	8, 10
Pigment specific normalized difference (PSND)	$(R_{810nm} - R_{676nm})/(R_{810nm} + R_{676nm})$	Blackburn 1998	17, 26
Normalized difference index (NDI_{750_700})	$(R_{750nm} - R_{700nm})/(R_{750nm} + R_{700nm})$	Gitelson and Merzlyak 1994, Sims and Gamon 2002	19, 22
Normalized difference index (NDI_{800_680})	$(R_{800nm} - R_{680nm})/(R_{800nm} + R_{680nm})$	Sims and Gamon 2002	17, 25
Normalized pigments chlorophyll ratio index (NPCI)	$(R_{680nm} - R_{430nm})/(R_{680nm} + R_{430nm})$	Peñuelas et al. 1994	1, 17
Structure-insensitive pigment index (SIPI)	$(R_{800nm} - R_{445nm})/(R_{800nm} + R_{680nm})$	Peñuelas et al. 1995	2, 17, 25
Others			
Modified simple ratio (mSR_{750_445})	$(R_{750nm} - R_{445nm})/(R_{705nm} - R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Modified normalized ratio (mNR_{750_445})	$(R_{750nm} - R_{705nm})/(R_{750nm} + R_{705nm} - 2*R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Optimized soil adjusted vegetation index (OSAVI)	$(1 + 0.16)*(R_{800nm} - R_{670nm})/(R_{800nm} + R_{670nm} + 0.16)$	Rondeaux et al. 199	17, 25
Modified chlorophyll absorption in reflectance index (MCARI)	$[(R_{700nm} - R_{670nm}) - (0.2*(R_{700nm} - R_{550nm}))*(R_{700nm}/R_{670nm})]$	Daughtry et al. 2000	9, 17, 19
Transformed chlorophyll absorption in reflectance index (TCARI)	$3*[(R_{700nm} - R_{670nm}) - (0.2*(R_{700nm} - R_{550nm}))*(R_{700nm}/R_{670nm})]$	Haboudane et al. 2002	9, 17, 19
Plant senescence reflectance index (PSRI)	$(R_{680nm} - R_{500nm})/(R_{750nm})$	Merzlyak et al. 1999	6, 17, 22
Carotenoids	$[4.145*(S_{760nm}/S_{500nm})*(R_{500nm}/R_{760nm})]-1.171$	Chapelle et al. 1992	5, 23
Chlorophyll b	$2.94*[((S_{675nm}/R_{650nm}*S_{700nm})*(R_{650nm}*R_{700nm}/R_{675nm}))]+0.378$	Chapelle et al. 1992	15, 17, 18
Chlorophyll a	$22.735[=(S_{675nm}/S700_{nm})*(R_{700nm}/R_{675nm})] - 10.407$	Chapelle et al. 1992	17, 18

TABLE 3. SITE CHARACTERISTICS

	Fincastle	Hays
Field size (ha)	31	28
Soil type	Chin light loam, fluvial lacustrine	Aeolian loamy sand overlying fine lacustrine till
# of grid sampling points	51	54
Type of irrigation	High pressure corner	Low pressure
Cultivar	Frito-Lay 1625	Snowden
N Fertilizer	Fall 1998 112 kg/ha	Fall 1998 157 kg/ha,
	At hilling 20 kg/ha	At hilling 41 kg/ha
	Fertigation 30 kg/ha	Fertigation 50 kg/ha
P Fertilizer	Fall 1998 39 kg/ha	Fall 1998 59 kg/ha
	Spring 1999 29 kg/ha	Spring 1999 0 kg/ha
K Fertilizer	Fall 1998 56 kg/ha	Fall 1998 56 kg/ha
	Spring 1999 0 kg/ha	Spring 1999 0 kg/ha
Petiole N sampling	July 9, 28 and August 13	July 7, 30 and August 17
Seeded	April	April
Hilled	April	April
Harvested	September 15-17	September 20, 24-25,27

TABLE 4. INPUT PARAMETERS FOR THE FLAASH ATMOSPHERIC CORRECTION MODEL.

Parameter	Input
Latitude/Longitude	49.9867N, 111.8523W
Sensor altitude	2.286 km
Ground elevation	0.786 km
Atmospheric model	Sub-Artic Summer
Aerosol model	Rural
Visibility	40 km

TABLE 5. RELATIONSHIP BETWEEN THE VARIOUS PROPOSED INDICES AND PETIOLENITRATE N SAMPLES

Index	Fincastle	Hays
SIMPLE RATIO		
SR_{800_680}	0.751	NS
SR_{695_430}	-0.734	-0.356
SR_{605_760}	-0.781	NS
SR_{695_760}	-0.748	NS
SR_{695_670}	0.449	-0.318
SR_{750_705}	0.820	NS
SR_{750_550}	0.821	NS
SR_{677_717}	-0.639	NS
SR_{550_850}	-0.832	NS
SR_{710_850}	-0.832	NS
SR_{735_700}	0.821	NS
PSSR	0.764	NS
NORMALIZED DIFFERENCE INDEX		
NGVDI	0.809	NS
PRI	0.770	NS
PSND	0.706	NS
NDI_{750_700}	0.809	NS
NDI_{750_705}	0.696	NS
NDI_{800_680}	0.707	NS
SIPI	-0.660	NS
OTHER		
mSR_{750_705}	0.821	0.326
mNR_{750_705}	0.813	0.308
OSAVI	0.722	NS
MCARI	0.445	-0.298
TCARI	-0.800	-0.317
PSRI	-0.597	
Carotenoids	0.746	NS
Chlorophyll a	-0.448	0.313
Chlorophyll b	-0.674	NS
PSRI	-0.597	NS
NPCI	-0.702	NS
# OF OBSERVATIONS	N=51	N=54

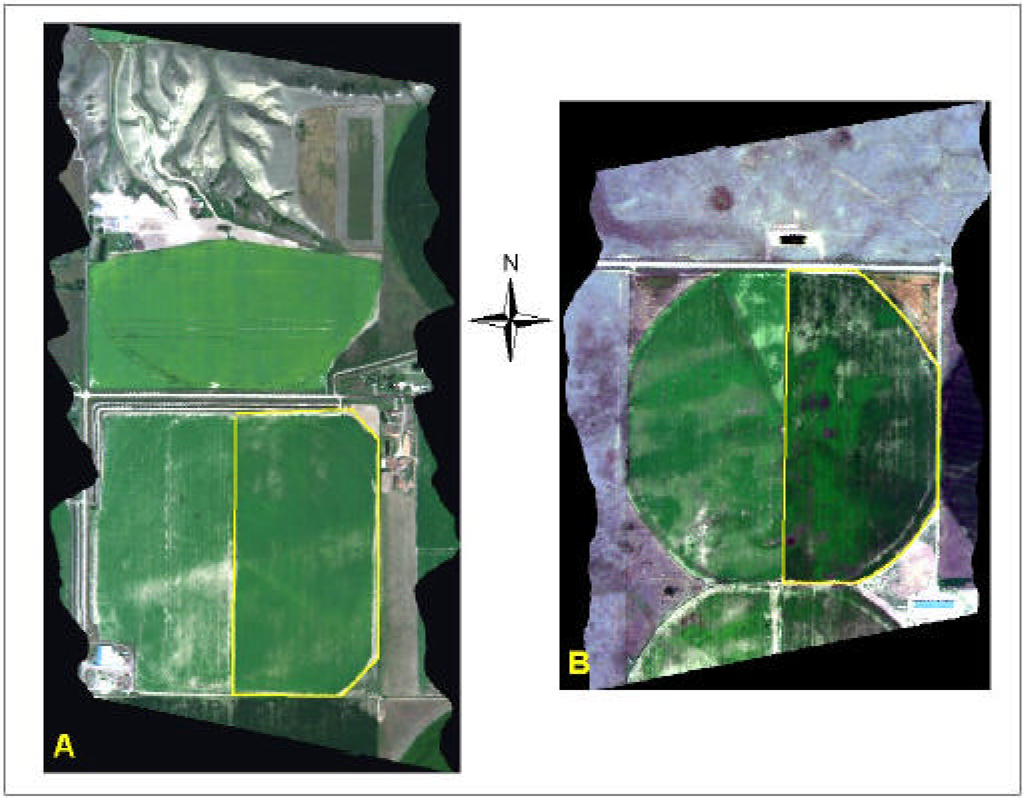

FIGURE 1. TRUE COLOUR COMPOSITE IMAGES ACQUIRED JULY 28, 1999 OF THE FINCASTLE (A) AND HAYS (B) SITES.

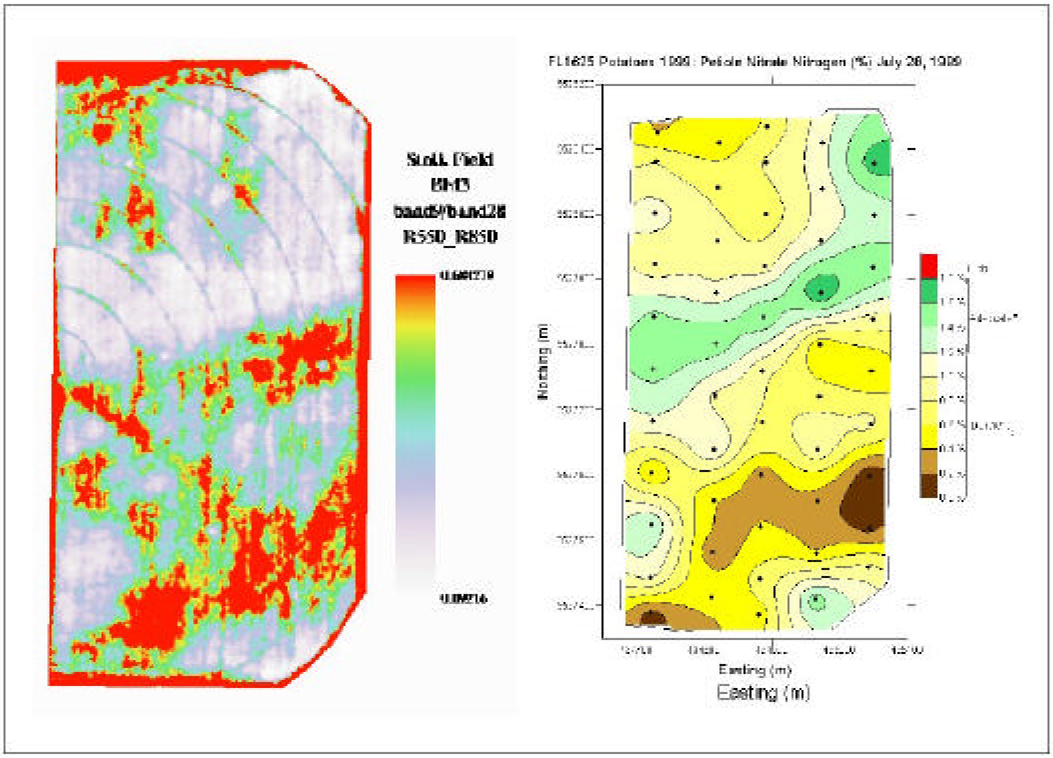

FIGURE 2. FINCASTLE SITE: SR_{550_850} INDEX IMAGE AND PETIOLE-N MAPS DERIVED FROM GROUND-BASED SAMPLING

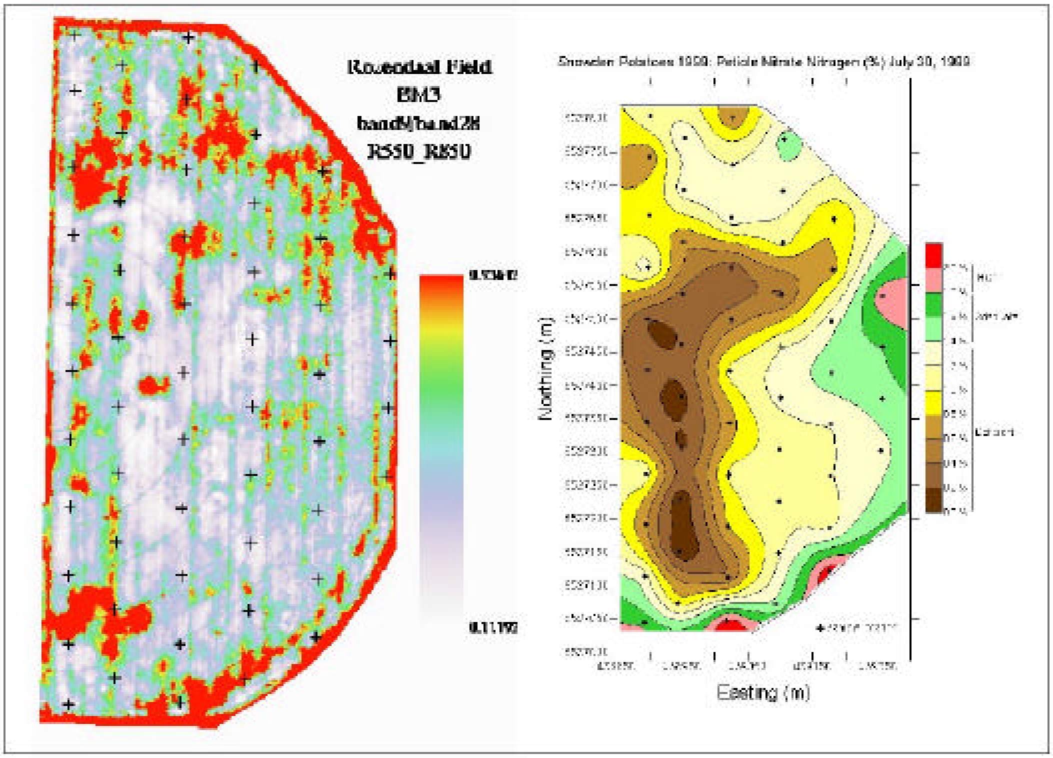

FIGURE 3 HAYS SITE: SR_{550_850} INDEX IMAGE AND PETIOLE-N MAPS DERIVED FROM GROUND-BASED SAMPLING.

Research Team Information

a) Research Team Leader:

Title: Dr.	**First Name:** R. Colin	**Last Name:** McKenzie

Position: Research Scientist, Soil and Water Agronomy *(deceased)*

Organization/Institution: Crop Diversification Centre South

Department: Alberta Agriculture, Food and Rural Development

Address:	**City:**	**Prov./State:**

Postal Code/Zip:	**E-mail Address:**
Phone Number:	**Fax Number:**

Past experience relevant to project:

1. Determining nutrient content of feedlot manure (2001-2002).
2. The influence of compost and phosphorus fertilizer on disease in potatoes (1999-2000).
3. Response of irrigated potatoes to phosphorus fertilizer and compost (1999-2001).
4. Site specific management of irrigated potatoes (1996-1999).
5. Salinity tolerance of forage and turf grasses (1993-1995).
6. Phosphorus and potassium requirement of irrigated alfalfa (1989-1994).

Degrees /Certificates /Diplomas:	**Institution Received From**:
Ph.D., The effect of subsoil acidity on root development and crop growth of several crops.	Univ. of Alberta (1970-1973)
MSc., The effect of coal humic acids on soil structure and as a slow release source of nitrogen.	Univ. of Alberta (1968-1970)
BSA in Agriculture	Univ. of Saskatchewan

Publications and Patents:

# of Refereed papers: 15	**Conference proceedings:** 16
Relevant Patents obtained: 0	**Other relevant citations:** 3 Chapters in Books

Other evidence of productivity during past 6 years:

- Invited speaker at International Drainage Conference in India (Feb. 2000).
- External examiner for 2 Ph.D. graduate students (2000-2002).
- Provided a course on measurement of salinity for Pakistan engineers and soil specialist (2001-2002).

b) Research Team Members

Name	***Institution***
1. R. C. McKenzie	CDC South, AAFRD
2. C.A. Shaupmeyer	AAFRD
3. M. Green	AAFRD
4. T.W. Goddard	AAFRD
5. D.C. Penney	AAFRD

Personal Data Sheet for Research Team Members

Title: Ms | **First Name:** Shelley A. | **Last Name:** Woods

Position: Soil and Water Research Scientist

Organization/Institution: Crop Diversification Centre South | **Department:** AAFRD

Mailing Address: SS #4 | **City:** Brooks | **Prov:** AB | **Postal Code:** T1R 1E6

E-mail Address: Shelley.A.Woods@gov.ab.ca

Phone Number: (403)362-1352 | **Fax Number:** (403)362-1311

Past experience relevant to project: (Point form, concise.)

Involved as junior research scientist and senior technologist in the following relevant projects. Duties included management of field work, data organization and analysis, report writing and presentation of results.

- Phosphorus and Compost on Potatoes 2000-2001
- Precision Farming of Potatoes 1996-1999
- Precision Farming of Dry Beans and Peas 1995, 1997-1998
- Salinity Tolerance of Forage and Turf Grasses (1991-1993, 2002)
- Nutrient Requirements of Irrigated Alfalfa (1994-1997)

Degrees /Certificates /Diplomas:	**Institution Received From:**
Ph.D. (Soil Physics) - <u>In Progress</u>	University of Saskatchewan
Master of Environmental Design (Env. Sci.) 1992	University of Calgary
Bachelor of Science (Physics) 1989	University of Alberta

Publications and Patents:

# of Refereed papers: 2	Conference proceedings: >15
Relevant Patents obtained: 0	Other relevant citations: 1 Master's thesis. 1 textbook chapter, 2 magazine articles, 2 Ropin' the Web articles

Other evidence of productivity during past 6 years: (Point form, concise)

- currently completing a Ph.D. in soil physics (AAFRD sponsored)
- managed the Alberta component of a national agricultural greenhouse gas emissions study
- successfully solicited Potato Growers of Alberta for substantial funding
- completed program reviews and published annual report in the absence of my supervisor
- gave seminars to a variety of college, university and industry groups
- presented papers, posters and oral reports at provincial, national and international conferences
- won second prize for student presentations at the 2002 Alberta Soil Science Workshop
- two-year recipient of the University of Saskatchewan's Soil Science tuition scholarship (2000 and 2001)

Personal Data Sheet for Research Team Members

The personal information being collected is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

Title: Mr.	**First Name:** Clive A.	**Last Name:** Schaupmeyer	
Position: Potato Specialist *(retired)*			
Organization/Institution:		**Department:** AAFRD	
Mailing Address: 2207 – 16 Ave.	**City:** Coaldale	**Prov:** AB	**Postal Code:** T1M 1N7
E-mail Address: clives@shaw.ca			
Phone Number: (403)345-6457	**Fax Number:** n/a		

Past experience relevant to project:

1. Agronomic research projects aimed at improving potato plant stands, population, plant performance, quality and yields.
2. Effects of in-row spacing on yield and size distribution of potatoes (1993-1996).
3. Development of optimum management profiles for new potato varieties (1995-1998).

Degrees /Certificates /Diplomas:	**Institution Received From:**
M.Sc. (Extension Education)	Univ. of Guelph (1976)
B.Sc. (Soils/Horticulture)	Univ. of Alberta (1968)

Publications and Patents:

# of Refereed papers: 10	Conference proceedings: Several
Relevant Patents obtained: 0	Other relevant citations:

Other evidence of productivity during past 6 years:

Personal Data Sheet for Research Team Members

The personal information being collected is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

<table>
<tr><td colspan="2">Title: Mr.</td><td colspan="2">First Name: Murray</td><td colspan="2">Last Name: Green</td></tr>
<tr><td colspan="6">Position: Farm Machine Engineer (retired)</td></tr>
<tr><td colspan="4">Organization/Institution:</td><td colspan="2">Department: AAFRD</td></tr>
<tr><td>Mailing Address:</td><td colspan="2">City:</td><td colspan="2">Prov:</td><td>Postal Code:</td></tr>
<tr><td colspan="6">E-mail Address: murray.green@shaw.ca</td></tr>
<tr><td colspan="2">Phone Number:</td><td colspan="4">Fax Number:</td></tr>
<tr><td colspan="6">Past experience relevant to project:
1. Variable rate fertilizer application system to control the input of fertilizer based on prescribed requirements (1994-1996).
2. Precision farming systems to maximize profits and miniize environmental impacts (1993-1996).
3. Site-specific management of potatoes (1996-1999).
4. Yield mapping of irrigated edible beans (1997-1998).</td></tr>
<tr><td colspan="3">Degrees /Certificates /Diplomas:
B.Sc.Eng. (Agricultural Engineering)</td><td colspan="3">Institution Received From:
Univ. of Saskatchewan (1967)</td></tr>
<tr><td colspan="6">Publications and Patents:</td></tr>
<tr><td colspan="3"># of Refereed papers:
Relevant Patents obtained: 0</td><td colspan="3">Conference proceedings:
Other relevant citations:</td></tr>
<tr><td colspan="6">Other evidence of productivity during past 6 years:</td></tr>
</table>

Personal Data Sheet for Research Team Members

The personal information being collected is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

Title: Mr.	**First Name:** Thomas W.		**Last Name:** Goddard
Position: Soil Conservation Specialist			
Organization/Institution: AAFRD		**Department:** Conservation & Development	
Mailing Address: 7000-113 St.	**City:** Edmonton	**Prov:** AB	**Postal Code:** T6H 5T6
E-mail Address: Tom.Goddard@gov.ab.ca			
Phone Number: (780) 427-3720	**Fax Number:** (780) 422-0474		

Past experience relevant to project:

1. Development and evaluation of precision farming technologies for canola production and research (1996-1999).
2. Landscape analysis for precision farming and model applications (1996-1999).
3. Geographic management of agronomic practice. (1995-96)
4. Precision farming to optimize yields and minimize environmental impact (1993-1997).

Degrees /Certificates /Diplomas:	**Institution Received From:**
M.Sc. (Soil Science)	Univ. of Alberta (1988)
B. Sc. (Agriculture)	Univ. of Alberta (1979)

Publications and Patents:

# of Refereed papers: 8	Conference proceedings: 45
Relevant Patents obtained: 0	Other relevant citations: 4

Other evidence of productivity during past 6 years:

1. Development of Scientifically Defensible Estimates of N_2O Emissions from Agricultural Ecosystems in Canada (CCAF, 00-03), Grant, Juma, Goddard, Kryzanowski, Zhang Solberg, Pattey.
2. Assessing the Nitrous Oxide Tradeoffs to Carbon Sequestering Management Practices (CCAF, 00-01) Lemke, Desjardins, Keng, Kharabata, Smith, Goddard, Ellert, Monreal, Drury, Rochette, Pattey.
3. Landscape dynamics and crop-soil model verification. (ARI, AESA, 99-01) Kryzanowski, Grant, Goddard.
4. Impacts of Cropping Systems to Climate Change and Adaptation Strategies for Agriculture in the Prairie Regions. (PARC, 00-01) Manunta, Goddard, Cannon.
5. Phosphorus mobility in soil landscapes: a site-specific approach. (CABIF, 99-02). Li, Chang, Amrani, Goddard, Heaney, Olson, Zhang, Feng.
6. Soil landscape management study crop yields. (MII, 01) Nolan, Lohstraeter, Coen, Brierley, Pettapiece, Goddard
7. Carbon sequestration and greenhouse gas flux in selected Alberta catenas containing wetlands (IWWR 02-07) Goddard/Fuller, Kryzanowski, Brierley, Zhang.
8. Emissions of N_2O from Cereal-Pea and Cereal-Lentil rotations in western Canada (NRCan 01-02). Lemke, Goddard, Selles.
9. Soil Variability for Agronomic and Environmental Crop Production - SVAECP (boardmember)
10. Advisory committee member – Land Information Systems program, Olds College
11. Invited committee member – Managed Ecosystems program development, Canadian Institute of Advanced Research (CIAR).

Personal Data Sheet for Research Team Members

The personal information being collected is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

Title: Mr.	**First Name:** Douglas C.	**Last Name:** Penney
Position: Head, Soil Fertility and Agronomy Section *(retired)*		
Organization/Institution:	**Department:** AAFRD	
Mailing Address:	**City:**	**Prov:** / **Postal Code:**
E-mail Address: dpenney@mail.telusvelocity.net		
Phone Number:	**Fax Number:**	

Past experience relevant to project:

1. Precision farming technologies for canola production and research (1996).
2. Precision farming systems to maximize profits and minimize environmental impacts (1996).
3. Precision farming management systems for potatoes (1995).
4. Optimal seedplaced fertilizer for airseeded crops (1994).

Degrees /Certificates /Diplomas:	**Institution Received From:**
M.Sc. (Soil Fertility)	Univ. of Alberta (1973)
B.Sc. (Soil Science)	Univ. of Alberta (1962)

Publications and Patents:

# of Refereed papers:	Conference proceedings:
Relevant Patents obtained: 0	Other relevant citations:

Other evidence of productivity during past 6 years:

I. 1996 Fincastle Grid Sample Data

1996 Fincastle Site (FL1625)																
	Position Data		**Moisture**		**Soil Characteristics**			**Petiole Nutrient Contents**								
Site	Easting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Clay (%)		pH	NO_3-N (%)			P (%)			Ca (%)		
Info✤			DR					DT^1	DT^2	DT^3	DT^1	DT^2	DT^3	DT^1	DT^2	DT^3
Depth (cm)				(0-50)	(0-60)	(60-90)	(0-90)									
1	434777.637	5527480.426	298	350	11	14	7.4	0.96	0.20	0.18	0.48	0.16	0.11	1.36	1.49	1.78
2	434781.031	5527683.803	321	352	13	18	7.6	0.08	0.03	0.06	0.54	0.34	0.18	0.87	1.08	1.55
3	434783.654	5527839.738	328	379	17.5	25	7.7	0.53	0.25	0.00	0.53	0.31	0.11	1.03	1.10	1.21
4	434786.785	5528039.644	306	379	23	23	8.2	1.29	0.34	0.01	0.27	0.12	0.06	1.43	1.22	1.27
5	434973.944	5528031.152	295	333	23	28	7.7	1.48	0.38	0.12	0.56	0.22	0.12	1.16	1.02	1.21
6	434971.236	5527835.103	307	389	12.5	19	7.4	1.15	0.59	0.14	0.51	0.23	0.13	1.23	1.59	1.59
7	434969.571	5527672.749	289	344	11	17	7.3	0.98	0.31	0.07	0.49	0.15	0.13	1.34	1.71	1.73
8	434965.784	5527471.701	315	379	9	10	7.3	0.90	0.01	0.02	0.52	0.22	0.18	1.09	1.22	1.49
Means			**307**	**363**	**15**	**19**	**7.6**	**0.92**	**0.26**	**0.08**	**0.49**	**0.22**	**0.13**	**1.19**	**1.30**	**1.48**

✤ Additional Information, as follows.

DR – June 28 – August 16, 1996

DT^1 – July 4, 1996
DT^2 – July 30, 1996
DT^3 – August 20, 1996

II. 1996 Hays Grid Sample Data

1996 Hays Site	Snowden)															
	Position Data		Moisture		Soil Characteristics			Petiole Nutrient Contents								
Site	Easting (m)	Northing (m)	Irrigation + Precip. (mm)	Consumptive Use (mm)	Clay (%)		PH	NO_3-N (%)			P (%)			Ca (%)		
Info♣			DR					DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]
Depth (cm)				(0-100)	(0-60)	(60-90)	(0-30)									
1	438902.045	5537073.788	359	356	12	35	5.6		1.19	0.34	0.38	0.19	0.07	0.9	1.0	1.2
2	438902.672	5537123.641	384	392	10	9	6.6	2.00	0.59	0.06	0.41	0.17	0.07	0.9	1.1	1.8
3	438903.484	5537181.997	321	331	8	7	6.6	2.09	0.37	0.05	0.44	0.18	0.06	0.9	1.2	2.0
4	438904.003	5537237.907	398	384	10	21	6.2	2.38	1.47	0.35	0.46	0.23	0.07	1.0	1.1	1.4
5	438904.662	5537293.805	391	383	17	23	6.5	2.32	1.75	0.71	0.42	0.22	0.07	0.8	0.9	1.4
6	438905.223	5537351.503	371	375	11	10	7.2	2.48	1.56	0.43	0.50	0.21	0.07	0.8	0.9	1.5
7	438906.604	5537417.929	372	383	10	17	6.3	1.86	0.95	0.33	0.44	0.13	0.07	1.0	1.2	1.7
8	438907.019	5537506.409	390	406	9	7	7.1	1.48	0.71	0.08	0.44	0.10	0.07	1.0	1.4	1.7
9	438907.631	5537568.681	423	446	10	9	6.4	1.55	0.67	0.14	0.39	0.11	0.07	0.9	1.3	1.7
10	438908.385	5537626.645	401	390	9	9	6.3	1.59	0.66	0.12	0.44	0.12	0.07	1.0	1.3	1.6
11	438908.782	5537679.863	390	398	11	17	6.6	1.96	1.04	0.40	0.43	0.12	0.08	1.0	1.2	1.5
12	438909.163	5537733.54	373	386	36	48	7.5	2.35	1.25		0.30	0.16		1.1	1.1	
13	438909.557	5537789.555	331	373	20	26	7.6	2.07	1.08	0.32	0.25	0.13	0.06	1.1	1.5	1.8
14	438986.812	5537755.953	342	352	44	47	7.8	2.13	1.24	0.84	0.35	0.14	0.07	1.0	1.3	1.8
15	438986.256	5537697.291	358	383	14	31	7.2	2.02	0.88	0.38	0.48	0.16	0.08	1.0	1.2	1.5
16	438985.613	5537636.566	302	344	18	40	7.2	2.26	1.35	0.47	0.49	0.19	0.07	0.9	1.1	1.6
17	438984.958	5537568.789	366	363	9	7	7.2	1.70	0.97	0.37	0.50	0.16	0.08	0.8	1.1	1.7
18	438983.743	5537474.191	368	354	11	14	7.1	1.76	0.69	0.16	0.47	0.12	0.08	0.7	1.1	1.5
19	438982.247	5537346.354	365	374	14	26	7.1	2.07	0.00	0.41	0.50	0.00	0.08	0.9	0.0	1.5
20	438981.503	5537250.395	354	381	9	8	7.3	2.02	0.64	0.35	0.49	0.19	0.07	0.9	1.1	1.5
21	438980.989	5537187.362	358	363	9	7	7.8	1.53	0.23	0.03	0.34	0.13	0.07	0.9	1.2	1.6
22	438980.163	5537128.009	370	384	8	6	8	1.62	0.49	0.19	0.35	0.13	0.06	0.9	1.0	1.6
23	438979.531	5537070.395	334	355	10	13	6.2	1.80	1.30	0.40	0.39	0.20	0.07	1.0	0.8	1.5
24	439058.761	5537122.957	348	387	9	8	6.1	2.01	0.75	0.27	0.38	0.11	0.06	0.9	1.2	1.7
25	439059.473	5537193.538	373	376	7	11	5.9	2.33	0.75	0.11	0.45	0.15	0.07	1.2	1.4	1.7
26	439060.845	5537292.797	399	404	13	38	5.9	2.08	0.84	0.29	0.44	0.13	0.06	0.9	1.3	1.7
27	439061.772	5537447.533	393	402	16	29	6.7	2.16	1.19	0.71	0.48	0.14	0.08	1.0	1.0	1.5
28	439063.901	5537597.375	353	379	8	23	7	2.09	1.24	0.30	0.41	0.12	0.07	0.9	1.3	1.6
29	439065.186	5537668.442	373	415	7	6	6.9	2.09	0.84	0.22	0.41	0.10	0.08	1.0	1.2	1.7
30	439066.187	5537731.877	330	362	8	7	6.4	2.34	1.51	0.29	0.49	0.15	0.07	1.0	1.3	1.7
31	439123.012	5537670.624	382	400	5	25	6.7	1.82	0.70	0.10	0.45	0.12	0.07	1.0	1.2	1.6
32	439121.895	5537594.491	378	410	7	10	6.5	1.92	0.69	0.17	0.42	0.09	0.07	1.0	1.3	1.5
33	439119.689	5537422.167	344	410	19	34	6.4	2.20	1.07	0.52	0.43	0.10	0.07	0.9	1.2	1.7
34	439117.792	5537256.015	382	438	15	34	6.6	1.92	0.89	0.31	0.46	0.13	0.07	0.9	1.2	1.6
35	439117.272	5537156.568	335	353	12	16	6.8	2.06	1.19	0.38	0.39	0.12	0.06	0.8	1.1	1.7
36	439169.852	5537252.858	350	378	12	29	6.3	2.31	1.02	0.48	0.38	0.10	0.06	0.8	1.4	1.6
37	439171.477	5537400.514	378	395	29	30	7.6	2.09	0.99	0.53	0.31	0.17	0.07	1.0	1.1	1.5
38	439174.2	5537609.394	336	373	9	10	6.8	2.32	1.30	0.45	0.45	0.11	0.06	1.0	1.4	1.9
39	439218.719	5537469.349	357	385	16	50	6.1	2.21	1.23	0.75	0.35	0.12	0.07	1.0	1.2	1.5
40	439218.169	5537376.241	351	391	13	48	6.7	2.42	1.04	0.70	0.42	0.14	0.07	1.0	1.2	1.5
Means			**365**	**383**	**13**	**21**	**6.8**	**2.04**	**0.96**	**0.35**	**0.42**	**0.14**	**0.07**	**0.9**	**1.2**	**1.6**

♣ Additional Information, as follows.
DR – June 17 – September 09, 1996
DT[1] – July 3, 1996
DT[2] – July 30, 1996
DT[3] – August 20, 1996

III. 1997 Fincastle Grid Sample Data

1997 Fincastle Site (Russet Burbank)																									
	Position Data		Moisture		Soil Characteristics							Petiole Nutrient Contents									Hand-Sampled Tuber Data				
Site	Easting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Clay (%)		$CaCO_3$ (%)	NO_3-N (ppm)		PO_4-P (ppm)	K (ppm)	NO_3-N (%)			P (%)			K (%)			Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity	Chipping Score
Info✚			DR							Kel	Kel	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]					
Depth (cm)				(0-100)	(0-60)	(60-90)	(0-30)	(0-60)	(60-90)	(0-15)	(0-30)														
B1	430474.374	5523475.42	388	457.8	10			3.5			164.0	1.00	0.90	0.21	0.27	0.15	0.10				47	40	153.9	1.084	6.5
C1	430474.374	5523407.42	511	616.2	17		1.85	4.9			330.5	0.87	0.41	0.06	0.26	0.18	0.08	6.3	7.7	6.6	32	28	122.2	1.080	6.0
D1	430474.374	5523339.42	429	609	24			22.1		99	250.0	1.43	1.73	0.98	0.29	0.25	0.15				48	43	124.4	1.087	7.5
E1	430474.374	5523271.42	346	467.5	9			3.3			144.0	0.70	0.53	0.26	0.37	0.31	0.19				60	40	140.6	1.086	6.5
F1	430474.374	5523203.42	421	530.2	10			7.7			167.0	0.89	0.93	1.69	0.55	0.46	0.29	6.2	7.7	6.9	66	57	194.8	1.089	7.5
G1	430474.374	5523135.42	463	578.1	9			12.8			239.0	0.51	0.69	1.11	0.60	0.48	0.29				57	50	127.7	1.086	6.0
H1	430474.374	5523067.42	449	548.4	8			2.2			186.0	0.36	0.20	0.17	0.66	0.57	0.36				58	36	109.7	1.087	6.5
I1	430474.374	5522999.42	374	456	8			5.7			243.5	1.21	0.81	0.72	0.62	0.52	0.34	6.4	8.1	7.3	61	47	198.7	1.083	8.0
J1	430474.374	5522931.42	372	432.5	9			16.8		152	257.5	1.95	1.58	0.87	0.55	0.50	0.29				49	30	157.1	1.077	7.5
A2	430542.374	5523543.42	408	496.1	7	7		2.9	2.6		186.0	1.26	1.12	0.15	0.41	0.17	0.18				57	35	221.3	1.086	7.5
B2	430542.374	5523475.42	435	573.5	8			4.8		101	290.0	0.69	0.45	0.30	0.57	0.45	0.30	6.4	7.6	6.5	66	46	144.3	1.088	7.5
C2	430542.374	5523407.42	518	602.2	20			4.2			329.5	1.26	1.10	0.28	0.48	0.55	0.23				8	4	40.4	1.021	6.0
D2	430542.374	5523339.42	420	572	12			7.2			227.0	0.69	1.35	1.40	0.56	0.54	0.33				66	41	124.9	1.081	5.0
E2	430542.374	5523271.42	354	485	10			7.4			181.5	0.83	0.66	1.67	0.48	0.40	0.29	6.3	7.1	6.2	60	48	120.1	1.078	5.5
F2	430542.374	5523203.42	441	538.5	8			8.9		66	185.5	0.71	0.85	1.61	0.48	0.55	0.33				58	32	118.7	1.084	6.5
G2	430542.374	5523135.42	446	595.1	9			10.7			188.5	0.75	0.88	1.66	0.61	0.55	0.37				67	44	135.4	1.085	6.5
H2	430542.374	5523067.42	428	525.9	7			9.4		57	150.5	0.37	0.29	0.19	0.57	0.40	0.22	6.0	7.2	6.5	66	41	143.5	1.086	7.0
I2	430542.374	5522999.42	420	554.8	8			24.7			330.5	0.94	0.89	0.83	0.63	0.59	0.34				68	45	105.6	1.084	6.5
J2	430542.374	5522931.42	375	460.1	9			7.8			199.5	1.30	1.38	1.34	0.62	0.55	0.30				57	47	140.4	1.081	8.0
K2	430542.374	5522863.42	402	492.6	7			6.2			204.0	2.36	1.78	1.74	0.61	0.5	0.43	6.5	7.8	7.3	66	47	169.2	1.074	6.0
A3	430610.374	5523543.42	367	496.9	9	20		12.2	20.6	107	429.0	1.69	2.28	1.53	0.42	0.36	0.22				65	44	228.8	1.081	8.0
B3	430610.374	5523475.42	417	563.3	8	8		3.5	4.3		210.5	0.72	0.57	0.10	0.51	0.52	0.25				54	29	129.7	1.083	6.5
C3	430610.374	5523407.42	461	608.8	19	34		6.6	3.3		356.5	1.07	1.45	1.00	0.50	0.52	0.39	6.4	8.1	7.0	48	33	115.2	1.078	7.0
D3	430610.374	5523339.42	470	620.9	18	24		6.6	3.6		304.5	0.78	1.75	1.17	0.42	0.41	0.29				62	43	158.3	1.082	6.0
E3	430610.374	5523271.42	382	475.4	7	9		3.1	1.8	78	171.5	0.61	1.03	0.67	0.47	0.49	0.28				62	45	153.7	1.087	6.5
F3	430610.374	5523203.42	453	561.3	8	10		1.7	1.7		182.5	0.39	0.31	0.39	0.40	0.36	0.15	6.1	7.4	5.8	67	49	171.5	1.090	6.5
G3	430610.374	5523135.42	452	536.7	9	8		7.7	3.2		255.0	0.43	0.47	0.74	0.56	0.55	0.34				70	46	120.9	1.087	7.0
H3	430610.374	5523067.42	453	542.4	7	8		8.3	5.1		238.5	0.50	0.08	0.20	0.60	0.51	0.34				69	55	133.2	1.093	7.0
I3	430610.374	5522999.42	402	503.8	9	10		7.9	7.8		258.5	1.16	0.56	0.47	0.67	0.56	0.31	6.4	8.0	6.2	57	53	135.6	1.087	7.5
J3	430610.374	5522931.42	456	578.8	13	14		26.6	6.9		169.5	1.93	1.59	1.24	0.59	0.53	0.34				46	27	149.6	1.075	6.5
K3	430610.374	5522863.42	453	530.3	11	11		6.4	9.0	152	244.0	2.35	1.90	1.61	0.60	0.52	0.37				59	37	120.4	1.077	5.5
A4	430678.374	5523543.42	431	535.3	7	8		3.5	3.3		205.5	0.86	0.71	0.53	0.51	0.59	0.43		7.1	6.3	56	41	122.3	1.090	7.5
B4	430678.374	5523475.42	434	539.5	6	6		3.1	2.8		196.0	0.62	0.35	0.27	0.53	0.59	0.42				71	54	129.8	1.090	8.5
C4	430678.374	5523407.42	441	556.8	11	10		16.4	13.3	98	267.0	1.70	1.58	1.37	0.35	0.47	0.23				64	47	145.2	1.081	7.0
D4	430678.374	5523339.42	424	553.2	10	17		4.6	4.6		269.5	0.76	1.12	1.41	0.55	0.62	0.38	6.5	8.0	6.5	66	58	143.3	1.087	6.0
E4	430678.374	5523271.42	384	490.5	7	7		3.0	2.8		271.5	0.37	0.33	0.29	0.51	0.54	0.27				71	55	138.7	1.086	5.5
F4	430678.374	5523203.42	412	530.2	7	7		4.6	3.6		246.0	0.54	0.97	0.92	0.63	0.62	0.39				61	44	95.7	1.085	6.0
G4	430678.374	5523135.42	414	515.6	8	9		11.3	13.6		367.0	0.67	0.70	0.83	0.57	0.53	0.28	6.4	7.4	6.1	70	60	114.6	1.091	7.0
H4	430678.374	5523067.42	458	558.2	9	10		5.2	6.1		259.5	0.60	0.40	0.73	0.52	0.43	0.25				73	52	100.7	1.087	7.0
I4	430678.374	5522999.42	468	570.1	7	7	0.2	6.9	5.1	78	256.0	0.63	0.70	0.69	0.58	0.53	0.30				52	39	87.1	1.080	5.5
J4	430678.374	5522931.42	438	555.6	11	10		6.4	2.7		156.5	1.34	0.85	1.06	0.29	0.23	0.12	6.4	7.4	6.4	39	33	128.1	1.087	6.5
K4	430678.374	5522863.42	448	562.1	16	42		9.1	22.1		193.0	1.34	2.03	1.56	0.50	0.50	0.27				58	45	112.8	1.087	8.5
A5	430746.374	5523543.42	369	464.4	7	6		3.4	3.8	94	208.5	0.67	0.49	0.11	0.63	0.54	0.32				50	33	75.0	1.081	7.5
B5	430746.374	5523475.42	425	527.6	10	16	0	4.3	18.0		229.5	0.87	0.66	1.51	0.62	0.42	0.39	6.6	6.8	6.3	61	46	109.2	1.092	6.5
C5	430746.374	5523407.42	429	559.4	14	11		6.5	8.8		261.5	1.41	1.32	1.05	0.40	0.30	0.21				56	39	132.8	1.088	7.5
D5	430746.374	5523339.42	429	573.6	10	28		3.2	7.4		168.0	0.15	0.52	1.50	0.61	0.48	0.44				72	60	116.0	1.090	7.0
E5	430746.374	5523271.42	424	552.3	8	21		2.0	4.5		173.5	0.24	0.36	1.03	0.65	0.45	0.51	6.3	6.7	7.0	81	65	100.7	1.089	6.5
F5	430746.374	5523203.42	481	647.8	12	30		10.1	12.2	205	454.5	0.32	0.07	0.03	0.64	0.54	0.43				49	21	65.6	1.084	6.5
G5	430746.374	5523135.42	429	568.7	26	36		17.0	30.7		145.5	1.04	0.85	1.12	0.42	0.24	0.20				48	35	116.4	1.082	6.5
H5	430746.374	5523067.42	469	557.7	13	16		3.6	2.3		250.5	0.13	0.05	0.07	0.64	0.59	0.51	6.0	7.1	6.3	54	32	81.5	1.090	6.5
I5	430746.374	5522999.42	462	553.3	13	15		3.3	2.6		188.0	0.15	0.04	0.18	0.62	0.63	0.40				61	42	91.3	1.084	7.0
J5	430746.374	5522931.42	437	553.1	10	15		1.7	2.3	115	172.5	0.13	0.03	0.23	0.62	0.56	0.36				76	60	133.0	1.087	5.5
K5	430746.374	5522863.42	382	546.1	10	22	0.1	2.2	2.6		300.5	0.67	0.67	0.90	0.59	0.58	0.40	6.0	7.2		48	35	109.1	1.087	7.0
Means			**427**	**541.2**	**11**	**15**	**0.54**	**7.5**	**7.2**	**108**	**236.1**	**0.89**	**0.85**	**0.82**	**0.53**	**0.47**	**0.31**	**6**	**7.5**	**6**	**59**	**43**	**129.4**	**1.084**	**6.7**

✚ Additional Information, as follows.
DR – June 24 – September 18, 1997
Kel – Kelowna method
DT[1] – July 7, 1997
DT[2] – July 24, 1997
DT[3] – August 13, 1997

IV. 1997 Hays Grid Sample Data

1998 Hays Site (Snowden)	Position Data		Moisture		Soil Characteristics								Petiole Nutrient Contents									Hand-Sampled Tuber Data				
Site	Fasting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Clay (%)		$CaCO_3$ (%)	NO_3-N (ppm)		PO_4-P (ppm)	K (ppm)		NO_3-N (%)			P (%)			K (%)			Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity	Chipping Score
Info✚			DR							Kel	AA	Kel	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]					
Depth (cm)				(0-100)	(0-60)	(60-90)	(0-30)	(0-60)	(60-90)	(0-15)	(0-30)	(0-30)														
D1	438562.2	5537593.3	432	525	8	5		3.8	2.5	17	176.9	119	1.25	0.21	0.06	0.48	0.13	0.09	6.2	7.3		61	61	120.4	1.085	50.5
E1	438562.2	5537525.3	428	599	22	42		3.9	1.7	20	243.8	155	1.69	0.81	0.26	0.38	0.12	0.09			6.6	48	47	109.8	1.084	44.5
F1	438562.2	5537457.3	443	562	11	28		4.1	2.9	13	123.6	74	1.45	0.83	0.13	0.49	0.12	0.10				56	55	111.2	1.088	44.5
G1	438562.2	5537389.3	442	577	13	35		5.0	1.7	15	136.1	87	1.56	0.29	0.25	0.39	0.13	0.10				51	50	121.8	1.084	44
H1	438562.2	5537321.3	433	574	17	30		2.5	2.3	17	127.5	81	1.70	0.51	0.10	0.31	0.15	0.10	6.1	6.9	5.8	48	47	148.3	1.085	52
I1	438562.2	5537253.3	426	525	8	25		3.6	2.2	15	127.5	76	1.52	0.87	0.22	0.42	0.15	0.11				54	53	105.8	1.084	48
C2	438630.2	5537661.3	411	559	30	29		6.1	1.4	10	163.5	91	2.07	0.63	0.34	0.27	0.11	0.09				56	55	132.7	1.090	50.5
D2	438630.2	5537593.3	424	545	6	14	0.05	8.9	3.9	13	172.5	111	1.70	0.99	0.18	0.37	0.12	0.10				56	52	143.7	1.082	51.5
E2	438630.2	5537525.3	427	569	18	38		3.5	1.5	16	335.4	206	1.94	0.51	0.27	0.30	0.14	0.09	6.5	8.4	7.4	61	59	158.6	1.083	52
F2	438630.2	5537457.3	407	528	22	41	0	8.7	1.5	13	151.9	99	1.50	0.98	0.19	0.33	0.12	0.10				44	44	134.2	1.089	54.5
G2	438630.2	5537389.3	444	596	31	43		4.2	1.5	12	136.6	85	1.83	0.76	0.37	0.25	0.12	0.09				45	45	123.1	1.088	43.5
H2	438630.2	5537321.3	453	583	15	36		3.1	1.1	12	123.5	69	1.82	1.17	0.27	0.34	0.20	0.11	6.4	7.5	5.1	52	51	150.1	1.085	46
I2	438630.2	5537253.3	396	480	6	4	0	6.5	4.7	16	105.4	60	0.92	0.15	0.02	0.47	0.14	0.12				37	36	133.7	1.083	43.5
J2	438630.2	5537185.3	415	498	5	4	0	5.4	1.3	15	102.6	64	1.12	0.21	0.01	0.50	0.18	0.12				39	39	130.6	1.083	39.5
B3	438698.2	5537729.3	438	574	33	40	1.35	3.3	1.8	14	178.0	90	1.47	0.52	0.14	0.23	0.11	0.10				40	38	97.8	1.091	51.5
C3	438698.2	5537661.3	450	547	11	37		5.3	2.2	14	137.5	76	1.36	0.46	0.19	0.25	0.10	0.09	6.3	7.0	6.1	55	54	124.5	1.088	46
D3	438698.2	5537593.3	415	559	21	45		3.2	1.5	13	132.4	72	1.15	0.61	0.21	0.31	0.11	0.09				56	52	177.5	1.085	50
E3	438698.2	5537525.3	378	497	10	20	0	9.4	1.6	18	298.6	176	1.75	0.93	0.15	0.34	0.13	0.09				68	61	179.5	1.082	44
F3	438698.2	5537457.3	390	485	7	5		4.6	2.2	20	109.9	65	0.35	0.06	0.01	0.46	0.14	0.10	6.2	6.6	6.3	47	46	109.2	1.087	45.5
G3	438698.2	5537389.3	415	501	8	8		2.7	0.5	15	111.8	75	1.07	0.16	0.03	0.31	0.10	0.11				49	48	154	1.087	45.5
H3	438698.2	5537321.3	389	506	6	7		3.4	7.1	16	130.5	93	1.29	0.29	0.06	0.45	0.15	0.10				47	45	121.2	1.084	41.5
I3	438698.2	5537253.3	438	564	27	32		2.1	1.4	9	130.6	78	1.45	0.71	0.20	0.36	0.15	0.10	6.3	5.8	4.2	58	57	136.6	1.088	47
J3	438698.2	5537185.3	369	504	6	6	0.85	2.7	1.9	24	131.4	83	1.23	0.36	0.09	0.42	0.15	0.11				50	50	118.8	1.080	49.5
K3	438698.2	5537117.3	450	587	14	43		5.4	3.8	13	86.5	59	1.41	0.51	0.26	0.45	0.17	0.11				56	55	136.3	1.088	50
a4	438766.2	5537763.3	419	551	15	31	1.2	3.4	1.4	12	159.6	97	1.64	0.55	0.27	0.22	0.11	0.10				50	47	162.7	1.091	47
b4	438766.2	5537695.3	405	548	28	29		4.8	1.2	15	210.4	111	1.87	0.90	0.32	0.24	0.10	0.09	6.1	6.8	7.0	46	40	149.7	1.085	45
c4	438766.2	5537627.3	379	522	15	44		2.4	1.5	15	110.1	72	1.53	0.94	0.35	0.32	0.12	0.09				66	65	134.2	1.090	47.5
d4	438766.2	5537559.3	397	541	20	40		3.0	1.5	13	191.1	107	1.92	1.02	0.25	0.26	0.11	0.09				58	52	168	1.087	47
e4	438766.2	5537491.3	382	467	8	18		2.4	1.6	13	125.1	85	1.31	0.16	0.05	0.38	0.12	0.09	6.1	7.3	6.9	58	57	150.2	1.085	42
f4	438766.2	5537423.3	388	479	11	24		4.3	1.0	15	292.5	155	1.85	0.89	0.01	0.29	0.10	0.11				46	43	146.4	1.086	46.5
g4	438766.2	5537355.3	373	529	23	39		3.8	1.7	12	100.9	67	1.42	0.56	0.09	0.37	0.11	0.10				49	48	136.1	1.086	39.5
h4	438766.2	5537287.3	409	597	30	43		2.3	1.5	10	132.8	77	1.75	1.06	0.35	0.26	0.10	0.09	6.1	7.1	5.5	55	53	135.2	1.090	50.5
i4	438766.2	5537219.3	409	524	8	18		3.3	1.5	11	133.9	88	1.76	0.61	0.42	0.42	0.12	0.12				55	55	155.2	1.085	44.5
j4	438766.2	5537151.3	399	513	7	11		2.4	0.7	8	81.8	52	1.29	0.46	0.04	0.44	0.17	0.12				46	44	145.1	1.084	44
k4	438766.2	5537083.3	400	510	8	7		6.6	2.1	12	94.5	57	1.86	0.89	0.28	0.43	0.20	0.13	6.2	6.2	4.6	51	50	122	1.083	47
A5	438834.2	5537797.3	402	516	19	27		2.7	2.4	11	232.2	127	1.97	0.61	0.22	0.20	0.13	0.08				53	53	154.1	1.086	46
B5	438834.2	5537729.3	441	568	30	37		4.5	1.8	16	216.7	122	2.13	0.92	0.25	0.18	0.11	0.08				56	55	153.3	1.089	48
C5	438834.2	5537661.3	432	555	9	12		5.1	1.7	15	136.2	87	1.17	0.14	0.02	0.36	0.12	0.09	6.3	7.2	7.0	40	40	124.5	1.082	48
D5	438834.2	5537593.3	410	539	15	45	0.7	3.2	2.8	14	154.9	92	1.60	0.16	0.03	0.39	0.13	0.11				47	46	143.1	1.084	48
E5	438834.2	5537525.3	394	478	10	12		5.6	3.0	12	106.4	64	1.83	0.16	0.07	0.5	0.19	0.12				54	54	177.1	1.086	46.5
F5	438834.2	5537457.3	375	489	11	38		9.9	2.8	14	112.0	68	1.83	0.23	0.11	0.42	0.14	0.12	6.2	6.8	6.3	61	55	140.1	1.087	38.5
G5	438834.2	5537389.3	380	546	18	40		2.6	2.8	11	121.5	71	1.55	0.40	0.10	0.42	0.13	0.12				48	48	121.4	1.082	45.5
H5	438834.2	5537321.3	396	516	12	36	0	6.1	2.7	14	134.0	82	1.49	0.65	0.27	0.45	0.15	0.14				48	46	138.6	1.086	42.5
I5	438834.2	5537253.3	412	573	19	38	0	3.1	1.9	11	103.1	69	1.58	0.77	0.45	0.43	0.16	0.12	6.2	7.0	4.9	65	59	159.1	1.085	39.5
J5	438834.2	5537185.3	424	535	8	25		2.6	2.1	13	113.1	71	1.13	0.25	0.05	0.44	0.16	0.12				44	43	133.5	1.090	46
K5	438834.2	5537117.3	448	590	19	32		2.8	3.0	10	107.4	67	1.13	0.53	0.02	0.36	0.13	0.13				32	31	98.5	1.086	47
L5	438834.2	5537049.3	445	591	27	45		2.7	1.7	15	226.0	120	1.29	0.91	0.31	0.47	0.22	0.13	6.4	7.6	6.1	53	50	155.5	1.082	43.5
Means			**412**	**539**	**15**	**28**	**0.4**	**4.3**	**2.1**	**14**	**150**	**90**	**1.52**	**0.58**	**0.18**	**0.36**	**0.14**	**0.10**	**6.2**	**7.0**	**6.0**	**51**	**50**	**137.9**	**1.086**	**46.3**

✚ Additional Information, as follows.

DR – June 23 – September 4, 1997
Kel – Kelowna method
AA – Ammonium Acetate method
DT[1] – July 3, 1997
DT[2] – July 23, 1997
DT[3] – August 12, 1997

V. 1998 Fincastle Grid Sample Data

1998 Fincastle Site (Russet Burbank)																														
	Position Data		Moisture				Soil Characteristics								Petiole Nutrient Contents									Hand-Sampled Tuber Data				
Site	Easting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Available Water (%)		Clay (%)		$CaCO_3$ (%)	NO_3-N (ppm)		PO_4-P (ppm)	K (ppm)		NO_3-N (%)			P (%)			K (%)			Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity	French Fry Score
Info✤			DR									Kel	AA	Kel	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]					
Depth (cm)				(0-100)	(0-60)	(60-100)	(0-60)	(60-90)	(0-30)	(0-60)	(60-90)	(0-15)	(0-30)	(0-30)														
A1	430812.375	5523543.126	361	363.2	34	64	10	11	0.20	1.8	1.1	32.5	125.5	148.6	0.86	1.36	1.57	0.30	0.19	0.13	6.5	6.6	5.3	39	27	141.0	1.066	9.3
B1	430811.632	5523475.175	379	391.4	31	52	10	28		1.4	5.3	20.8		152.4		1.05	0.95		0.13	0.09		6.4	4.8	42	27	96.1	1.071	9.3
C1	430810.417	5523407.056	382	395.3	122	88	12	8		2.2	1.0	40.9		258.8	1.26	1.71	1.21	0.28	0.21	0.14	7.4	8.2	8.5	42	30	139.4	1.074	9.5
D1	430809.695	5523339.225	382	376.7	68	177	6	7		0.9	1.5	34.0		129.4	0.19	0.40	0.22	0.43	0.19	0.12	5.7	5.2	3.4	44	33	105.8	1.075	8.8
E1	430808.867	5523271.117	389	387.5	83	170	8	8		7.1	3.5	39.8		163.6	0.61	1.66	1.57	0.46	0.27	0.21	6.7	7.1	6.0	46	34	134.7	1.084	9.3
F1	430807.816	5523203.228	573	531.3	165	203	10	21		1.1	0.9	34.8		105.4	0.51	0.62	0.52	0.19	0.12	0.10	6.0	5.1	4.6	30	22	110.4	1.068	9.0
G1	430806.907	5523135.176	396	360.2	63	111	8	7	2.90	0.9	1.2	39.3	92.5	121.0	0.62	1.11	1.28	0.20	0.13	0.15	6.0	4.6	5.3	45	31	128.1	1.075	8.5
H1	430806.02	5523067.21	421	425.9	56	63	11	12		1.4	1.7	22.8		116.8	0.86	1.04	1.22	0.17	0.14	0.17	6.2	4.7		37	24	138.1	1.078	8.8
I1	430805.056	5522999.311	432	436.0	78	114	9	8		4.2	9.4	47.0		94.6	0.58	0.36	0.65	0.25	0.13	0.13	5.9	5.3	5.3	35	20	112.5	1.067	8.3
J1	430804.199	5522931.362	447	448.3	110	191	10	17		1.2	4.3	57.8		114.0	0.44	0.98	0.92	0.33	0.19	0.20	6.2	5.4	6.5	39	35	175.8	1.073	6.8
K1	430803.338	5522863.337	434	461.5	95	108	24	27		2.7	3.9	62.0		157.8	1.67	1.82	1.63	0.30	0.26	0.20	6.5	7.5	7.1	55	47	171.1	1.083	7.8
A2	430885.597	5523576.237	289	306.5	-4	37	13	10		2.4	3.0	19.7		131.2	2.26	2.02	1.87	0.33	0.17	0.13	7.0	5.7	6.0	37	32	172.6	1.074	8.3
B2	430884.757	5523508.167	400	463.9	28	11	11	44		1.8	6.6	21.1		80.0	1.45	1.97	2.48	0.33	0.22	0.20	6.0	5.2	4.3	39	34	130.7	1.083	9.0
C2	430883.885	5523440.255	361	415.0	74	114	21	23	8.65	10.5	30.5	33.8	163.5	132.8	1.14	1.23	1.66	0.27	0.21	0.20	5.9	6.7	7.2	31	17	113.1	1.074	8.5
D2	430883.145	5523372.328	364	393.0	81	51	9	6		2.4	3.0	31.6		229.4	1.75	1.88	1.99	0.33	0.21	0.21	7.1	7.9	8.1	57	42	137.0	1.079	9.3
E2	430882.246	5523304.386	373	407.9	130	150	10	10		1.1	3.0	32.7		195.4	1.30	1.50	1.65	0.22	0.16	0.18	7.6	6.2	7.5	47	39	206.0	1.077	9.0
F2	430881.387	5523236.416	360	418.0	95	168	10	9	6.95	2.7	4.2	13.3	87.0	178.6	1.07	1.67	1.25	0.14	0.15	0.19	6.6	5.0	6.1	31	26	171.1	1.076	9.5
G2	430880.517	5523168.414	356	402.0	71	115	9	9		2.2	5.6	26.4		184.0	1.28	1.67	1.65	0.19	0.11	0.19	8.0	5.2	7.2	52	50	198.5	1.080	7.8
H2	430879.658	5523100.519	528	533.6	74	114	9	8		1.0	1.5	23.7		101.2	1.16	1.69	0.92	0.24	0.17	0.19	6.9	6.0	7.4	40	34	156.4	1.074	9.0
I2	430878.826	5523032.568	402	417.8	80	217	10	9		0.8	1.1	20.4		154.4	1.02	1.58	1.70	0.22	0.15	0.20	6.8	4.8	6.7	41	32	130.3	1.070	8.8
J2	430877.991	5522964.592	373	391.8	92	135	11	10	0.40	0.8	0.8	32.1	119.0	166.6	1.16	1.47	1.39	0.36	0.17	0.19	7.0	5.8	6.0	58	43	163.3	1.077	7.8
K2	430877.172	5522896.629	388	462.7	37	108	14	16		2.6	4.4	46.2		167.6	1.27	1.79	1.75	0.45	0.28	0.21	7.4	6.4	6.4	45	31	142.0	1.079	9.7
L2	430876.273	5522828.614	313	351.0	87	109	14	20		2.9	3.9	39.1		148.8	2.51	2.15	2.01	0.46	0.20	0.22	7.2	5.3	6.7	44	34	131.8	1.074	9.0
A3	430958.199	5523541.139	314	313.9	65	128	13	13		1.0	3.2	27.9		174.6	0.88	1.07	1.30	0.21	0.10	0.08	7.3	5.3	4.1	32	16	77.1	1.061	9.0
B3	430957.419	5523473.105	370	351.4	60	100	8	8		0.6	1.4	20.3		102.0	0.66	0.84	0.99	0.33	0.11	0.09	8.5	6.1	5.0	46	26	92.9	1.074	8.0
C3	430956.612	5523405.18	380	360.2	132	177	17	31	0.55	0.7	0.6	43.1	286.0	310.0	1.60	1.57	1.50	0.30	0.16	0.10	9.0	9.0	9.0	50	41	145.5	1.075	9.3
D3	430955.742	5523337.179	415	405.3	73	117	12	14		0.2	1.4	20.1		138.0	1.26	1.78	1.62	0.18	0.10	0.10	7.1	5.0	3.7	40	28	105.1	1.076	8.8
E3	430954.96	5523269.237	408	408.6	91	187	12	15		0.3	0.7	11.8		100.0	1.07	1.68	1.74	0.19	0.11	0.10	7.4	4.3	3.9	33	23	106.5	1.075	9.3
F3	430954.204	5523201.266	414	407.6	40	76	9	9		0.0	0.0	11.9		59.6	0.08	0.12	0.12	0.15	0.08	0.07	6.6	5.2	5.0	29	15	86.6	1.065	7.5
G3	430953.393	5523133.326	398	399.6	72	119	10	15		0.3	1.7	9.14		57.8	0.48	0.73	0.81	0.23	0.09	0.09	6.7	4.0	3.2	41	31	116.5	1.076	7.8
H3	430952.655	5523065.387	488	462.0	139	137	15	13	8.15	8.1	13.2	16.3	91.5	109.0	1.44	1.36	0.89	0.20	0.12	0.09	7.7	5.6	5.4	31	22	127.4	1.070	8.5
I3	430951.737	5522997.333	456	442.1	108	108	11	15		2.8	8.1	21.0		122.6	0.91	0.97	0.97	0.25	0.10	0.10	8.1	6.0	3.8	39	29	116.7	1.069	8.3
J3	430951.063	5522929.518	408	417.2	74	99	14	12		1.5	4.4	21.8		92.2	1.71	1.67	1.38	0.19	0.12	0.12	7.5	5.0	6.5	30	22	137.7	1.075	8.5
K3	430950.116	5522861.567	320	340.8	46	137	15	36		5.8	23.9	42.4		257.4	2.03	2.17	1.89	0.30	0.10	0.11	8.5	7.2	7.5	42	36	156.8	1.064	8.5
B4	431030.577	5523506.315	285	324.8	51	91	10	10	0.25	1.1	1.3	24.6	84.0	168.6	0.91	1.36	1.48	0.29	0.17	0.11	5.0	5.2	3.9	36	29	111.4	1.070	8.5
C4	431029.8	5523438.124	391	455.2	101	151	23	31		1.4	2.6	34.7		583.2	1.64	1.47	1.46	0.23	0.18	0.12	6.4	6.2	5.5	52	31	128.5	1.068	8.3
D4	431029.115	5523370.278	395	442.3	79	109	19	24		0.9	1.1	24.7		212.2	1.11	1.30	1.09	0.22	0.17	0.11	6.5		5.8	45	28	133.5	1.075	9.5
E4	431028.422	5523302.245	418	435.5	102	120	16	30		1.2	2.0	29.3		143.8	1.01	1.35	1.48	0.27	0.18	0.14	6.4	5.3	4.8	45	35	141.2	1.084	9.8
F4	431027.637	5523234.197	427	451.9	45	114	16	35	1.10	1.0	1.6	15.8	65.0	73.0	1.04	1.24	1.42	0.16	0.16	0.11	5.8		3.6	44	35	117.8	1.076	7.5
G4	431027.011	5523166.323	418	443.4	107	198	9	9		0.8	1.7	23.9		451.8	0.80	0.95	1.18	0.28	0.19	0.12	5.9	5.3	4.4	47	29	109.4	1.074	8.8
H4	431026.258	5523098.333	422	422.3	103	181	10	14		0.8	0.8	27.5		180.4	0.46	0.25	0.42	0.20	0.14	0.10	6.1	7.5	6.5	42	25	85.3	1.066	9.0
I4	431025.488	5523030.342	398	390.9	63	79	9	10		1.0	1.0	38.6		117.6	1.08	1.53	1.36	0.18	0.20	0.12	6.1	6.8	5.7	42	34	119.0	1.076	8.2
J4	431024.776	5522962.35	433	429.6	63	98	17	14		1.2	2.9	12.0		260.0	0.82	1.29	1.17	0.14	0.14	0.13	5.4	4.9	4.0	33	25	107.0	1.070	8.5
K4	431023.95	5522894.345	316	347.2	-2	9	13	14	0.45	1.0	1.4	35.6	196.5	429.2	1.35	1.56	1.01	0.20	0.16	0.14	6.7	6.5	6.6	53	36	117.1	1.074	9.0
B5	431100.839	5523472.144	319	348.5	21	9	9	7		1.8	2.9	30.6		94.8	1.07	1.88	1.49	0.48	0.21	0.15	5.8	5.7	3.8	49	32	80.9	1.080	8.5
C5	431100.222	5523403.549	320	349.0	35	18	10	10		1.0	1.2	40.8		128.8	0.96	1.25	1.53	0.27	0.14	0.11	6.0	5.3	2.6	45	27	92.6	1.080	8.5
D5	431099.213	5523334.033	400	424.6	122	144	21	25	6.15	2.3	9.6	25.5	134.0	240.8	1.41	1.23	0.88	0.30	0.20	0.16	6.6	6.5	6.4	45	37	191.5	1.083	8.5
E5	431098.364	5523267.723	396	425.4	108	165	16	31		1.9	6.9	31.1		213.8	1.22	2.09	1.20	0.43	0.26	0.17	6.9	7.4	6.6	65	54	123.4	1.085	9.5
F5	431097.599	5523200.61	413	416.1	101	181	9	25		2.6	2.5	31.5		145.6	0.78	1.65	0.89	0.39	0.26	0.15	6.6	6.4	4.8	53	42	109.7	1.083	8.5
G5	431096.721	5523133.014	426	432.1	68	134	9	9	0.00	1.5	3.1	39.2	43.5	156.2	0.33	1.73	1.44	0.65	0.33	0.24	6.9	6.4	5.7	76	52	118.6	1.084	8.7
H5	431095.435	5523062.111	399	427.5	36	68	9	9		1.0	2.7	38.3		201.8	0.15	0.63	0.40	0.26	0.12	0.09	7.1	6.7	7.0	50	38	124.7	1.076	8.6
I5	431093.623	5522995:354	449	496.2	104	135	11	28		1.3	2.1	31.2		283.6	1.26	2.28	1.15	0.43	0.28	0.23	6.9	7.5	7.8	69	59	167.8	1.084	8.5
J5	431092.706	5522928.4	324	357.5	52	113	20	28		0.5	1.3	32.7		222.4	2.27	1.93	1.64	0.44	0.28	0.17	6.8	7.4	7.4	67	55	147.2	1.082	9.8
Means			**393**	**408.9**	**76**	**116**	**12**	**16**	**2.98**	**1.9**	**3.9**	**29.9**	**124**	**174.8**	**1.09**	**1.39**	**1.28**	**0.28**	**0.17**	**0.14**	**6.7**	**6.0**	**5.7**	**44**	**33**	**130.2**	**1.075**	**8.7**

✤ Additional Information, as follows.
DR – June 19 – September 16, 1998
Kel – Kelowna method
AA – Ammonium Acetate method
DT[1] – July 7, 1998
DT[2] – July 23, 1998
DT[3] – August 11, 1998

VI. 1998 Hays Grid Sample Data

1998 Hays Site (Snowden)																													
	Position Data		Moisture				Soil Characteristics								Petiole Nutrient Contents									Hand-Sampled Tuber Data					
Site	Easting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Available Water (%)		Clay (%)		$CaCO_3$ (%)	NO_3-N (ppm)		PO_4-P (ppm)	K (ppm)		NO_3-N (%)			P (%)			K (%)			Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity	French Fry Score	Chipping Score
Info✚			DR									Kel	AA	Kel	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]						
Depth (cm)				(0-100)	(0-60)	(60-100)	(0-60)	(60-90)	(0-30)	(0-60)	(60-90)	(0-15)	(0-30)	(0-30)															
D1	438531.588	5536799.196	421	475	76	100	26	29		5.7	2.7	21		135	1.42	0.46	1.05	0.26	0.11	0.11	6.6	6.0		50	43	84	1.086		56.5
E1	438530.645	5536731.164	475	520	109	125	24	28		2.5	0.6	5		165	1.17	0.30	1.07	0.16	0.09	0.11	7.2	6.9	5.9	56	45	87	1.086		59.8
F1	438529.643	5536663.144	396	442	79	122	19	16	5.15	0.6	0.0	2	159	174	1.40	0.99	1.36	0.20	0.11	0.15	7.5	6.8	6.8	43	36	82	1.087		60.3
G1	438528.756	5536595.036	414	442	89	182	8	16		0.7	5.7	21		103	0.65	0.32	1.26	0.26	0.15	0.36	6.7	6.8	6.9	45	39	89	1.082		59.0
H1	438527.841	5536527.115	465	502	187	255	9	12		3.4	2.0	22		157	0.82	0.55	1.28	0.23	0.09	0.18	8.0	9.0	8.4	45	37	83	1.080		59.0
I1	438526.875	5536459.222	423	453	95	145	10	10	0	3.7	3.0	26	224	249	0.94	0.53	1.70	0.39	0.15	0.33	8.2	8.6	9.4	54	47	92	1.079		61.0
B2	438606.003	5536900.103	430	493	80	97	12	10		3.2	0.6	31		255	1.84	1.44	1.60	0.71	0.33	0.34	8.4	8.6	8.2	66	60	96	1.078		62.0
C2	438605.04	5536832.07	385	428	86	154	11	25		7.7	2.7	32		211	0.71	0.65	0.93	0.36	0.13	0.17	7.9	8.0	6.8	62	58	107	1.081		59.0
D2	438604.228	5536764.072	455	491	115	174	14	31	0	5.8	1.9	29	193	230	0.93	0.78	1.25	0.38	0.15	0.21	7.8	7.4	7.6	70	63	113	1.072		58.8
E2	438603.286	5536696.175	388	412	99	171	11	13		6.4	1.6	34		181	0.30	0.16	0.53	0.36	0.15	0.15	7.7	7.8	6.7	52	46	101	1.080		53.8
F2	438602.362	5536628.131	402	458	104	191	6	18		1.6	1.9	22		109	0.18	0.36	1.18	0.36	0.23	0.33	6.9	6.8	6.8	55	50	112	1.079		56.0
G2	438601.431	5536560.217	386	407	110	164	7	27		1.8	8.0	20		84	0.41	0.38	0.61	0.42	0.24	0.21	6.8	7.1	5.7	54	46	81	1.081		60.3
H2	438600.605	5536492.16	420	468	113	189	10	33		5.0	2.8	28		164	0.48	0.58	1.04	0.39	0.20	0.22	7.5	6.9	6.1	63	56	88	1.079		63.8
I2	438599.74	5536424.228	408	423	114	205	7	11	0	2.3	3.4	26	158	136	0.42	0.37	1.05	0.37	0.19	0.22	7.7	7.1	7.3	49	44	107	1.077		57.3
J2	438598.797	5536356.45	425	493	72	101	7	17		0.7	1.7	19		160	0.44	0.50	0.75	0.31	0.18	0.15	7.7	7.2	6.6	46	40	112	1.083		61.8
B3	438679.351	5536933.121	466	498	86	144	13	34		4.1	1.0	24		190	0.90	0.77	0.93	0.22	0.09	0.12	7.6	7.9	6.2	68	61	97	1.086		62.0
C3	438678.595	5536865.14	416	443	97	183	11	28		3.7	1.8	21		177	0.43	0.50	1.06	0.32	0.10	0.13	7.7	7.8	7.2	63	60	109	1.082		55.0
D3	438677.665	5536797.213	412	399	100	184	7	9		1.8	2.3	23		124	0.29	0.23	0.70	0.41	0.10	0.17	7.3	6.9	6.6	46	42	98	1.085		60.0
E3	438676.925	5536729.388	386	395	129	180	10	29		6.9	10.7	27		154	0.68	0.49	0.86	0.38	0.10	0.16	7.4	6.9	6.6	52	44	99	1.078		61.5
F3	438676.024	5536661.359	388	428	154	205	8	33	0	1.6	2.8	24	96	92	0.35	0.48	0.37	0.38	0.14	0.14	7.0	5.9	6.0	41	32	67	1.077		61.3
G3	438675.042	5536593.392	377	387	257	284	7	6		1.6	2.0	25		158	0.01	0.11	0.42	0.17	0.08	0.12	5.8	7.2	7.4	30	19	48	1.061		64.8
H3	438674.216	5536525.461	408	426	244	273	7	7		4.5	2.4	37		131	0.04	0.06	0.18	0.25	0.09	0.15	4.9	7.1	7.2	40	27	56	1.072		61.8
I3	438673.328	5536457.421	411	399	202	242	7	13		2.4	1.8	2		128	0.59	0.31	0.62	0.51	0.14	0.14	7.1	7.8	7.3	45	38	74	1.079		62.3
J3	438672.503	5536389.524	419	422	94	118	10	15	0	1.8	2.4	24	161	146	1.03	0.66	0.70	0.31	0.10	0.13	7.3	7.4	7.6	39	34	88	1.078		55.3
K3	438671.534	5536321.514	417	413	93	112	10	10		6.9	2.9	28		172	0.63	0.41	1.05	0.27	0.09	0.14	7.4	8.0	6.9	42	36	82	1.075		61.8
A4	438752.834	5536966.219	442	495	76	81	9	8		3.8	2.3	26		166	0.85	0.92	1.10	0.50	0.19	0.17	7.1	7.4	5.4	58	53	96	1.078		61.3
B4	438752.263	5536898.3	436	497	82	136	14	40		2.4	0.7	18		213	1.39	1.21	1.32	0.37	0.15	0.21	7.4	7.4	7.3	50	44	100	1.080		59.3
C4	438751.451	5536830.325	470	518	115	181	16	38	0	2.5	0.7	16	190	205	1.40	1.48	1.57	0.38	0.19	0.25	7.5	7.1	7.2	69	62	92	1.082		62.5
D4	438750.56	5536762.421	441	479	137	201	8	17		1.8	4.6	16		97	0.61	0.67	1.08	0.41	0.24	0.22	6.9	6.9	5.4	61	56	98	1.081		55.5
E4	438749.75	5536694.55	430	487	144	202	9	15		2.2	1.7	22		176	1.14	1.36	1.25	0.50	0.20	0.28	7.5	7.4	7.5	75	68	106	1.078		63.0
F4	438748.917	5536626.513	422	495	233	218	10	31		2.6	5.9	18		144	0.13	0.27	0.47	0.29	0.14	0.20	5.7	6.8	6.3	41	24	57	1.082		64.0
G4	438748.016	5536558.501	418	468	232	288	8	8		4.1	1.9	24		308	0.28	0.56	0.93	0.32	0.17	0.23	6.6	7.9	6.9	48	36	63	1.073		58.5
H4	438747.285	5536490.606	412	490	167	220	15	30		3.5	3.5	23		184	0.57	0.05	0.72	0.29	0.18	0.22	6.3	7.4	7.8	54	42	69	1.076		53.3
I4	438746.373	5536422.601	439	507	94	144	27	32	0	1.1	0.7	20	187	178	1.48	1.13	1.38	0.37	0.19	0.24	7.4	6.7	7.5	64	60	105	1.080		61.0
J4	438745.465	5536354.681	428	493	110	168	29	38		4.0	0.0	12		247	2.13	1.42	1.03	0.30	0.17	0.18	7.7	7.1	7.5	60	55	102	1.084		57.5
K4	438744.374	5536286.5	416	506	72	134	8	30		1.7	1.5	14		90	0.80	0.35	0.96	0.42	0.16	0.32	7.0	6.7	6.1	38	30	75	1.079		59.5
A5	438826.358	5536999.112	512	554	61	80	25	45		5.6	1.5	18		176	1.40	1.70	1.55	0.75	0.29	0.19	7.5	7.2	7.9	68	54	127	1.077	9.0	
B5	438825.46	5536931.216	481	514	48	84	27	29	0	1.3	0.0	13	190	185	0.59	0.88	0.97	0.59	0.17	0.13	7.8	7.1	7.9	71	59	117	1.076	8.3	
C5	438824.708	5536863.288	484	504	70	95	16	37		2.6	1.5	16		160	0.43	0.80	1.56	0.64	0.17	0.12	7.8	7.0	7.0	69	46	100	1.077	8.8	
D5	438823.788	5536795.26	466	486	92	108	16	37		1.9	1.3	11		113	0.38	0.65	1.34	0.60	0.16	0.13	7.8	6.7	6.6	80	62	119	1.078	7.5	
E5	438822.922	5536727.377	447	451	191	213	8	10	0	3.1	3.1	19	166	181	0.08	0.17	0.86	0.78	0.27	0.13	7.7	7.5	6.9	55	28	74	1.067	8.3	
F5	438822.052	5536659.395	427	443	173	214	7	11		3.4	1.4	26		215	0.11	0.05	0.70	0.76	0.21	0.13	7.6	7.3	7.3	62	30	65	1.068	9.0	
G5	438821.264	5536591.318	406	429	197	217	7	17		6.8	7.3	26		112	0.03	0.05	0.33	0.71	0.23	0.14	7.2	6.4	6.4	52	28	70	1.072	8.0	
H5	438820.662	5536523.294	423	475	160	148	10	31	0	2.2	1.3	24	147	139	0.02	0.13	0.12	0.46	0.17	0.12	6.5	7.7	7.4	0					
I5	438819.477	5536455.622	450	469	147	121	20	35		1.7	1.7	13		278	0.10	0.02	0.15	0.23	0.09	0.08	6.3	7.4	8.0	0					
J5	438818.753	5536387.448	444	410	129	246	7	8		1.8	1.0	22		156	0.15	0.54	1.16	0.61	0.21	0.13	7.6	7.0	7.6	60	41	92	1.074	7.8	
K5	438817.96	5536319.488	424	449	75	129	7	11	0.05	0.7	1.8	15	109	91	0.23	0.39	1.00	0.71	0.14	0.18	7.4	7.1	6.6	46	27	79	1.068	8.3	
L5	438817.128	5536251.791	455	489	83	138	10	25		2.4	1.8	27		128	0.58	0.30	1.49	0.73	0.16	0.25	7.3	7.7	6.5	71	47	100	1.075	8.0	
Means			**428**	**463**	**122**	**168**	**12**	**22**	**0.43**	**3.1**	**2.4**	**21**	**165**	**165**	**0.67**	**0.57**	**0.97**	**0.42**	**0.16**	**0.19**	**7.2**	**7.3**	**7.0**	**53**	**45**	**90**	**1.078**	**8.3**	**59.7**

✚ Additional Information, as follows.

DR – June 19 – September 9, 1998
Kel – Kelowna method
AA – Ammonium Acetate method
DT[1] – July 6, 1998
DT[2] – July 22, 1998
DT[3] – August 10, 1998

VII. 1999 Fincastle Grid Sample Data

1999 Fincastle Site (FL1625)	Position Data		Moisture		Soil Characteristics										Petiole Nutrient Contents									Hand-Sampled Tuber Data			
Site	Easting (m)	Northing (m)	Irrigation + Precipitation (mm)	Consumptive Use (mm)	Avaliable Water %		Clay (%)		$CaCO_3$ (%)	NO_3-N (ppm)		PO_4-P (ppm)	K (ppm)		NO_3-N (%)			P (%)			K (%)			Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity
Info✚			DR									Kel	AA	Kel	DT^1	DT^2	DT^3	DT^1	DT^2	DT^3	DT^1	DT^2	DT^3				
Depth (cm)				(0-100)	(0-60)	(60-100)	(0-60)	(60-90)	(0-30)	(0-60)	(60-90)	(0-15)	(0-30)	(0-30)													
A1	434730.679	5528125.947	334	341	105	89	20	21	3.6	1.7	2.3	16	231	143	0.33	0.38	0.34	0.50	0.17	0.16	9.6	8.0	5.4	32	28	117.8	1.107
B1	434729.205	5528082.462	317	321	81	76	22	22	3.4	0.6	0.0	12	180	110	0.42	0.79	1.16	0.14	0.14	0.14	9.0	7.3	5.3	35	32	140.0	1.104
C1	434727.815	5528002.959	342	347	68	19	17	23	1.1	0.0	0.0	18	165	90	1.22	1.09	0.62	0.33	0.31	0.22	8.6	8.2	5.3	28	23	129.4	1.104
D1	434727.121	5527924.325	313	323	76	42	24	36	2.0	0.3	0.0	27	140	80	1.12	0.85	0.61	0.41	0.24	0.22	8.8	7.8	5.3	37	32	137.6	1.105
E1	434726.007	5527843.383	310		70	56	15	19	1.0	0.5	0.0	63	164	95	1.35	1.45	1.19	0.63	0.52	0.42	9.4	8.7	5.3	35	31	145.5	1.097
F1	434724.132	5527763.290	348	335	108	102	12	20	0.6	0.4	0.0	54	136	83	0.43	1.49	1.71	0.72	0.47	0.41	9.3	7.8	5.4	27	26	131.6	1.098
G1	434723.837	5527683.163	349	329	109	152	15	33	0.4	0.5	0.5	54	168	108	0.85	1.16	1.77	0.67	0.51	0.39	9.5	8.7	5.3	31	29	148.0	1.097
H1	434722.733	5527603.904	346	295	58	19	11	12	0.7	0.2	0.5	43	161	105	0.51	0.38	0.72	0.55	0.43	0.34	9.7	8.4	5.3	33	28	177.2	1.100
I1	434721.204	5527523.984	329	341	40	13	17	31	0.6	0.6	0.0	48	145	92	2.06	1.46	1.10	0.65	0.59	0.47	10.4	9.3	5.2	34	31	132.4	1.099
J1	434720.141	5527442.917	344	343	67	63	12	22	0.4	0.2	0.0	35	106	67	0.72	1.07	1.27	0.62	0.48	0.43	9.6	8.2	5.3	42	31	167.6	1.097
K1	434720.093	5527389.989	301	391	41	55	12	18	0.6	1.7	3.9	46	203	133	0.20	0.12	0.95	0.63	0.42	0.27	10.1	9.2	5.3	34	31	117.7	1.103
A2	434821.375	5528111.025	356	352	159	147	26	28	4.6	1.4	0.7	12	196	118	0.93	0.48	0.66	0.29	0.17	0.16	9.8	8.1	5.3	31	28	121.5	1.105
B2	434819.845	5528041.725	327	350	98	35	23	20	6.3	0.4	0.0	19	138	78	1.22	0.74	0.52	0.29	0.21	0.23	8.2	7.4	5.7	36	26	145.6	1.111
C2	434818.367	5527960.253	330	342	28	19	24	22	9.8	0.2	0.0	14	118	64	1.16	0.91	0.80	0.15	0.16	0.17	8.0	6.7	4.9	33	28	132.1	1.110
D2	434817.490	5527881.581	312	336	40	10	24	26	6.4	1.1	0.8	48	129	71	1.08	1.04	0.78	0.47	0.24	0.21	9.2	8.0	5.0	39	29	188.4	1.100
E2	434816.193	5527802.046	362	343	52	32	19	22	2.7	1.1	0.6	48	122	67	1.53	1.54	1.30	0.59	0.56	0.54	8.8	7.8	5.3	33	28	144.8	1.097
F2	434815.005	5527721.508	277	293	51	46	13	19	0.8	0.8	4.7	56	152	87	0.56	0.94	0.80	0.64	0.50	0.39	9.9	8.4	5.0	47	33	179.0	1.097
G2	434813.753	5527640.814	301	298	56	55	13	20	1.5	0.6	13.4	54	169	100	0.57	1.24	1.33	0.68	0.53	0.43	10.0	8.9	5.3	47	34	185.5	1.099
H2	434812.930	5527561.976	287	307	39	48	11	16	1.0	0.8	7.1	46	131	80	0.37	0.41	0.99	0.62	0.48	0.28	9.8	8.6	5.0	39	34	148.9	1.102
I2	434811.710	5527482.351	326	332	47	30	11	14	1.3	0.2	0.0	35	103	55	0.31	0.25	0.40	0.62	0.42	0.23	9.6	8.1	5.3	37	31	156.8	1.113
J2	434810.697	5527412.397	341	368	14	-15	12	12	1.0	0.2	0.7	44	121	70	0.76	0.49	0.78	0.68	0.49	0.33	10.1	8.5	5.3	39	33	140.0	1.104
A3	434892.218	5528136.163	224	209	112	100	22	26	4.2	10.7	1.7	50	247	157	0.58	0.62	1.01	0.40	0.19	0.18	9.6	8.2	5.4	34	27	98.3	1.101
B3	434891.082	5528081.190	424	400	143	209	28	36	2.7	0.4	0.0	20	178	95	1.57	0.83	0.53	0.29	0.19	0.20	8.9	7.9	4.0	45	35	143.5	1.103
C3	434890.411	5528001.030	346	352	78	31	22	22	3.1	0.3	0.0	18	125	73	0.72	0.66	0.34	0.30	0.17	0.25	8.5	7.4	4.0	37	33	119.2	1.105
D3	434888.758	5527920.383	278	268	58	19	16	19	1.2	0.2	0.0	26	155	85	0.97	0.89	0.95	0.45	0.28	0.29	9.1	8.2	3.9	35	30	122.3	1.100
E3	434887.428	5527842.011	329	343	68	133	19	28	1.9	3.0	1.8	56	143	76	2.00	1.57	1.47	0.51	0.44	0.41	9.6	7.8	4.0	42	36	147.6	1.090
F3	434886.304	5527761.250	291		34	2	11	23	0.6	1.0	14.3	53	120	70	0.20	0.85	0.98	0.56	0.49	0.45	9.1	7.8	4.0	45	32	150.4	1.095
G3	434885.096	5527681.959	276	253	63	14	12	20	0.8	1.3	11.7	59	153	92	0.52	0.77	0.93	0.60	0.44	0.44	9.7	8.2	3.9	47	38	159.6	1.098
H3	434884.016	5527601.598	352	333	63	121	10	12	0.6	0.8	4.9	52	138	88	0.44	0.28	0.43	0.68	0.46	0.38	9.6	8.0	4.0	44	37	135.8	1.100
I3	434882.794	5527522.059	289	282	57	99	10	10	0.6	0.8	2.8	65	137	92	0.64	0.42	0.68	0.69	0.43	0.37	9.9	8.5	4.0	36	32	169.1	1.100
J3	434881.429	5527441.844	324	307	82	90	11	15	0.5	1.7	13.0	63	159	108	1.23	0.71	1.15	0.66	0.42	0.44	10.0	8.7	3.7	20	17	149.8	1.090
K3	434880.339	5527386.710	418		61	115	10	19	0.5	1.4	7.0	67	199	141	0.18	0.46	0.64	0.80	0.45	0.40	10.3	8.9	3.6	39	34	136.4	1.102
A4	434975.144	5528110.152	235	208	57	92	19	23	0.8	0.7	0.0	39	233	129	1.86	1.14	1.16	0.37	0.22	0.16	9.1	8.4	3.9	34	27	117.1	1.096
B4	434974.128	5528040.093	263	289	131	110	35	29	4.2	0.9	0.6	16	139	75	1.74	1.09	0.45	0.29	0.22	0.16	8.5	7.8	3.9	38	29	126.8	1.106
C4	434972.866	5527960.541	287	302	63	61	15	22	0.7	1.9	2.8	24	174	102	1.14	1.14	0.86	0.58	0.33	0.29	9.6	8.5	4.3	37	32	132.3	1.102
D4	434971.754	5527880.276	299	321	50	31	18	21	1.0	1.1	0.8	39	146	85	1.77	1.83	1.58	0.50	0.50	0.50	8.8	8.2	3.7	37	32	131.6	1.090
E4	434970.519	5527800.434	250	282	33	6	10	10	0.5	1.9	14.3	63	137	86	1.12	0.44	0.80	0.63	0.51	0.35	10.3	9.3	3.8	42	39	128.4	1.106
F4	434969.323	5527720.352	270	283	24	38	12	16	0.6	3.0	10.4	56	157	98	0.95	0.72	0.97	0.55	0.48	0.35	9.8	8.7	3.6	43	26	177.5	1.094
G4	434967.996	5527640.531	275	258	31	58	13	22	0.7	1.3	20.7	52	144	85	0.85	0.99	0.82	0.66	0.53	0.48	10.2	8.7	3.6	44	30	123.2	1.097
H4	434966.619	5527560.295	387	353	52	62	11	16	0.8	0.9	4.6	42	139	87	0.55	0.33	0.40	0.74	0.49	0.42	10.2	8.5	3.8	46	43	113.5	1.099
I4	434965.319	5527480.535	261	253	32	46	10	12	0.5	4.7	12.4	53	169	113	0.64	0.41	0.56	0.70	0.40	0.30	10.4	8.6	3.7	41	37	149.0	1.099
J4	434963.881	5527410.613	283	267	37	93	12	21	1.0	8.0	29.8	46	169	106	1.45	1.50	1.51	0.67	0.49	0.44	10.8	8.8	3.9	45	41	127.4	1.088
B5	435050.858	5528079.374	158	166	66	102	31	30	4.3	23.6	8.3	23	188	111	1.94	1.72	1.68	0.25	0.24	0.22	8.6	8.1	4.0	36	32	144.8	1.103
C5	435050.299	5527999.572	281	316	47	1	22	22	13.2	1.4	1.3	20	146	93	1.49	1.22	1.27	0.25	0.21	0.22	8.8	8.3	3.7	27	26	126.4	1.106
D5	435049.829	5527919.449	257	248	67	67	31	37	1.1	1.9	1.2	22	205	119	1.92	1.57	1.48	0.35	0.28	0.35	9.1	8.6	3.5	38	29	139.0	1.093
E5	435048.239	5527839.823	329	329	-10	41	13	24	0.8	4.5	18.4	72	150	92	0.50	0.92	1.17	0.64	0.51	0.49	10.4	8.5	3.7	40	31	173.4	1.099
F5	435046.776	5527759.335	301	308	30	39	10	17	1.0	2.0	4.6	70	193	120	1.01	0.42	0.53	0.64	0.49	0.46	10.8	9.8	3.6	43	36	153.2	1.098
G5	435045.437	5527678.991	314	306	57	81	13	25	0.8	2.1	12.1	78	256	168	0.96	0.87	1.02	0.70	0.58	0.47	10.7	9.8	3.4	31	28	110.9	1.098
H5	435044.123	5527599.538	360	380	28	31	10	11	1.1	2.1	13.5	40	214	146	0.54	0.03	0.03	0.81	0.53	0.51	10.1	8.9	3.8	44	36	148.0	1.106
I5	435042.906	5527519.281	279	317	9	9	10	11	0.9	6.4	22.0	43	384	278	0.46	0.12	0.07	0.69	0.50	0.38	10.1	9.5	3.5	38	34	112.0	1.101
J5	435041.392	5527458.930	219	204	28	35	11	25	1.0	23.9	52.1	59	293	201	1.45	0.86	1.03	0.73	0.56	0.60	10.7	9.8	3.1	40	39	142.6	1.099
Means			**308**	**309**	**60**	**59**	**16**	**21**	**2.0**	**2.5**	**6.3**	**43**	**168**	**103**	**0.96**	**0.86**	**0.91**	**0.54**	**0.39**	**0.34**	**9.6**	**8.4**	**4.4**	**38**	**31**	**141.1**	**1.100**

✚ Additional Information, as follows.
DR – July 2 – September 3, 1999
Kel – Kelowna method
AA – Ammonium Acetate method
DT^1 – July 9, 1999
DT^2 – July 28, 1999
DT^3 – August 13, 1999

VIII. 1999 Hays Grid Sample Data

1999 Hays Site (Snowden)

Site	Position Data: Easting (m)	Position Data: Northing (m)	Moisture: Irrigation + Precipitation (mm)	Moisture: Consumptive Use (mm)	Moisture: Avaliable Water %	Moisture: Avaliable Water %	Soil Characteristics: Clay (%)	Soil Characteristics: Clay (%)	Soil Characteristics: $CaCO_3$ (%)	Soil Characteristics: NO_3-N (ppm)	Soil Characteristics: NO_3-N (ppm)	Soil Characteristics: PO_4-P (ppm)	Soil Characteristics: K (ppm)	Soil Characteristics: K (ppm)	Petiole Nutrient Contents: NO_3-N (%)	Petiole Nutrient Contents: NO_3-N (%)	Petiole Nutrient Contents: NO_3-N (%)	Petiole Nutrient Contents: P (%)	Petiole Nutrient Contents: P (%)	Petiole Nutrient Contents: P (%)	Petiole Nutrient Contents: K (%)	Petiole Nutrient Contents: K (%)	Petiole Nutrient Contents: K (%)	Hand-Sampled Tuber Data: Total Yield (t/ha)	Hand-Sampled Tuber Data: Medium Tuber Yield (t/ha)	Hand-Sampled Tuber Data: Mean Tuber Weight (g)	Hand-Sampled Tuber Data: Opacity	Hand-Sampled Tuber Data: Specific Gravity
Info✚			DR									Kel	AA	Kel	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]	DT[1]	DT[2]	DT[3]					
Depth (cm)				(0-100)	(0-60)	(60-100)	(0-60)	(60-90)	(0-30)	(0-60)	(60-90)	(0-15)	(0-30)	(0-30)														
A1	438901.353	5537802.739	202	287	94	75	36	42	1.6	0.39	0.00	24	485	282	1.59	1.15	0.27	0.23	0.14	0.09	9.6	5.4	4.8	30	26	114.5	59.70	1.097
B1	438900.519	5537742.303	198	319	49	76	31	32	1.4	0.88	0.00	19	237	168	1.22	0.64	0.71	0.20	0.12	0.10	9.0	5.3	4.6	28	26	93.9	60.50	1.098
C1	438899.251	5537654.886	202	302	12	19	6	5	2.1	0.00	0.00	22	157	196	0.27	0.85	0.04	0.22	0.14	0.12	9.4	5.4	4.7	31	30	105.0	61.48	1.100
D1	438898.355	5537577.275	202	286	139	94	8	18	2.8	1.34	2.98	25	258	204	1.98	1.32	1.09	0.30	0.22	0.19	10.8	5.1	4.6	30	25	91.8	59.96	1.099
E1	438897.233	5537499.906	207	294	162	198	7	14	1.3	0.72	7.06	18	185	118	0.66	0.19	0.18	0.30	0.12	0.12	10.1	5.3	4.4	41	35	116.3	59.96	1.102
F1	438896.412	5537422.836	190	312	145	185	7	10	0.9	0.52	12.70	19	117	91	0.76	0.31	0.01	0.23	0.42	0.24	8.9	5.3	4.6	24	21	84.4	58.99	1.110
G1	438895.245	5537345.214	191	223	198	204	7	12	1.1	0.31	0.51	21	148	95	1.22	0.37	0.38	0.19	0.09	0.14	10.6	5.3	4.7	28	21	62.0	60.56	1.094
H1	438894.223	5537268.288	225	302	115	136	7	14	0.8	0.00	0.00	21	121	151	1.30	1.19	0.90	0.16	0.12	0.10	8.3	5.3	4.6	50	45	100.9	61.78	1.090
I1	438893.407	5537190.871	235	292	140	117	11	31	1.2	3.17	1.25	30	261	160	1.21	0.62	0.06	0.20	0.19	0.09	10.3	5.3	4.7	45	40	91.5	60.52	1.094
J1	438892.435	5537113.489	214	343	131	218	11	28	0.5	0.00	0.67	21	120	122	0.38	1.31	0.00	0.23	0.20	0.10	9.7	5.3	4.7	30	27	97.6	60.16	1.110
K1	438891.946	5537045.230	221	308	98	162	16	19	0.4	0.53	0.00	21	155	187	1.59	1.75	1.39	0.18	0.20	0.13	9.7	5.3	4.8	37	32	107.8	60.69	1.091
C2	438953.123	5537770.223	208	266	106	108	28	50	0.8	0.95	0.00	25	262	206	1.43	1.37	0.95	0.17	0.13	0.10	8.3	5.3	4.3	24	35	175.9	61.10	1.101
D2	438952.023	5537693.018	205	284	65	91	19	40	1.0	0.00	0.00	23	189	189	0.78	1.30	0.65	0.19	0.14	0.10	9.3	4.9	4.7	18	17	79.0	60.63	1.109
E2	438951.139	5537615.713	219	315	46	96	20	31	0.7	0.57	0.79	28	211	199	1.48	0.61	0.23	0.24	0.15	0.10	10.4	5.2	4.7	16	35	88.5	55.57	1.097
F2	438950.097	5537538.058	200	294	66	99	9	9	0.6	1.44	8.44	34	207	162	1.34	0.34	0.02	0.36	0.15	0.11	10.6	2.7	4.7	20	37	111.6	56.35	1.095
G2	438949.070	5537461.360	191	232.5	131	137	11	9	0.5	0.43	0.91	26	128	107	0.99	0.21	0.00	0.26	0.12	0.09	10.6	2.6	4.7	19	33	117.3	59.68	1.101
H2	438947.981	5537383.411	190	239	198	234	14	11	0.8	0.00	1.03	29	97	91	1.30	0.12	0.00	0.26	0.17	0.11	10.3	2.5	4.8	22	33	125.9	57.55	1.095
I2	438947.748	5537306.217	183	270.5	127	144	12	25	0.5	0.00	1.08	18	129	91	1.04	0.14	0.01	0.28	0.16	0.10	9.7	2.4	4.7	29	40	152.9	60.06	1.098
J2	438946.142	5537228.829	183	217	178	181	8	9	0.7	0.00	2.02	19	112	106	1.19	0.04	0.00	0.28	0.13	0.10	10.5	2.6	4.8	26	38	92.4	61.43	1.100
K2	438945.078	5537151.613	187	217.5	186	164	18	24	1.1	0.82	0.97	18	149	119	1.53	0.04	0.00	0.42	0.15	0.13	10.4	2.7	5.6	18	12	41.4	57.08	1.108
L2	438944.151	5537074.166	197	283	106	119	19	22	1.9	1.08	1.10	18	136	184	1.58	0.89	0.27	0.21	0.15	0.12	8.4	2.6	4.7	21	36	88.4	58.01	1.092
A3	439028.024	5537801.346	184	214	90	80	27	38	0.4	1.23	0.00	21	302	217	1.79	0.60	1.06	0.27	0.16	0.13	9.5	2.6	4.6	21	36	95.1	61.69	1.093
B3	439026.928	5537730.751	230	288	34	93	11	14	0.8	0.40	0.00	23	222	175	1.34	1.20	0.56	0.36	0.17	0.11	9.4	5.7	4.7	29	32	112.9	59.76	1.101
C3	439025.803	5537651.912	204	280	78	111	39	41	0.8	0.94	0.00	22	220	139	1.83	1.35	1.20	0.24	0.13	0.11	8.8	5.3	4.2	21	30	101.9	57.27	1.093
D3	439024.693	5537576.041	206	290.5	30	112	7	11	0.7	0.00	0.00	20	140	114	1.09	0.28	0.02	0.42	0.22	0.13	9.3	5.8	4.7	20	30	98.9	62.61	1.099
E3	439023.847	5537498.624	224	316.5	107	221	7	17	0.8	0.00	1.21	21	149	189	1.62	0.49	0.04	0.35	0.17	0.13	8.9	5.7	4.7	27	46	116.0	61.21	1.099
F3	439022.916	5537421.286	183	225	213	127	12	21	0.3	1.80	0.98	29	349	183	2.65	1.08	1.14	0.38	0.20	0.28	10.8	5.9	3.6	23	35	82.2	60.96	1.089
G3	439021.796	5537343.987	184	275	134	128	11	19	0.7	1.35	0.94	18	153	95	1.65	0.69	0.19	0.42	0.21	0.15	10.0	5.8	4.7	30	46	135.4	60.49	1.095
H3	439020.753	5537266.777	192	275.5	162	243	15	43	0.4	0.77	0.57	24	129	91	1.99	1.07	0.44	0.31	0.16	0.14	9.7	5.8	4.6	25	43	90.7	57.59	1.095
I3	439019.930	5537189.617	197	234.5	186	241	11	20	1.0	3.25	9.33	27	117	114	2.81	0.85	0.41	0.43	0.20	0.17	10.1	5.8	4.7	22	34	142.4	58.22	1.095
J3	439019.162	5537111.949	196	246.5	192	200	11	15	1.0	0.55	2.23	29	146	186	2.85	0.38	0.61	0.43	0.16	0.17	10.6	5.8	4.4	24	39	92.3	61.38	1.098
K3	439018.309	5537046.828	136	220.5	135	176	25	36	0.9	2.92	2.42	29	237	178	2.77	2.14	1.51	0.52	0.28	0.20	11.0	5.7	3.9	20	34	92.1	59.26	1.096
B4	439105.437	5537768.650	254	299.5	101	175	30	46	1.1	1.06	0.00	17	172	114	1.63	1.47	1.06	0.22	0.13	0.09	8.4	5.6	4.4	24	22	110.8	62.16	1.101
C4	439104.332	5537691.258	236	283	105	196	11	32	0.5	1.33	0.86	21	141	88	1.97	1.36	0.73	0.42	0.23	0.14	9.0	5.6	4.7	30	29	103.0	60.76	1.096
D4	439103.144	5537613.871	204	275	49	168	9	25	0.6	0.88	0.66	31	96	75	1.58	1.07	0.19	0.43	0.25	0.15	9.0	5.6	4.5	20	19	93.7	62.31	1.103
E4	439102.189	5537536.393	213	247	148	150	15	23	0.4	4.21	8.48	21	119	83	2.50	0.37	0.05	0.51	0.27	0.20	10.7	5.9	4.4	20	16	63.8	60.59	1.095
F4	439101.235	5537459.127	211	296	94	135	21	37	0.4	0.93	0.00	15	132	73	.1.60	1.18	0.66	0.23	0.17	0.12	8.7	5.8	4.6	27	26	111.4	61.43	1.098
G4	439100.034	5537381.661	202	263	23	59	12	32	0.5	1.24	0.53	5	125	60	1.36	1.26	0.80	0.44	0.27	0.18	9.4	5.9	4.4	22	20	137.9	61.49	1.095
H4	439099.090	5537304.598	191	247	30	140	17	39	0.6	0.43	0.00	12	90	85	1.02	1.04	0.60	0.27	0.15	0.12	8.2	5.4	3.6	16	14	78.4	60.83	1.106
I4	439098.094	5537227.026	193	279	35	88	12	32	0.4	1.58	1.54	25	170	138	1.91	1.17	0.69	0.29	0.20	0.15	8.9	5.8	4.4	35	29	154.8	59.53	1.093
J4	439097.389	5537149.713	198	276	73	125	11	28	0.5	0.73	0.75	16	225	153	1.49	1.16	0.61	0.25	0.17	0.12	9.4	5.9	4.4	23	23	135.0	59.85	1.094
K4	439092.546	5537072.361	181	242	60	162	17	39	0.6	0.87	0.53	21	191	108	1.92	1.42	0.84	0.37	0.18	0.15	9.8	5.9	4.4	30	29	124.5	61.55	1.100
C5	439181.201	5537649.607	207	302.5	-13	50	8	30	0.3	1.15	0.00	14	104	82	1.65	0.79	0.43	0.48	0.17	0.16	9.4	5.8	4.1	19	19	104.7	63.54	1.106
D5	439179.149	5537574.110	213	267	17	76	7	8	0.8	0.52	0.00	20	140	83	1.61	0.71	0.17	0.55	0.18	0.14	9.9	5.9	4.4	12	11	109.6	58.89	1.108
E5	439178.921	5537496.708	203	204	18	77	24	47	0.4	0.91	0.54	15	112	98	1.72	1.32	0.93	0.34	0.16	0.14	8.5	5.4	3.6	24	16	127.0	60.26	1.097
F5	439178.087	5537419.385	189	181	56	132	25	44	0.7	1.50	0.61	19	159	108	1.69	1.52	1.04	0.32	0.16	0.13	8.8	5.5	3.8	25	24	127.1	58.50	1.097
G5	439177.265	5537342.207	202	241	59	136	13	36	0.0	0.80	0.60	13	150	93	1.78	1.20	0.85	0.41	0.19	0.15	9.6	5.7	4.3	24	22	106.4	58.45	1.098
H5	439176.047	5537264.613	213	329.5	41	113	10	36	0.4	0.64	0.64	16	123	87	1.61	1.19	0.52	0.41	0.20	0.14	9.0	5.5	4.0	19	16	91.1	58.39	1.101
I5	439174.920	5537187.333	128	357	2	0	11	36	0.3	0.71	0.83	17	144	85	1.70	1.12	0.59	0.48	0.20	0.18	9.9	5.6	4.4	19	18	56.3	58.16	1.100
E6	439256.758	5537534.400	155	191	1	44	19	40	1.0	2.57	8.63	19	124	96	2.26	1.97	1.25	0.52	0.18	0.14	9.4	5.4	4.0	16	16	101.3	62.44	1.110
F6	439256.500	5537457.460	167	266	45	90	18	52	0.2	1.53	0.87	19	153	96	2.10	1.60	1.40	0.42	0.20	0.19	9.6	5.5	4.4	23	23	119.0	60.68	1.104
G6	439255.838	5537379.924	193	287	35	67	16	46	0.5	0.82	0.55	13	124	81	1.98	1.51	0.90	0.46	0.18	0.15	9.6	5.5	4.4	22	21	157.4	61.18	1.107
H6	439254.010	5537302.641	146	215.5	3	64	15	40	0.4	1.44	2.19	18	126	144	1.90	1.33	1.22	0.52	0.17	0.12	9.2	5.6	4.2	19	18	110.0	60.60	1.106
Means			**198**	**269.8**	**91**	**129**	**15**	**28**	**0.8**	**0.99**	**1.66**	**21**	**169**	**131**	**1.59**	**0.96**	**0.56**	**0.33**	**0.18**	**0.14**	**9.6**	**5.1**	**4.5**	**25**	**26**	**106.1**	**60.1**	**1.099**

✚ Additional Information, as follows.
DR – July 7 – September 3, 1999
Kel – Kelowna method
AA – Ammonium Acetate method
DT[1] – July 7, 1999
DT[2] – July 30, 1999
DT[3] – August 17, 1999

IX. 1999 Vauxhall Grid Sample Data

	Position Data		EM38 Soil Salinity Data		Hand-Sampled Tuber Data			
Site	Easting (m)	Northing (m)	E.C. Horizontal (dS/m)	E.C. Vertical (dS/m)	Total Yield (t/ha)	Medium Tuber Yield (t/ha)	Mean Tuber Weight (g)	Specific Gravity
Depth (cm)			(0-60)	(0-120)				
2	417803.452	5545198.060	5.0	5.7	27	21	99.2	1.105
3	417802.606	5545208.771	0.5	4.3	36	27	98.4	1.091
4	417803.706	5545217.884	3.7	4.7	34	24	95.8	1.086
5	417802.545	5545231.981	3.7	5.4	40	34	122.8	1.094
6	417804.655	5545250.974	3.2	5.0	40	35	114.5	1.103
7	417804.179	5545258.717	2.7	4.6	44	31	103.5	1.102
8	417806.070	5545284.676	2.7	4.7	43	35	105.0	1.100
9	417806.324	5545311.932	3.8	5.7	30	25	131.4	1.106
10	417807.379	5545353.228	0.3	0.1	49	40	101.6	1.110
11	417807.760	5545368.950	0.3	0.2	46	38	107.9	1.105
12	417805.729	5545433.224	0.3	0.2	35	28	104.9	1.089
13	417734.776	5545134.595	4.2	3.9	25	14	103.0	1.097
14	417732.885	5545139.708	3.8	4.1	34	29	118.9	1.100
15	417734.047	5545146.255	2.9	3.9	38	30	108.1	1.096
16	417735.376	5545160.364	1.8	3.2	41	36	106.0	1.098
17	417735.460	5545160.352	2.7	3.7	39	32	112.6	1.093
18	417735.746	5545177.626	3.2	4.8	38	32	103.8	1.099
19	417735.340	5545186.596	0.3	3.8	44	34	114.2	1.100
20	417735.547	5545201.099	4.7	5.3	48	35	91.3	1.099
21	417735.846	5545227.155	2.3	4.4	41	34	101.8	1.095
22	417736.294	5545240.162	1.8	3.8	40	29	95.8	1.099
23	417737.002	5545292.974	1.6	3.3	39	29	82.9	1.097
24	417742.783	5545420.668	0.6	2.1	36	29	105.3	1.095
25	417741.043	5545425.065	0.4	1.7	31	20	93.3	1.100
26	417742.753	5545437.498	0.3	0.8	47	37	105.4	1.087
27	417743.677	5545453.048	0.3	0.9	40	36	127.3	1.089
28	417744.943	5545473.627	0.3	1.2	27	18	80.6	1.085
29	416599.690	5545133.444	6.4	6.0	38	31	118.3	1.108
30	416601.295	5545137.559	6.8	6.1	28	20	125.4	1.108
31	416604.731	5545132.820	6.6	6.1	20	14	115.6	1.111
32	416611.542	5545131.133	7.0	6.1	18	14	101.4	1.114
33	416624.477	5545146.228	6.2	6.0	20	16	108.2	1.107
34	416628.008	5545148.094	5.0	5.5	34	27	134.4	1.104
35	416633.429	5545150.672	1.8	3.4	50	40	124.9	1.092
36	416637.308	5545159.760	0.5	2.2	56	48	148.9	1.096
37	416643.724	5545165.115	2.9	4.2	32	21	119.5	1.098
38	416652.716	5545157.126	1.9	3.4	48	40	138.4	1.099
39	416663.907	5545183.050	1.0	2.5	46	41	134.2	1.101
40	416671.818	5545173.875	0.4	1.6	49	43	147.6	1.101
41	416677.985	5545170.589	0.6	2.2	46	38	153.3	1.100
42	416684.811	5545190.281	0.4	1.8	49	37	157.0	1.101
43	416689.479	5545197.304	0.2	1.6	55	50	142.5	1.098
44	416704.301	5545206.294	0.3	1.2	44	37	147.9	1.097
45	416712.669	5545218.766	0.3	1.2	52	47	154.4	1.103
46	417011.817	5545102.675	5.9	7.3	10	4	86.2	1.113
47	417009.936	5545087.434	6.1	6.7	43	17	81.7	1.096
48	417011.213	5545067.675	7.8	8.5	27	12	117.2	1.097
49	416989.494	5545069.341	2.0	3.2	32	10	60.1	1.080
50	416990.820	5545052.866	1.5	2.6	25	13	78.9	1.078
51	416988.397	5545040.775	1.8	2.7	27	8	37.6	1.085
52	417010.838	5545041.948	5.2	5.5	28	13	89.6	1.088
53	417014.113	5545023.477	3.5	4.6	27	17	79.9	1.084
54	417012.063	5545009.248	3.1	4.6	6	3	19.4	1.129
55	417010.002	5544984.904	1.6	3.0	58	48	172.1	1.097
56	417011.943	5544966.075	1.4	2.7	45	38	186.5	1.092
57	417011.061	5544955.561	0.5	1.9	51	48	224.0	1.089
58	417014.215	5544939.563	2.4	4.0	36	32	179.8	1.101
59	417020.608	5544932.424	1.5	3.4	37	33	140.2	1.103
60	417020.454	5544919.843	0.2	1.7	49	44	157.8	1.091
61	417010.756	5544922.446	0.3	1.7	58	52	176.1	1.090
62	417025.447	5544919.278	0.5	1.9	51	46	150.4	1.092
Means			**2.5**	**3.6**	**38**	**30**	**117.1**	**1.098**

Introduction

Potato, a high value crop in southern Alberta, requires large amounts of fertilizers, pesticides and irrigation water. With respect to nitrogen (N), a balance between supply and utilization is required to optimize crop growth and economic return as well as minimize environmental impact. Application of excess N results in delayed maturity, reduced tuber set and dry matter yield, and increased incidence of hollow heart. Thus, too much nitrogen leads to a reduction in net returns and potentially ground water contamination due to leaching. Conversely, too little N reduces profitability due to a reduction in yield and an increase in susceptibility to blight (Schaupmeyer 1992). Early detection of N deficiency in crops such as potatoes allows producers an opportunity to more closely match their application rates to the real time N requirements of the crop thereby optimizing returns and alleviating concerns about environmental contamination.

Potato fields are closely monitored during the growing season for the onset of nutrient deficiencies, disease and pests. With respect to nutrients, typically test areas are established in a field and 40 to 50 petioles from representative plants are collected at each sampling date for determination of primarily N but also P and K content. In Alberta in mid-July, the target range for petiole nitrate N for potatoes under irrigation is 1.0 to 2.0%; below 1.0% the plants are considered to be deficient in N. Based upon the petiole sampling, N can be applied through fertigation. This method of petiole sampling provides only limited information regarding spatial variability across the whole field and does not provide information suitable for use with variable rate equipment.

and harvesting of the potato crop. The characteristics of the sites and fertilizer applications are given in Table 2.

Petiole Sampling

A sampling grid was set up in each field in the fall of 1998; the grid sampling points were located with differential GPS methods. Petiole samples were collected at each grid sampling point at Fincastle on July 9, July 28 and August 13 and at Hays on July 7, July 30 and August 17, 1999. Within 5 m of each grid sampling point, 45 to 70 petioles were taken from the fourth leaf of representative plants. The tissues were analyzed to determine nitrate N and total N as well as a number of other elements (McKenzie et al. 2002). The N levels in the tissues were compared to sufficiency limits used by various Alberta and USA soils laboratories. The geographic coordinates of the grid points together with their associated petiole nitrate N values were imported into the grid-based graphics program Surfer™ (Golden Software Inc, Colorado, USA). The data between the grid points were interpolated using kriging to produce a map delineating petiole nitrate N levels across each of the test fields.

Remote sensing data

On July 28, 1999, Itres acquired digital images over the test fields. The image data were acquired over the spectral range 420-965 nm using a Compact Airborne Spectrographic Imager at 2 and 3-m resolution. The spectral bands in which data were acquired varied with the resolution from 36 to 48 respectively. The image data were radiometrically corrected and geocoded by Itres.

The data were imported into the ENVI™ image analysis software package (Research Systems Inc. Colorado, USA) and converted from spectral radiance units (μW

3). Visual comparison of the petiole-N maps derived in Surfer™ using the grid point petiole nitrate N data and the index SR_{550_850} shows similarities in the patterns across both fields. Generally, areas of low petiole nitrate N exhibited high values for the SR_{550_850} index. Correlation analysis showed a strong relationship between most of the chlorophyll/N indices and petiole nitrate N for the Fincastle site (Table 4). The strongest relationships were evident with simple ratios involving either reflectance in the green band (550 nm) or the red-edge (700-710 nm) and the near infrared reflectance (750-850 nm). These observations can be attributed to the greater range of chlorophyll/N content to which reflectance at 550 and 700-710 nm responds. The absorption feature at 660-680 nm saturates at relatively low chlorophyll content and thus relative to 550 or 700-710 nm is insensitive to variation in chlorophyll/N.

At the Hays site, visually there were some similarities between the spatial patterns within the image of the SR_{550_850} index and the kriged map of the ground based sampling. The extent of the N deficient areas in the remote sensing image appeared less than in the kriged map. The imagery may provide a more accurate representation of the spatial variability given that each pixel in the remote sensing image represents information from an area of 2 x 2 m on the ground while the ground data is an interpolation from grid points at greater than 100 m apart. Quantitative analysis showed only a limited number of indices were significantly related to petiole nitrate N. The strength of the relationship was poor compared to that at the Fincastle site. The lack of a strong relationship may reflect uncertainty in the georeferencing of the airborne imagery and the sampling sites and the heterogeneity of the crop reflectance in the areas selected for sampling. (Deguise et al. 1998).

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TABLE 2. PUBLISHED ALGORITHMS FOR CHLOROPHYLL/N ESTIMATION USING REMOTE SENSING DATA

Index	Formula	Citation	CASI bands
Simple ratio			
SR_{800_670}	(R_{800nm}/R_{670nm})		17, 25
SR_{695_430}	$(R_{695nm}R_{430nm})$	Carter 1994	1, 18
SR_{605_760}	(R_{605nm}/R_{760nm})	Carter 1994	12, 23
SR_{695_760}	(R_{695nm}/R_{760nm})	Carter 1994	18, 23
SR_{695_670}	(R_{695nm}/R_{670nm})	Carter 1994	17, 18
SR_{750_705}	(R_{750nm}/R_{705nm})	Gitelson and Merzlyak 1996, Sims and Gamon 2002	19, 22
SR_{750_550}	(R_{750nm}/R_{550nm})	Gitelson and Merzlyak 1996, Lichtenthaler et al. 1996	9, 22
SR_{667_717}	(R_{667nm}/R_{717nm})	Leblon et al. 2001	17, 20
SR_{550_850}	(R_{550nm}/R_{850nm})	Schepers et al. 1996	9, 28
SR_{710_850}	(R_{710nm}/R_{850nm})	Schepers et al. 1996	19, 28
SR_{800_680}	(R_{800nm}/R_{680nm})	Sims and Gamon 2002	17, 25
SR_{735_700}	(R_{735nm}/R_{700nm})	Gitelson and Merzlyak. 1999	19, 21
Pigment specific simple ratio (PSSR)	(R_{810nm}/R_{676nm})	Blackburn 1998	17, 26
Normalized difference index			
Normalized green difference vegetation index (NGVDI)	$(R_{750nm} - R_{550nm})/(R_{750nm} + R_{550nm})$	Gitelson et al. 1996	9, 22
Photochemical reflectance index (PRI)	$(R_{531nm} - R_{570nm})/(R_{531nm} + R_{570nm})$	Gamon et al. 1992	8, 10
Pigment specific normalized difference (PSND)	$(R_{810nm} - R_{676nm})/(R_{810nm} + R_{676nm})$	Blackburn 1998	17, 26
Normalized difference index (NDI_{750_700})	$(R_{750nm} - R_{700nm})/(R_{750nm} + R_{700nm})$	Gitelson and Merzylak 1994, Sims and Gamon 2002	19, 22
Normalized difference index (NDI_{800_680})	$(R_{800nm} - R_{680nm})/(R_{800nm} + R_{680nm})$	Sims and Gamon 2002	17, 25
Normalized pigments chlorophyll ratio index (NPCI)	$(R_{680nm} - R_{430nm})/(R_{680nm} + R_{430nm})$	Peñuelas et al. 1994	1, 17
Structure-insensitive pigment index (SIPI)	$(R_{800nm} - R_{445nm})/(R_{800nm} + R_{680nm})$	Peñuelas et al. 1995	2, 17, 25
Others			
Modified simple ratio (mSR_{750_445})	$(R_{750nm} - R_{445nm})/(R_{705nm} - R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Modified normalized ratio (mNR_{750_445})	$(R_{750nm} - R_{705nm})/(R_{750nm} + R_{705nm} - 2*R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Optimized soil adjusted vegetation index (OSAVI)	$(1 + 0.16)*(R_{800nm} - R_{670nm})/(R_{800nm} + R_{670nm} + 0.16)$	Rondeaux et al. 199	17, 25
Modified chlorophyll absorption in reflectance index (MCARI)	$[(R_{700nm} - R_{670nm}) - (0.2*(R_{700nm} - R_{550nm}))*(R_{700nm}/R_{670nm})]$	Daughtry et al. 2000	9, 17, 19
Transformed chlorophyll absorption in reflectance index (TCARI)	$3*[(R_{700nm} - R_{670nm}) - (0.2*(R_{700nm} - R_{550nm}))*(R_{700nm}/R_{670nm})]$	Haboudane et al. 2002	9, 17, 19
Plant senescence reflectance index (PSRI)	$(R_{680nm} - R_{500nm})/(R_{750nm})$	Merzlyak et al. 1999	6, 17, 22
Carotenoids	$[4.145*(S_{760nm}/S_{500nm})*(R_{500nm}/R_{760nm})]-1.171$	Chapelle et al. 1992	5, 23
Chlorophyll b	$2.94*[((S_{675nm}/R_{650nm}*S_{700nm})*(R_{650nm}*R_{700nm}/R_{675nm}))]+0.378$	Chapelle et al. 1992	15, 17, 18
Chlorophyll a	$22.735[=(S_{675nm}/S700_{nm})*(R_{700nm}/R_{675nm})] - 10.407$	Chapelle et al. 1992	17, 18

TABLE 5. RELATIONSHIP BETWEEN THE VARIOUS PROPOSED INDICES AND PETIOLE NITRATE N SAMPLES

Index	Fincastle	Hays
SIMPLE RATIO		
SR_{800_680}	0.751	NS
SR_{695_430}	-0.734	-0.356
SR_{605_760}	-0.781	NS
SR_{695_760}	-0.748	NS
SR_{695_670}	0.449	-0.318
SR_{750_705}	0.820	NS
SR_{750_550}	0.821	NS
SR_{677_717}	-0.639	NS
SR_{550_850}	-0.832	NS
SR_{710_850}	-0.832	NS
SR_{735_700}	0.821	NS
PSSR	0.764	NS
NORMALIZED DIFFERENCE INDEX		
NGVDI	0.809	NS
PRI	0.770	NS
PSND	0.706	NS
NDI_{750_700}	0.809	NS
NDI_{750_705}	0.696	NS
NDI_{800_680}	0.707	NS
SIPI	-0.660	NS
OTHER		
mSR_{750_705}	0.821	0.326
mNR_{750_705}	0.813	0.308
OSAVI	0.722	NS
MCARI	0.445	-0.298
TCARI	-0.800	-0.317
PSRI	-0.597	
Carotenoids	0.746	NS
Chlorophyll a	-0.448	0.313
Chlorophyll b	-0.674	NS
PSRI	-0.597	NS
NPCI	-0.702	NS
# OF OBSERVATIONS	N=51	N=54

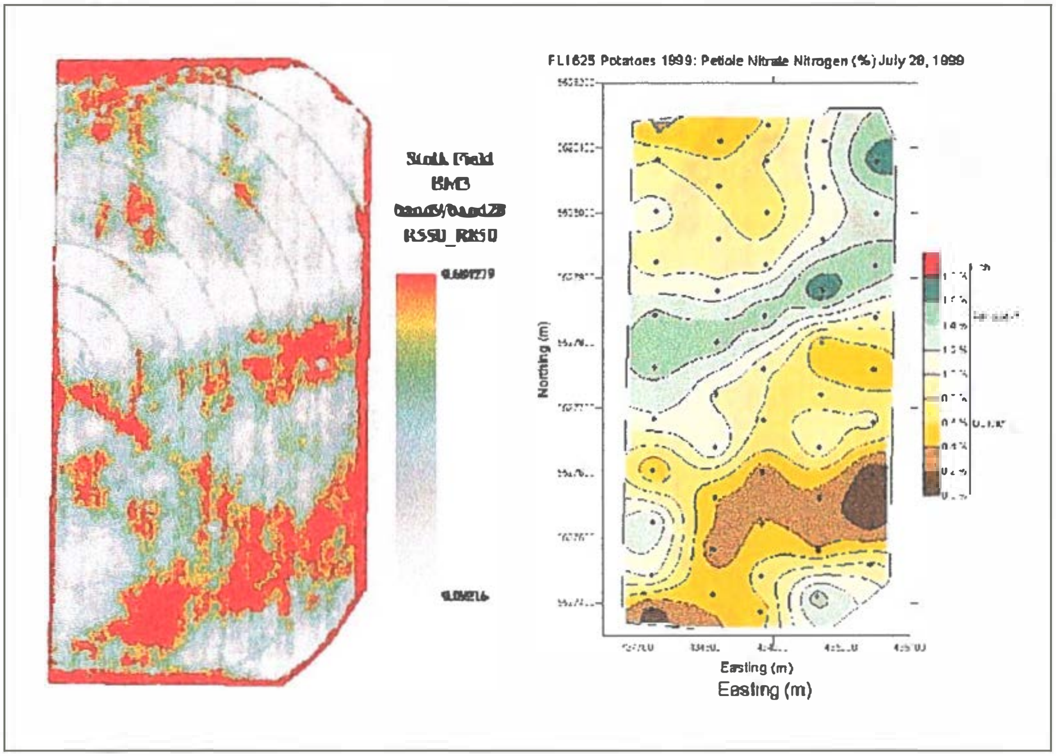

FIGURE 2. FINCASTLE SITE: SR_{550_850} INDEX IMAGE AND PETIOLE-N MAPS DERIVED FROM GROUND-BASED SAMPLING

Research Team Information

a) Research Team Leader:		
Title: Dr.	**First Name:** R. Colin	**Last Name:** McKenzie
Position: Research Scientist, Soil and Water Agronomy *(deceased)*		
Organization/Institution: Crop Diversification Centre South		
Department: Alberta Agriculture, Food and Rural Development		
Address:	**City:**	**Prov./State:**
Postal Code/Zip:	**E-mail Address:**	
Phone Number:	**Fax Number:**	

Past experience relevant to project:

1. Determining nutrient content of feedlot manure (2001-2002).
2. The influence of compost and phosphorus fertilizer on disease in potatoes (1999-2000).
3. Response of irrigated potatoes to phosphorus fertilizer and compost (1999-2001).
4. Site specific management of irrigated potatoes (1996-1999).
5. Salinity tolerance of forage and turf grasses (1993-1995).
6. Phosphorus and potassium requirement of irrigated alfalfa (1989-1994).

Degrees /Certificates /Diplomas:	Institution Received From:
Ph.D., The effect of subsoil acidity on root development and crop growth of several crops.	Univ. of Alberta (1970-1973)
MSc., The effect of coal humic acids on soil structure and as a slow release source of nitrogen.	Univ. of Alberta (1968-1970)
BSA in Agriculture	Univ. of Saskatchewan

Publications and Patents:

# of Refereed papers: 15	**Conference proceedings:** 16
Relevant Patents obtained: 0	**Other relevant citations:** 3 Chapters in Books

Other evidence of productivity during past 6 years:

- Invited speaker at International Drainage Conference in India (Feb. 2000).
- External examiner for 2 Ph.D. graduate students (2000-2002).
- Provided a course on measurement of salinity for Pakistan engineers and soil specialist (2001-2002).

b) Research Team Members

Name	*Institution*
1. R. C. McKenzie	CDC South, AAFRD
2. C.A. Shaupmeyer	AAFRD
3. M. Green	AAFRD
4. T.W. Goddard	AAFRD
5. D.C. Penney	AAFRD

Personal Data Sheet for Research Team Members

Title: Mr.	**First Name:** Clive A.	**Last Name:** Schaupmeyer	
Position: Potato Specialist *(retired)*			
Organization/Institution:		**Department:** AAFRD	
Mailing Address: 2207 – 16 Ave.	**City:** Coaldale	**Prov:** AB	**Postal Code:** T1M 1N7
E-mail Address: clives@shaw.ca			
Phone Number: (403)345-6457	**Fax Number:** n/a		

Past experience relevant to project:

1. Agronomic research projects aimed at improving potato plant stands, population, plant performance, quality and yields.
2. Effects of in-row spacing on yield and size distribution of potatoes (1993-1996).
3. Development of optimum management profiles for new potato varieties (1995-1998).

Degrees /Certificates /Diplomas:	**Institution Received From:**
M.Sc. (Extension Education)	Univ. of Guelph (1976)
B.Sc. (Soils/Horticulture)	Univ. of Alberta (1968)

Publications and Patents:

# of Refereed papers: 10	Conference proceedings: Several
Relevant Patents obtained: 0	Other relevant citations:

Other evidence of productivity during past 6 years:

Personal Data Sheet for Research Team Members

The personal information being collected is subject to the provisions of the Freedom of Information and Protection of Privacy Act.

Title: Mr.	**First Name:** Thomas W.		**Last Name:** Goddard
Position: Soil Conservation Specialist			
Organization/Institution: AAFRD		**Department:** Conservation & Development	
Mailing Address: 7000-113 St.	**City:** Edmonton	**Prov:** AB	**Postal Code:** T6H 5T6
E-mail Address: Tom.Goddard@gov.ab.ca			
Phone Number: (780) 427-3720	**Fax Number:** (780) 422-0474		

Past experience relevant to project:

1. Development and evaluation of precision farming technologies for canola production and research (1996-1999).
2. Landscape analysis for precision farming and model applications (1996-1999).
3. Geographic management of agronomic practice. (1995-96)
4. Precision farming to optimize yields and minimize environmental impact (1993-1997).

Degrees /Certificates /Diplomas:	**Institution Received From:**
M.Sc. (Soil Science)	Univ. of Alberta (1988)
B. Sc. (Agriculture)	Univ. of Alberta (1979)

Publications and Patents:

# of Refereed papers: 8	Conference proceedings: 45
Relevant Patents obtained: 0	Other relevant citations: 4

Other evidence of productivity during past 6 years:

1. Development of Scientifically Defensible Estimates of N_2O Emissions from Agricultural Ecosystems in Canada (CCAF, 00-03), Grant, Juma, Goddard, Kryzanowski, Zhang Solberg, Pattey.
2. Assessing the Nitrous Oxide Tradeoffs to Carbon Sequestering Management Practices (CCAF, 00-01) Lemke, Desjardins, Keng, Kharabata, Smith, Goddard, Ellert, Monreal, Drury, Rochette, Pattey.
3. Landscape dynamics and crop-soil model verification. (ARI, AESA, 99-01) Kryzanowski, Grant, Goddard.
4. Impacts of Cropping Systems to Climate Change and Adaptation Strategies for Agriculture in the Prairie Regions. (PARC, 00-01) Manunta, Goddard, Cannon.
5. Phosphorus mobility in soil landscapes: a site-specific approach. (CABIF, 99-02). Li, Chang, Amrani, Goddard, Heaney, Olson, Zhang, Feng.
6. Soil landscape management study crop yields. (MII, 01) Nolan, Lohstraeter, Coen, Brierley, Pettapiece, Goddard
7. Carbon sequestration and greenhouse gas flux in selected Alberta catenas containing wetlands (IWWR 02-07) Goddard/Fuller, Kryzanowski, Brierley, Zhang.
8. Emissions of N_2O from Cereal-Pea and Cereal-Lentil rotations in western Canada (NRCan 01-02). Lemke, Goddard, Selles.
9. Soil Variability for Agronomic and Environmental Crop Production - SVAECP (boardmember)
10. Advisory committee member – Land Information Systems program, Olds College
11. Invited committee member – Managed Ecosystems program development, Canadian Institute of Advanced Research (CIAR).

Alberta
AGRICULTURE, FOOD AND
RURAL DEVELOPMENT

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January 15, 2003

Dear Vern,

Please find enclosed a copy of the final report on the "Site Specific Management of Potatoes" project, which the PGA generously sponsored. Colin was working on it through his illness and had left instructions for me to complete it. It was a four-year (1996-1999) project that produced a great deal of detailed data. Colin's intent was to distill that down, as best as possible. I hope you will find this report useful and informative.

Thank you for your financial support of the project.

Best Regards,

Shelley S. Woods.

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Site Specific Management of Potatoes

AARI Project No. 96M979

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ABSTRACT

Potato crops have many characteristics that make them suitable for precision agriculture, such as a high value with costly inputs of pesticides, fertilizer and water. The application of fertilizer and pesticides on potatoes may cause environmental problems and the risks of these can be reduced by using precision farming techniques. This potential for use of precision agriculture technology has not been exploited to any great extent because problems exist which have not been fully resolved. Between 1996 and 1999 a project on the site specific management (or precision farming) of potatoes was undertaken. The goals of the project were to utilize yield monitoring and global positioning technology to generate maps and to measure the variability of the yield of potatoes in a field; to determine the effect of soil type, landscape position, nutrient level, fertility treatments, disease and weeds on the yield of potatoes; to determine yield and variability of crops over several years and relate this to field characteristics and to potato yield and quality; to evaluate the use of remote sensing and digital image analysis to detect nutrient deficiencies and diseases of potatoes; to measure the financial and environmental benefits of site specific management of potatoes; and to measure the movement of nitrogen below the root zone.

A yield monitor was successfully adapted to two farmers' potato harvesters and used to map tuber yields. Difficulties were encountered on parts of fields where soil lumps occurred, usually on areas with a high clay content. Yield maps were also developed from grid sampling. These grid samples were used to determine tuber yield, average tuber size and tuber quality as measured by specific gravity, chipping score and French fry score. Uniformity of irrigation affected tuber size. No relationship was found between chipping and French fry score and the measured factors of soil or water in the field. Grid sampling of the fields also showed variability in soil texture, which was correlated to various soil and plant chemical properties.

Two of six fields had sufficient variability of soil nitrogen to justify the cost of soil sampling and variable rate application. However, petiole NO_3-N in the first week of July was significantly negatively related to 0.0-0.60 m depth of soil clay and was not significantly related to soil NO_3-N. This means it would be more useful for farmers on these fields to base a site specific nitrogen application on soil clay content than on soil NO_3-N content. Soil P was significantly positively correlated to petiole P content but not clay content. Opportunities exist for precision applications of phosphorus particularly on two of the fields that had a history of receiving non-uniform applications of manure. However, phosphorus fertilizer applications based on grid sampling of soil phosphorus should provide some improvement in efficiency of uptake of phosphorus. Potassium levels in the soil from 1997 to 1999 were marginal to adequate on most grid sample sites. In 1997 and 1998 petiole K levels were deficient in the first week of July but became adequate to high in two later samplings. The reason for this is not known. It may be due to lower soil temperatures in early July restricting uptake, rather than the higher soil temperatures in the USA where the standards for petiole K were developed. There is a need to develop local standards for petiole K levels.

Precision fertilizer application is practiced on some potato farms in Canada, but the use of this technology is limited by the cost of soil sampling and analysis to accurately describe the field. If precision agriculture technology is to have widespread adoption in the potato industry, solutions to the obstacles of cost, soil lumps and other problems need to be incorporated into the technology.

INTRODUCTION

Since 1991, Global Positioning System (GPS) technology and yield monitoring equipment has made it possible to develop detailed yield maps of various crops. Farmers in the USA, Canada and Australia are interested in GPS as a means to increase profits by optimizing fertilizer applications. In western Europe, GPS has been used to avoid environmental contamination from excess application of fertilizers and manure. Other computer technology makes it possible to overlay maps of yields, soil or crops and measure relationships between them.

Since 1994, site specific management of cereal and oilseed crops in Alberta has increased steadily. Today, about 300 farmers in Alberta use yield monitors and some of these prepare yield maps of their fields. Site specific management of inputs can be done in a detailed or in a general manner by dividing the field into a few categories (Bouma et. al., 1995). Variable rate inputs can be applied with the assistance of GPS by a programmable fertilizer or herbicide applicator. Prototype irrigation systems have been developed to apply variable rates of water. (King et. al., 1995).

Potatoes are a high value crop requiring a lot of inputs, such as fertilizer, pesticides and irrigation. Potatoes are often grown on coarse textured soils that have low nutrient holding capacity and are high in field variability. Excess nitrogen can delay maturity of the crop and contribute to groundwater contamination. With the use of site specific management zones, with soil texture as a variable, the contamination of water can be reduced (Delgado and Duke, 2000; Whitley et. al., 2000). Insufficient nitrogen will reduce yield and increase the severity of early blight in potatoes. Phosphorus fertilizer applications for potatoes are higher than other crops, which represents an appreciable cost to farmers who are often growing potatoes on rented land. High phosphorus application may cause excess soil phosphorus, the major agricultural factor that contributes to water contamination. This results in the rapid growth and decay of algae in lakes, streams and rivers causing eutrophication and fish death. Recommendations for phosphorus requirements of potatoes by Tindall et. al. (1991) exceed those measured in a precision agriculture experiment by Davenport et. al. (1999). Traditional research under small plot conditions does not account for field variability and is usually conducted on uniform sites. The production of irrigated potatoes in southern Alberta has increased from about 9,000 ha in 1992 to

OBJECTIVES

1. To use a potato harvester equipped with a yield monitor and global positioning technology to generate maps and to measure the variability of the yield of potatoes in a field;
2. To determine the effect of soil type, landscape position, nutrient level, fertility treatments, disease and weeds on the yield of potatoes;
3. To determine yield and variability of crops over several years and relate this to field characteristics and to potato yield and quality;
4. To evaluate the use of remote sensing and digital image analysis to detect nutrient deficiencies and diseases of potatoes;
5. To measure the financial and environmental benefits of site specific management of potatoes;
6. To measure the movement of nitrogen below the root zone.

DEVIATIONS FROM OBJECTIVES

Remote sensing data with spectral analysis was obtained in the first year (1996) of the project on one field at Hays and in the fourth year (1999) at Hays and Fincastle. In 1997 and 1998 false color infrared imagery data was obtained on two fields. This type of infrared imagery was not useful for detailed analysis. In 1998 satellite multispectral imagery was obtained from Resource 21 and it was not feasible to do detailed analysis.

Yield of potatoes and yields of the previous crops on these fields was only obtained on two fields in 1997. Some of the other crops were sugarbeets for which a yield monitor was not available. Some of the grain was harvested with an older model combine, which was not suitable for attaching a yield monitor. Some grain fields were harvested with a custom operator who was not agreed upon until commencement of harvest. This did not provide an opportunity to install a yield monitor, so these fields were not monitored.

Nitrogen movement below the root zone was difficult to distinguish from residual nitrogen, which was also present in the till parent material. Only estimates of nitrogen movement through the soil profiles could be made.

production in southern Alberta. The cultivars Snowden and Frito Lay 1625 are both chipping types while the Russet Burbank are fryers (Table 2). They are all considered as "late" varieties. Farmer experiences are that Russet Burbank have demonstrated better response to higher nitrogen fertilizer applications thus, they are fertilized more heavily. Frito Lay 1625 are also noted for their extensive rooting (vertical and horizontal) so they may be able to better exploit soil fertility. Farmers used their normal methods of seeding, cultivation, irrigation, pest control and harvest of their potato fields. The farmers' fertilizer applications are given in Table 3. Soil nitrogen, phosphorus, potassium values in 1996 were obtained from the farmers' records and in 1997, 1998 and 1999 were obtained from the grid samples (Table 4) and from the farmers' or fertilizer company's records. Soil phosphorus was determined by the Kelowna method (Van Lorop, 1988) and soil potassium was determined by the ammonium acetate methods in 1999. In 1997 and 1998, soil potassium was determined by the Kelowna method (Van Lorop, 1988), which gives lower values than the ammonium acetate method.

Table 1. Legal location and legal description of potato fields monitored and date first irrigated.

Year/Site	Legal Land Location	Soil Type	First Irrigated	Pivot Irrigated
1996 Hays	E½ NE 9 12 14 W of 4	from 0-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994
Fincastle	E½ NW 7 11 14 W of 4	Chin light loam Fluvial lacustrine	1956	1984
1997 Hays	W½ NE 9 12 14 W of 4	from 0-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994*
Fincastle	W½ NW 27 10 15 W of 4	Cavendish loamy sand and dune sand	1956	1987
1998 Hays	W½ SE 9 12 14 W of 4	from 10-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994*
Fincastle	E½ NW 27 10 15 W of 4 E½ SW 34 10 15 W of 4	Cavendish loamy sand and dune sand	1956	1987
1999 Hays	E½ NE 9 12 14 W of 4	from 10-120 cm Aeolian loamy sand overlying fine lacustrine till	1978	1994*
Fincastle	E½ NW 7 11 14 W of 4	Chin light loam Fluvial lacustrine	1956	1984
Vauxhall	S½ SW 5 13 6 W of 4 E½ 5 13 6 W of 4	Clay loam to loam overlying Clay loam to clay till at about 1 m	1921	1995

* pivot converted from high pressure to low pressure in 1997

Fertilizer Treatments

In 1997, 1998 and 1999, strip fertility experiments were set out. In 1997, the treatments (Table 5) applied were centered around the N2 treatment (farmer rate) (Table 3). Each strip was 8 rows or 6.7 m wide on the Snowden field and 8 rows or 7.3 m wide on the Russet Burbank field. In 1998, the fertilizer strips were in addition to the farmers' fertilizer rates (Table 6). Each strip was 6 rows wide or 5.03 m at Hays and 5.49 m at Fincastle. This represented one pass of the potato harvester. Yields were acquired and positioned on the fertilizer strips in 1997 and 1998 with GPS and a yield monitor on the farmers' potato harvesters.

In 1999, fertilizer plots were set out at Hays. Each plot was 12 rows or 10.1 m wide by 400 m long and was replicated twice. Compost manure and fertilizer treatments (Table 7) were broadcast on the plots in October of 1998. The plots were not fertilized by the farmer, except for 41 kg/ha N at seeding and a fertigation application of 50 kg/ha N during the growing season. The potatoes were hilled and seeded by the farmer in April of 1999. Snowden potatoes were grown and the field was fertigated (Table 3) and irrigated similar to the remainder of the field. Counts of visibly diseased plants on 600 m rows in each treatment were made in August of 1999.

Table 3. Farmers' soil fertility (N, P and K) before fertilization and N, P and K fertilizers applied and depth of soil samples (kg/ha).

		Hays (kg/ha)	**Fincastle (kg/ha)**
1996	Soil N Fall 95^{0}	(29) 0.0-0.30 m	(73) 0.0-0.60 m
	Fertilizer N prior to seeding	120	59
	Banded N at hilling	34	0
	Fertigated N	58	11
	Total N	**241**	**144**
	Soil P	(35) 0.0-0.30 m	(67) 0.0-0.30 m
	Fert P	48	32
	Total P	**83**	**99**
	Total K not available		
1997	Soil N 0.0-0.60 m	37	67 (52)
	Fert N Fall 96	90	0
	Banded N at hilling	39	179
	Fertigated N	88	41
	Total N	**254**	**287**

Table 4. Soil analysis done for the site specific potato project.

Year	Sand (%)	Silt (%)	Clay (%)	$NO_3 - N$ (ppm)	NH4-N (ppm)	Miller Axley PO_4-P(ppm)	Kelowna PO_4-P (ppm)	Ammon Acetate K (ppm)	Kelowna K (ppm)	pH	2:1 extract E.C. (dS/m)	Zn (ppm)	Cu (ppm)	Mn (ppm)	Fe (ppm)	Na (ppm)	CaO_3 (ppm)	S (ppm)
1996 sampled May 26 0.0-0.90 m	✓	✓	✓	-	-	-	-	-	-	-	-	-				-	-	-
1997 sampled Oct.96 0.0-0.90m	✓	✓	✓	✓	1/6 of profiles	✓	0.0-0.15 m 0.15-0.30 m		0.0-0.15 m 0.15-0.30 m	✓	✓	1/6 of 0.0-0.15 m samples					Hays	
1998 sampled Oct. 97 0.0-0.90m	✓	✓	✓	✓	✓	✓	0.0-0.15 m 0.15-0.30 m		0.0-0.15 m 0.15-0.30 m	✓	✓	0/0-0.15 m						
1999 sampled Oct. 98 0.0-0.90 m	✓	✓	✓	✓	✓	✓	0.0-0.15 m 0.15-0.30 m	✓	0.0-0.15 m 0.15-0.30 m	✓	✓	0.0-0.15 m				✓	0.0-.15 0.15-0.30	✓

✓ all samples analyzed

Pest Monitoring

Diseases were monitored by walking the fields. Some areas of the Hays fields received excess water and developed water-induced rot of tubers. These areas were not harvested. In 1999 fertilizer, compost and manure treatments were set out as strips on the Hays field. Disease counts were made on two rows from the three 50 meter long strips from each of the two replicates of the treatments. The 1999 Vauxhall and Fincastle fields had very little disease on all fertilizer treatments so no disease counts were made in these fields.

In 1996 to 1998 weeds in all fields were widely dispersed and not clustered so they were not mapped with GPS or remote sensing techniques. In 1999 dense areas of Canada Thistle (*Cirsium arvense*) occurred on the Hays field. The perimeters of some of these GPS areas were mapped with differential GPS, by walking with a backpack unit obtaining correction data from a base station at the edge of the field. These areas were then located on the CASI images of the field.

Remote Sensing

In July 1996, Itres, a commercial remote sensing firm, collected airborne compact spectographic imager (CASI) data on the Hays potato field. Alberta Environment took color infrared photos at a scale of 1:5,000 and 1:10,000 on July 14, 1997, at Hays and Fincastle; July 23, 1998 at Hays and Fincastle and July 23, 1999 at Hays, Fincastle and 1:15,000 photos at Vauxhall. On July 28, 1999, CASI data were taken of the Hays, Fincastle and Vauxhall potato fields by Itres. GPS positions of ground control points were taken and used to prepare georeferenced images.

Tuber Samples

In 1997, 1998 and 1999, two samples were hand dug near each grid point prior to harvest. Each hand sample consisted of four uniformly spaced plants in 1.22 m of row. The farmer at Fincastle used 0.91 m row spacing between rows and the farmer at Hays used 0.84 m spacing between rows. In addition, in 1999, four samples were hand dug from each replicate of each fertilizer treatment.

Table 8. Petiole analysis volume and parameters.																		
		Sampling date			Analysis													
Year	Location	1st	2nd	3rd	Moisture	N	Ca	P	NO_3 N	K	S	Zn	B	Fe	Mg	Al	Ca	Na
1996	Hays	July 3	July 30	Aug. 20	✓	✓	✓	✓	✓		∉	∉	∉	∉	∉	∉	∉	∉
	Fincastle	July 4	July 30	Aug. 20	✓	✓	✓	✓	✓		∉	∉	∉	∉	∉	∉	∉	∉
1997	Hays	July 3	July 23	Aug. 12	✓	✓	✓	✓	✓	✓	∉	∉	∉	∉	∉	∉	∉	∉
	Fincastle	July 7	July 24	Aug. 13	✓	✓	✓	✓	✓	✓	∉	∉	∉	∉	∉	∉	∉	∉
1998	Hays	July 6	July 22	Aug. 10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Fincastle	July 7	July 23	Aug. 11	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1999	Hays	July 7	July 30	Aug. 17	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Fincastle	July 9	July 28	Aug. 13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Vauxhall	July 6	July 27	Aug. 11	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✓ all samples analyzed

∉ 1/5 of samples were analyzed

Table 10. GPS Applications 1996-1999.			
Year/Crop	**Site**	**GPS differential source**	**Monitor**
1996			
Russet Burbank Potatoes	Fincastle	Novatel RT-20 + local base corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
1997			
Russet Burbank Potatoes	Fincastle	Omnistar + geostationary corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
Wheat	Hays	Omnistar + geostationary corrections	Ag Leader
Barley	Fincastle	Omnistar + geostationary corrections	Ag Leader
1998			
Russet Burbank Potatoes	Fincastle	Novatel RT-20 + local base corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
1999			
FL1625 Potatoes	Fincastle	Novatel RT-20 + local base corrections	Harvestmaster
Snowden Potatoes	Hays	Novatel RT-20 + local base corrections	Harvestmaster
Russet Burbank Potatoes (salinity only)	Vauxhall	Novatel RT-20 + local base corrections	EM38 salinity meter

At Fincastle in 1996 and in 1999 and on the two halves of a field in 1997 and 1998, corner pivots were used. These pivots did not provide as much water to the corners as the rest of the field. When the corner arm was extended and operating, the remainder of the pivot appeared to have reduced output.

Piezometer measurements of groundwater depth movement and soil NO_3-N content at the Hays site in 1997 (Fig. 7) and Fincastle 1997 (Fig. 8) and 1998 are reported by Rodvang (1998 and 1999). Hays had less than half the NO_3 N than Fincastle. The Hays site was irrigated more than the Fincastle site. Nitrate levels were low at depth but this may be due to reducing conditions, causing denitrification. Once all nitrate is reduced, denitrifying bacteria tend to reduce sulphate to H_2S. The odor of H_2S was present at two of the well sites at Hays in 1997 indicating some sulphate was being reduced (Rodvang, 1998). At some of the wells, the texture was coarse permitting downward movement of water. At Hays, the flow of groundwater occurred from the irrigated field outward to the unirrigated rangeland. Irrigation has caused water table mounding below the sites. Water tables rose during the summer at Hays and reached a peak of 1.2 m below the ground at one site in 1997 and 1.65 m in 1998.

At Fincastle, the irrigation applications generally were less than at Hays. The water table followed the surface topography. In 1997 water table depths ranged from 1.7 to 3.5 m. In 1998 at Fincastle, water table depths varied from 1.5 to 2.5 m below ground level and were over 5 m deep at one of the six sites. Water levels rose during the summer in both years and declined after late August. Vertical hydraulic gradients indicated slight downward flow at most piezometer nests.

In 1997, nitrate was present in soil water at the piezometer sites at levels from 1 to 20 mg/kg at Fincastle. Nitrate levels at Hays were lower, from 1 to 6 mg/kg. Site 6 (R6 in Fig. 7) was located on native range adjacent to the potato field and had almost no nitrate to a depth of 1.5 m. The difference between the nutrient level at this site and the other 5 sites shows the effect of irrigated agriculture for 19 years.

6% were deficient to marginal (5-15 ppm N) and 4% were high (>20 ppm N). This site would offer possibilities for precision application of N with detailed mapping of soil N. This site had 27% of the 0.60-0.90 m samples with greater than average (165 kg/ha) soil N. The nitrogen at depth is evidence of leaching of nitrogen during previous cropping.

Soil N data collected from grid sampling for two fields for three years indicates only two of the six fields had sufficient variability in soil nitrogen to justify variable rate fertilization. Soil N for 6 fields (Fig. 11b) was not significantly related to petiole NO_3-N on July 3-7. This also indicates that when these fields were grouped together, variable rate application based on soil NO_3-N the previous fall does not offer possibilities for improved nitrogen management. Fincastle in 1997, and perhaps in 1999, had sufficient variability to justify the cost of sampling and analysis to determine soil nitrogen and then to apply variable rates of nitrogen fertilizer. The spatial soil fertility data must be collected before a decision can be made on the feasibility of variable rate fertilization.

Phosphorus

At Fincastle in 1997, soil phosphorus (P) for 0.0-0.15 m was high by Alberta Standards and exceeded 100 kg/ha P for 96% of the grid sample sites and exceeded 168 kg/ha P (20 ppm) for 58% of the sample sites (Table 12). This same field had 88% of the 0.0-0.30 m samples exceeding 200 kg/ha P and 46% of the samples exceeding 320 kg/ha P. The father of the current owners raised hogs from 1964 to about 1975 directly south of the 1997 site and used the 1997 field for spreading hog manure. It is not known how much hog manure was applied or what level the soil phosphorus reached but the subsequent 22 years cropping with little or no phosphorus fertilizer added has not yet reduced the soil P to levels which are environmentally safe. The adjacent field at Fincastle used in 1998 had only 6% of the samples for 0.0-0.15 m with soil P greater than 100 kg/ha.

In October 1998 before fertilizer was applied, the 1999 Fincastle site had high soil P in the 0.0-0.15 m layer (average 117 kg/ha) on the southern 67% of the field and adequate or marginal (average 50 kg/ha P) on the remainder of the field (Fig. 12a). The farmer had spread liquid hog manure on a portion of the field in the fall of 1997. This farmer applied 39 kg/ha P to the entire

Table 11. Soil nitrogen levels in ppm N (0.0-0.60 m depth) in October of the previous year for grid sample sites grouped by % according to Alberta Agriculture Standards.						
Location	**Year**	**Very deficient**	**Deficient**	**Marginal**	**Adequate**	**High**
ppm		**<5**	**5-7.5**	**7.5-15**	**15-20**	**>20**
Hays	97	73	19	8	0	0
	98	68	32	0	0	0
	99	100	0	0	0	0
Fincastle	97	40	25	26	6	4
	98	92	6	2	0	0
	99	90	2	4	0	4

Table 12. Soil phosphorus levels in ppm P (0.0-0.15 m depth) in October of the previous year for grid sample sites grouped by % according to Alberta Agriculture standards.						
Location	**Year**	**Deficient**	**Marginal**	**Adequate**	**High**	**Very high**
ppm		**<13**	**13-25**	**25-45**	**45-75**	**>75**
Hays	97✦	34	66	0	0	0
	98✦	8	60	31	0	0
	√	12	79	8	0	0
	99✦	2	60	38	0	0
	√	6	74	21	0	0
Fincastle	97✦	0	0	4	38	58
	98✦	20	35	39	6	0
	√	6	30	57	8	0
	99✦	6	16	12	64	0
	√	2	24	22	53	0

✦ Miller Axley method
√ Kelowna method

Table 13. Soil potassium levels in ppm K (0.0-0.15 m depth) in October of the previous year for grid sample sites grouped by % according to Alberta Agriculture standards.						
Location	**Year**	**Deficient**	**Marginal**	**Adequate -**	**Adequate +**	**High**
ppm		**0-75**	**75-150**	**150-225**	**225-300**	**>300**
Hays	97†◊	0	67	23	9	2
	98√	0	38	52	10	0
	99◊	0	26	39	14	21
Fincastle	97†◊	0	0	38	49	13
	98√	4	40	36	15	6
	99◊	0	4	71	16	10

† 0.0-0.30 m depth
√ Kelowna method
◊ Ammonium acetate method

Petiole Analysis

Potato producers routinely take petiole samples from late June through mid to late August. The samples are tested for nitrate nitrogen (NO_3-N) to help producers maintain consistent nitrogen health or to make corrections for insufficient N by fertigating the entire field. Historically, potato producers did not test for phosphorous or potassium status nor did they make adjustments for insufficient P and K. In the last 3 or 4 years, many have also been analyzing for P, K in addition to NO_3-N.

Nitrate Nitrogen

In 1996, petiole NO_3–N (Table 14) was adequate at most of the sites at the time of the first sampling but, despite fertigation with additional N, it decreased and became deficient at the time of the second and third sampling.

In 1997, petiole N at Hays (Table 14b) was adequate on 45% and deficient on 55% of the sites at the time of the first sampling and deficient on 100% of the sites at the time of the second or third samplings. Soil nitrate N was deficient on 92% of the sites (Table 11) the previous October and 77% of the field had less than 15% clay in the 0.0-0.60 m. The field received from 0.37-0.45 m of rainfall and irrigation from June 23 to September 9 (Fig. 3a). The coarse textured soils permitted leaching of nitrogen below the root zone, which meant there was excess moisture.

In 1997, the Fincastle site was deficient in petiole N (Table 14) on 88% of the field in early July to 62% by August 12. Fincastle received about the same amount of irrigation and rainfall as Hays but over a period one week longer than the Hays site (June 24 to September 18). The Russet Burbank potatoes at Fincastle used more water in the latter part of the season than the earlier maturing Snowden potatoes at Hays.

In 1998, petiole analysis on both Hays and Fincastle indicated that the percent of samples that were deficient decreased from highs of 96 and 76 early in July to 46 and 21 by August 10 or 11 (Table 14c). Total soil nitrogen plus fertilizer nitrogen (Table 3) was higher in 1998 than in 1997 and 1996. This may be the reason that the tissue nitrogen did not decline like it did in 1996 and

In 1998, both fields were mostly marginal in soil P (Table 12) but received high applications of fertilizer P (119 kg/ha Hays and 153 kg/ha at Fincastle, Table 3). Despite these high applications of fertilizer, available tissue P declined by Aug. 10-11 to become 46% deficient at Hays and 94% deficient at Fincastle (Table 14c).

In 1999, in early July, the tissue P levels in the Hays field were mostly marginal (85 %) with some areas (15%) high (Table 14d). The Fincastle field was 51% high and 45% marginal and 4% low. Petiole P levels were high or adequate in the part of the field that had received hog manure. In the remainder of the field, petiole P levels were adequate on July 9 and declined to become deficient or adequate on July 28 and August 13.

Petiole phosphorus on six fields for July 3-7 was highly significantly positively correlated to soil P (Fig. 14a) (r = 0.57**). On the same six fields, petiole phosphorus content was highly significantly negatively correlated to soil clay content (Fig. 14b) (r = 0.32**). This occurs because soil P is tied up in unavailable forms on clay. However, there was no significant correlation between soil P and clay content. In contrast to soil nitrogen, soil phosphorus content can be used as a basis for variable rate application of phosphorus fertilizers. Petiole P was highly significantly positively correlated to yield at all three sampling times (Fig. 14c, 14d and 14e). This indicates petiole P was low for optimum yields on these fields.

Potassium

Tissue K analysis was not done in 1996. In 1997, at both Hays and Fincastle, almost all sites were deficient in the first week of July (Table 14). By July 23 and 24 tissue levels increased and by August 12-13 the Hays field had 67% high levels of K and the Fincastle field had 100% high levels of K (Table 14 and Fig. 15). A similar pattern occurred in 1998. In 1997 mean tissue K at Hays was 6.2% July 3, 6.9% July 23 and 6.0% August 12. In 1997 at Fincastle, mean tissue K was 6.5% July 7, 7.5% July 24 and 6.4% August 13. However, in 1999 both Hays and Fincastle showed most of the field with excess levels of tissue K on July 7 and 9 (Fig. 16a) and this decreased to 0% with excess at Hays and 2% with excess at Fincastle by the 13th of August (Fig. 16b).

(+2.7% Hays and +5.3% Fincastle). These results indicate the farmers are at an optimum rate with respect to nitrogen. Phosphorus rates on these two fields may be low. Both of these fields had high phosphorus fertilizer applications (Table 3) and petiole P levels declined during the season (Table 12).

Table 16. 1998 potato yields (t/ha) and gross value on fertilizer strips.

Treatment	Hays		Fincastle	
	Yield	Gross value ($/ha)▲	Yield	Gross value ($/ha)▲
N	34.9	3685	33.2	3506
P	38.6	4076	37.8	3992
NP	37.5	3961	36.6	3865
Check	37.6	3970	35.9	3791

▲ Value is based on 80% marketable at $132/tonne.

In 1999, six treatments were set out at Hays (Table 7) consisting of two rates of compost, manure and phosphorus fertilizer. Disease counts on the foliage of the plants (Table 17) indicated that the low phosphorus treatment had a greater amount of foliar disease than all other treatments. The three high rate treatments also had a lower incidence of foliar disease than their corresponding low rate treatments, indicating an overall benefit of high rates of P, whatever the form, in terms of foliar disease. Because this field has been used a number of times for growing potatoes in the last 10 years, the level of foliar diseases was quite high. *Rhizoctonia* and scab counts were also made on the tuber surfaces. Variability on tuber disease counts was high and disease occurrence on tubers was low so no conclusions can be made regarding the influence of these treatments on tuber disease.

The 1999 Hays field has a history of developing low P levels in petioles in late July and August despite high rates of P fertilizer being applied. The treatments had no significant effect on tuber yields (Table 17) although compost and manure treatments yielded slightly more than the P treatments. Tuber numbers were also recorded for each treatment.

Pest Monitoring

Weeds

In most fields, the weeds did not occur in large numbers in any one area so they were not suitable for site specific management. In 1999 on the Hays field, there were patches from 10 m to 50 m in diameter, which were heavily infested with Canada Thistle. In late August prior to harvest, the perimeters of some of these patches were mapped with GPS. It was not possible to identify these patches on remote sensed imagery taken on July 28. If accurately identified, these patches of Canada Thistle could be controlled with spot applications of chemicals such as Lontrel (clopyralid) or Roundup (glyphosate). These chemicals are toxic to potatoes so this is an extreme treatment and the herbicides need to be applied precisely. The potential exists for developing an irrigation system, which will provide site specific applications of herbicides, as well as water (Eberlein, 1999).

Disease

Diseases were monitored each year on all fields. Disease incidence was low and diseased plants were scattered. No attempt was made to map disease. Late blight did occur in varying degrees on the fields prior to harvest and it would have been possible to map this disease but it is difficult to distinguish from vine senescence. Disease surveys were done in the middle of August when the incidence of late blight was low.

Insects

Colorado potato beetles were the only insect pest present at sufficient levels to require insecticide application by the farmers. Colorado potato beetles are native to southern Alberta so the problem of resistance to insecticides is not as important as in areas where it only occurs on potatoes. It is not necessary to retain non resistant populations for reproduction in portions of the fields as described by Weisz et. al.(1996). Flescher et. al.(1999) describes how Colorado potato beetle are most dense near the edge of fields thus making them suitable for site specific management. However, due to farmer vigilance and spray programs, the Colorado potato beetles never became a serious problem in any areas of the fields tested, so were not suitable for site specific management.

Table 18. Published algorithms for chlorophyll/N estimation using remote sensing data.

Index	Formula	Citation	CASI bands
Simple ratio			
$SR_{800\ 670}$	(R_{800nm}/R_{670nm})		17, 25
$SR_{695\ 430}$	$(R_{695nm}R_{430nm})$	Carter 1994	1, 18
$SR_{605\ 760}$	(R_{605nm}/R_{760nm})	Carter 1994	12, 23
$SR_{695\ 760}$	(R_{695nm}/R_{760nm})	Carter 1994	18, 23
SR_{695_670}	(R_{695nm}/R_{670nm})	Carter 1994	17, 18
SR_{750_705}	(R_{750nm}/R_{705nm})	Gitelson and Merzlyak 1996, Sims and Gamon 2002	19, 22
SR_{750_550}	(R_{750nm}/R_{550nm})	Gitelson and Merzlyak 1996, Lichtenthaler et al. 1996	9, 22
$SR_{667\ 717}$	(R_{667nm}/R_{717nm})	Leblon et al. 2001	17, 20
$SR_{550\ 850}$	(R_{550nm}/R_{850nm})	Schepers et al. 1996	9, 28
$SR_{710\ 850}$	(R_{710nm}/R_{850nm})	Schepers et al. 1996	19, 28
$SR_{800\ 680}$	(R_{800nm}/R_{680nm})	Sims and Gamon 2002	17, 25
$SR_{735\ 700}$	(R_{735nm}/R_{700nm})	Gitelson and Merzlyak. 1999	19, 21
Pigment specific simple ratio (PSSR)	(R_{810nm}/R_{676nm})	Blackburn 1998	17, 26
Normalized difference index			
Normalized green difference vegetation index (NGVDI)	$(R_{750nm} - R_{550nm})/(R_{750nm} + R_{550nm})$	Gitelson et al. 1996	9, 22
Photochemical reflectance index (PRI)	$(R_{531nm} - R_{570nm})/(R_{531nm} + R_{570nm})$	Gamon et al. 1992	8, 10
Pigment specific normalized difference (PSND)	$(R_{810nm} - R_{676nm})/(R_{810nm} + R_{676nm})$	Blackburn 1998	17, 26
Normalized difference index ($NDI_{750\ 700}$)	$(R_{750nm} - R_{700nm})/(R_{750nm} + R_{700nm})$	Gitelson and Merzylak 1994, Sims and Gamon 2002	19, 22
Normalized difference index ($NDI_{800\ 680}$)	$(R_{800nm} - R_{680nm})/(R_{800nm} + R_{680nm})$	Sims and Gamon 2002	17, 25
Normalized pigments chlorophyll ratio index (NPCI)	$(R_{680nm} - R_{430nm})/(R_{680nm} + R_{430nm})$	Peñuelas et al. 1994	1, 17
Structure-insensitive pigment index (SIPI)	$(R_{800nm} - R_{445nm})/(R_{800nm} + R_{680nm})$	Peñuelas et al. 1995	2, 17, 25
Others			
Modified simple ratio ($mSR_{750\ 445}$)	$(R_{750nm} - R_{445nm})/(R_{705nm} - R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Modified normalized ratio ($mNR_{750\ 445}$)	$(R_{750nm} - R_{705nm})/(R_{750nm} + R_{705nm} - 2*R_{445nm})$	Sims and Gamon 2002	2, 19, 22
Optimized soil adjusted vegetation index (OSAVI)	$(1 + 0.16)*(R_{800nm} - R_{670nm})/(R_{800nm} + R_{670nm} + 0.16)$	Rondeaux et al. 199	17, 25
Modified chlorophyll absorption in reflectance index (MCARI)	$[(R_{700nm} - R_{670nm}) - (0.2*(R_{700nm} - R_{550nm}))*(R_{700nm}/R_{670nm})]$	Daughtry et al. 2000	9, 17, 19
Transformed chlorophyll absorption in reflectance index (TCARI)	$3*[(R_{700nm} - R_{670nm}) - (0.2*(R_{700nm} - R_{550nm}))*(R_{700nm}/R_{670nm})]$	Haboudane et al. 2002	9, 17, 19
Plant senescence reflectance index (PSRI)	$(R_{680nm} - R_{500nm})/(R_{750nm})$	Merzlyak et al. 1999	6, 17, 22
Carotenoids	$[4.145*(S_{760nm}/S_{500nm})*(R_{500nm}/R_{760nm})]-1.171$	Chapelle et al. 1992	5, 23
Chlorophyll b	$2.94*[((S_{675nm}/R_{650nm}*S_{700nm})*(R_{650nm}*R_{700nm}/R_{675nm}))]+0.378$	Chapelle et al. 1992	15, 17, 18
Chlorophyll a	$22.735[=(S_{675nm}/S700_{nm})*(R_{700nm}/R_{675nm})] - 10.407$	Chapelle et al. 1992	17, 18

to correspond to soil texture, particularly in the northern end of the field at Hays and likely results from poorer growth on the coarse textured soils. Consistent with the observation that many of the proposed indices involve reflectance in similar wavebands, the spatial patterns in the images derived for the various indices were similar (Table 18). Only the images showing the spatial variability in the index SR_{550_850} derived from reflectance at 550 and 850 nm are shown (Fig. 18 and 19). Visual comparison of the petiole-N maps derived in Surfer™ using the grid point petiole nitrate N data and the index SR_{550_850} shows similarities in the patterns across both fields. Generally, areas of low petiole nitrate N exhibited high values for the SR_{550_850} index.

Fincastle Site

Correlation analysis showed a strong relationship between most of the chlorophyll/N indices and petiole nitrate N for the Fincastle site (Table 20). The strongest relationships were evident with simple ratios involving either reflectance in the green band (550 nm) or the red-edge (700-710 nm) and the near infrared reflectance (750-850 nm). These observations can be attributed to the greater range of chlorophyll/N content to which reflectance at 550 and 700-710 nm responds. The absorption feature at 660-680 nm saturates at relatively low chlorophyll content and thus relative to 550 or 700-710 nm is insensitive to variation in chlorophyll/N.

Hays Site

At the Hays site, visually there were some similarities between the spatial patterns within the image of the SR_{550_850} index and the kriged map of the ground based sampling. The extent of the N deficient areas in the remote sensing image appeared less than in the kriged map. The imagery may provide a more accurate representation of the spatial variability given that each pixel in the remote sensing image represents information from an area of 2 x 2 m on the ground while the ground data is an interpolation from grid points at greater than 100 m apart. Quantitative analysis showed only a limited number of indices were significantly related to petiole nitrate N. The strength of the relationship was poor compared to that at the Fincastle site. The lack of a strong relationship may reflect uncertainty in the georeferencing of the airborne imagery and the sampling sites and the heterogeneity of the crop reflectance in the areas selected for sampling (Deguise et al., 1998).

sensing imagery may account for the lack of a significant quantitative relationship at the Hays site. Further studies are being conducted to determine the ability to estimate plant N content using remote sensing techniques.

Soil Salinity

A soil salinity map was made of the additional Vauxhall potato field in 1999 (Fig. 20). This permitted identifying those areas of the field where problem levels of salinity occurred. Tuber samples in these areas were compared to measurements of electrical conductivity (E.C.) calculated from EM38 readings and a tolerance of potatoes to salinity was developed for this field (Fig. 21a). A 50% yield reduction of potatoes occurred at an E.C. of about 6 dS/m. This method is suitable for precision applications to potato production. A salinity tolerance limit and a salinity map means it is then possible to identify those areas where it is not feasible to grow potatoes. Specific gravity of tubers was found to be higher in saline soils than non-saline soils (Fig. 21b).

CONCLUSIONS

A yield monitor was successfully adapted to two farmers' potato harvesters. Maps of tuber yields were developed based on data collected from the harvester. Difficulties were encountered on parts of fields where soil lumps occurred. These lumps usually occurred on areas with a high clay content and resulted in false high yield readings from the mass-based yield sensor. This will be a major restriction to yield mapping of potatoes unless technology can be developed to separate tubers from soil lumps on the harvester belt.

Yield maps were also developed from grid sampling. These grid samples were used to determine tuber yield, average tuber size and tuber quality as measured by specific gravity, chipping score and French fry score. Uniformity of tuber quality is a major concern of processors. Uniformity of irrigation affected tuber size. No relationship was found between chipping and French fry score and the measured factors of soil or water in the field.

sampling of soil phosphorus should provide some improvement in efficiency of uptake of phosphorus.

Potassium levels in the soil from 1997 to 1999 were marginal to adequate on most grid sample sites. In 1997 and 1998 petiole K levels were deficient in the first week of July but became adequate to high in two later samplings. The reason for this is not known. It may be due to lower soil temperatures in early July restricting uptake, rather than the higher soil temperatures in the USA where the standards were developed. There is a need for research that will develop local standards for petiole K levels.

Diseases and insect pests were examined but their occurrence was very infrequent and highly variable, thus not predictable or manageable with site specific technologies. Weeds were carefully managed by farmers thus fields were too weed-free to allow for examination of the usefulness of site specific management for weed control. The sites used in the trials, like most potato fields, were extremely flat, which eliminated the opportunity for relating landscape position to potato yield.

Economic analysis indicated that grid sampling and site specific applications of P and K, on a field that received uneven manure applications, would have realized significant savings.

Remote sensing imagery was successful correlated to plant petiole NO3-N at one test site but not the other. Errors in the overlay of petiole sampling points on the remote sensing imagery may account for the lack of a significant quantitative relationship at the Hays site.

Piezometers were used to measure groundwater depth movement and soil NO_3-N content at the Hays (1997) and Fincastle (1997, 1998) sites. Overall, nitrate levels were low at depth but this may have been due to reducing conditions, causing denitrification. At the Hays site, flow of groundwater occurred from the irrigated field outward to an unirrigated rangeland. Irrigation has caused water table mounding below the sites and water tables rose during the summer at the Hays site.

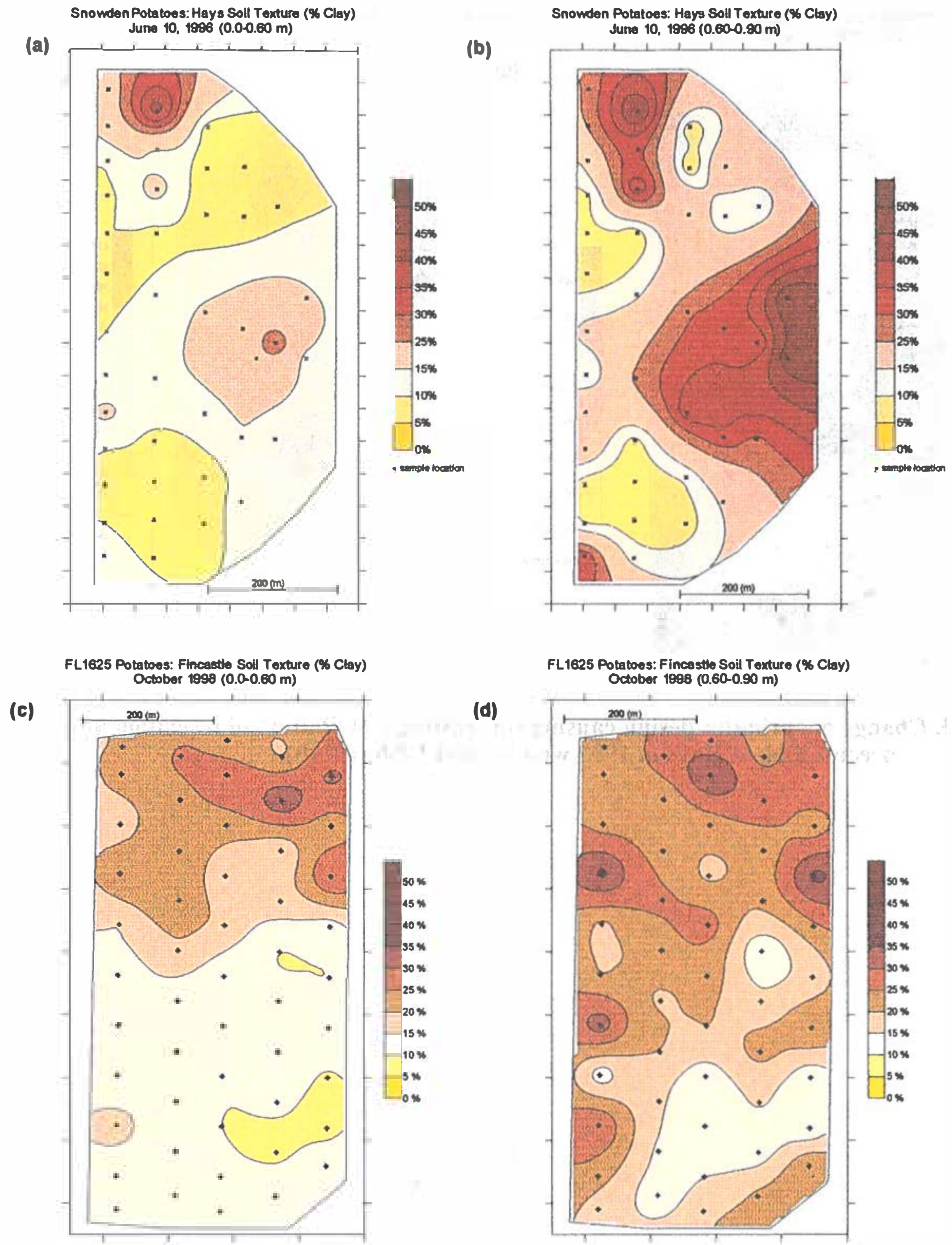


Figure 2. Soil texture maps of Hays 1996 (a and b) and Fincastle 1999 (c and d) fields for two soil depths 0.0-0.60 m and 0.60-0.90 m.

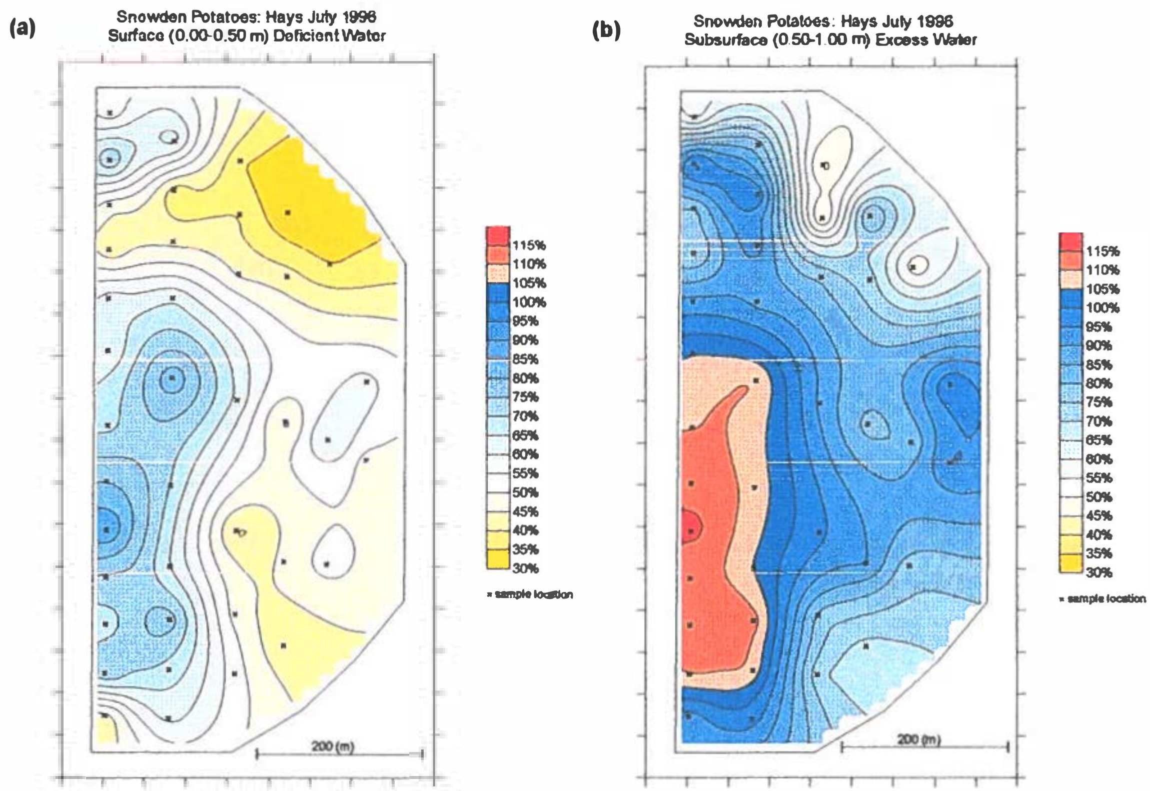


Figure 4. Percent of available moisture (100% = field capacity) in 1996 at Hays for (a) 0.0-0.50 m and (b) 0.50-1.00 m.

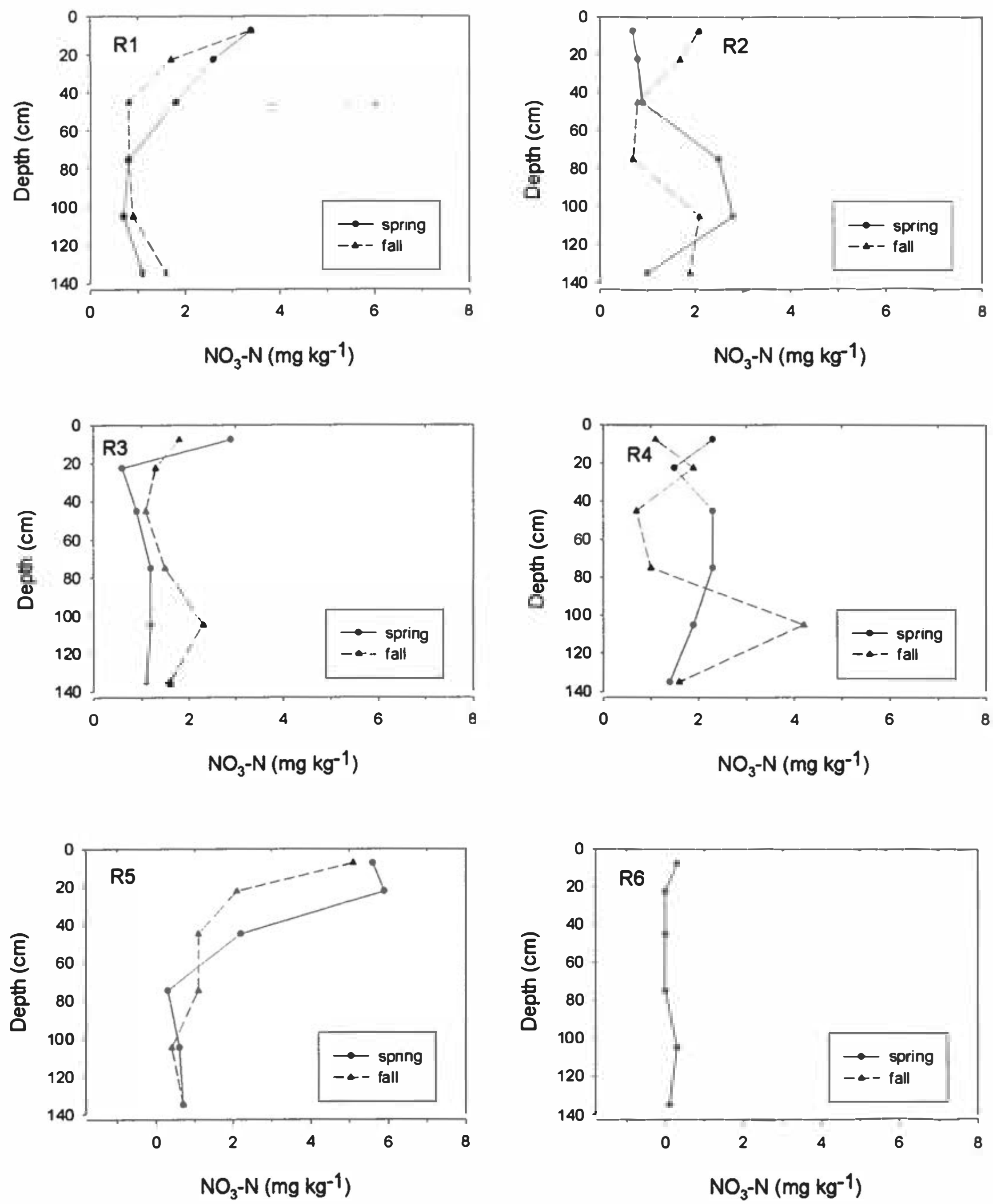


Figure 7. Soil NO_3-N at piezometer sites from 1997 at Hays.

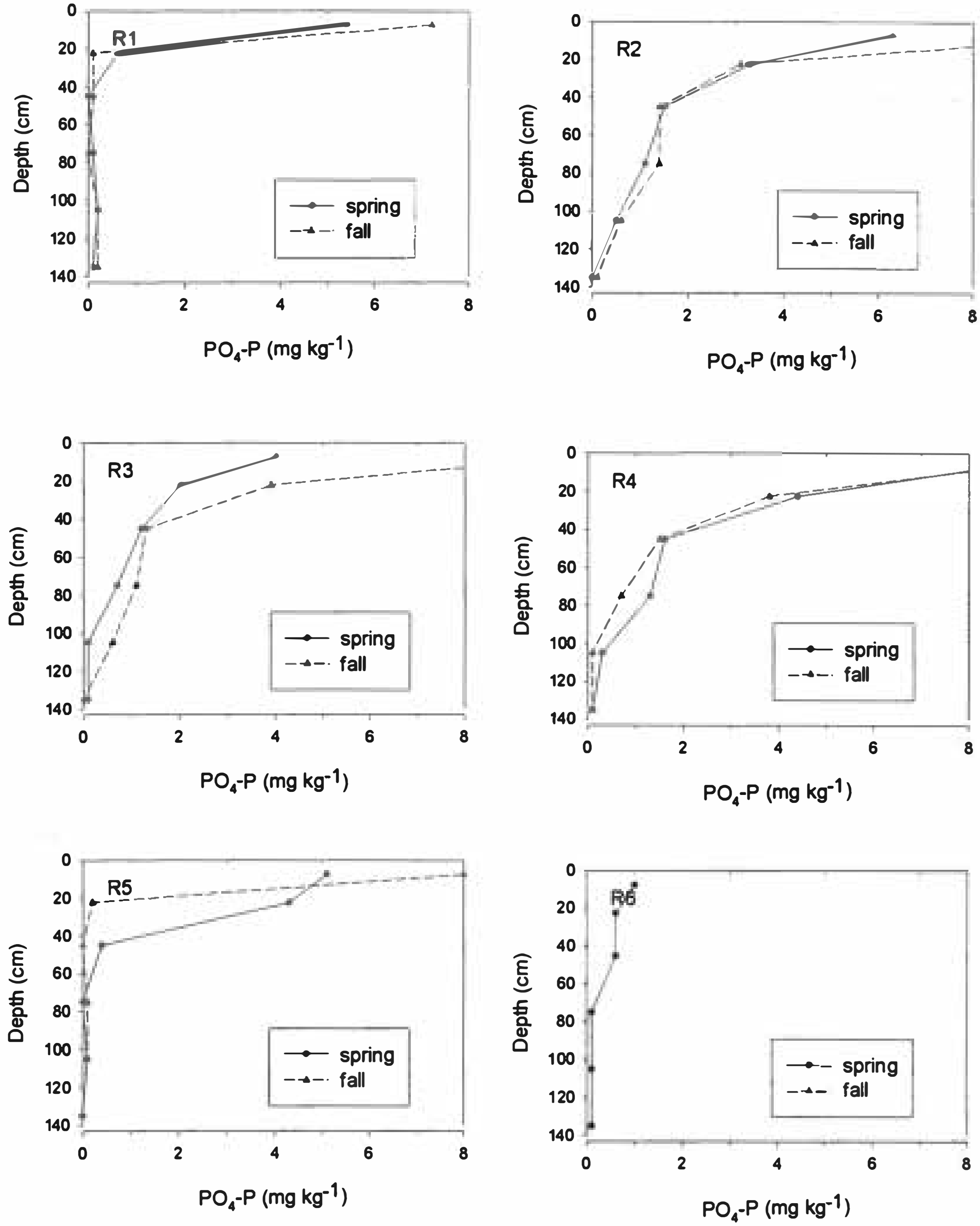
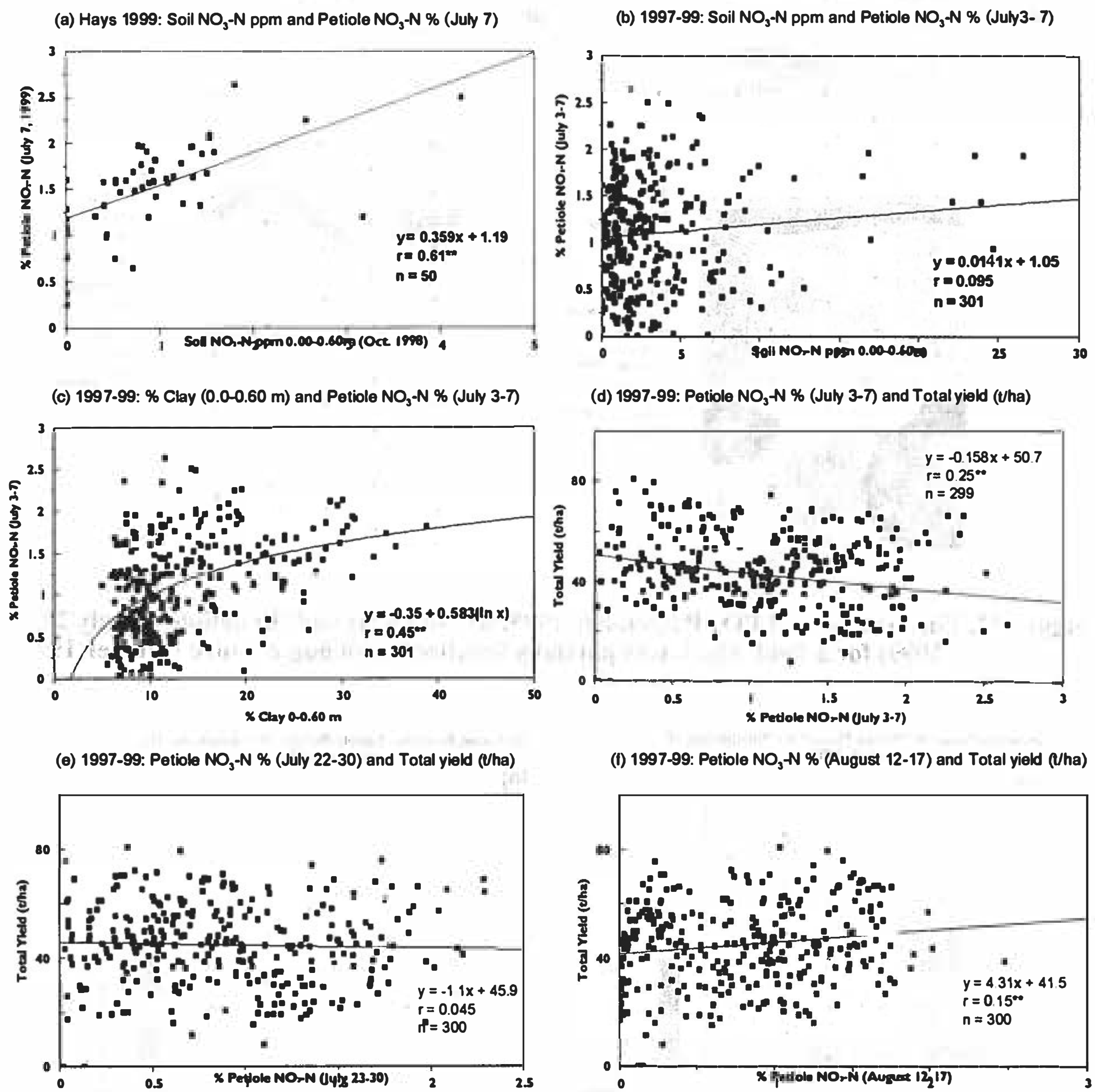


Figure 9. Soil PO4-P at piezometer sites from 1997 at Hays.



* = r significant at the 0.05 level, ** = r significant at the 0.01 level

Figure 11. Correlation between potato petiole NO_3-N and (a) soil NO_3-N for Hays 1999 and (b) soil NO_3-N, (c) soil clay and (d, e and f) total yield for Fincastle and Hays potatoes 1997-1999.

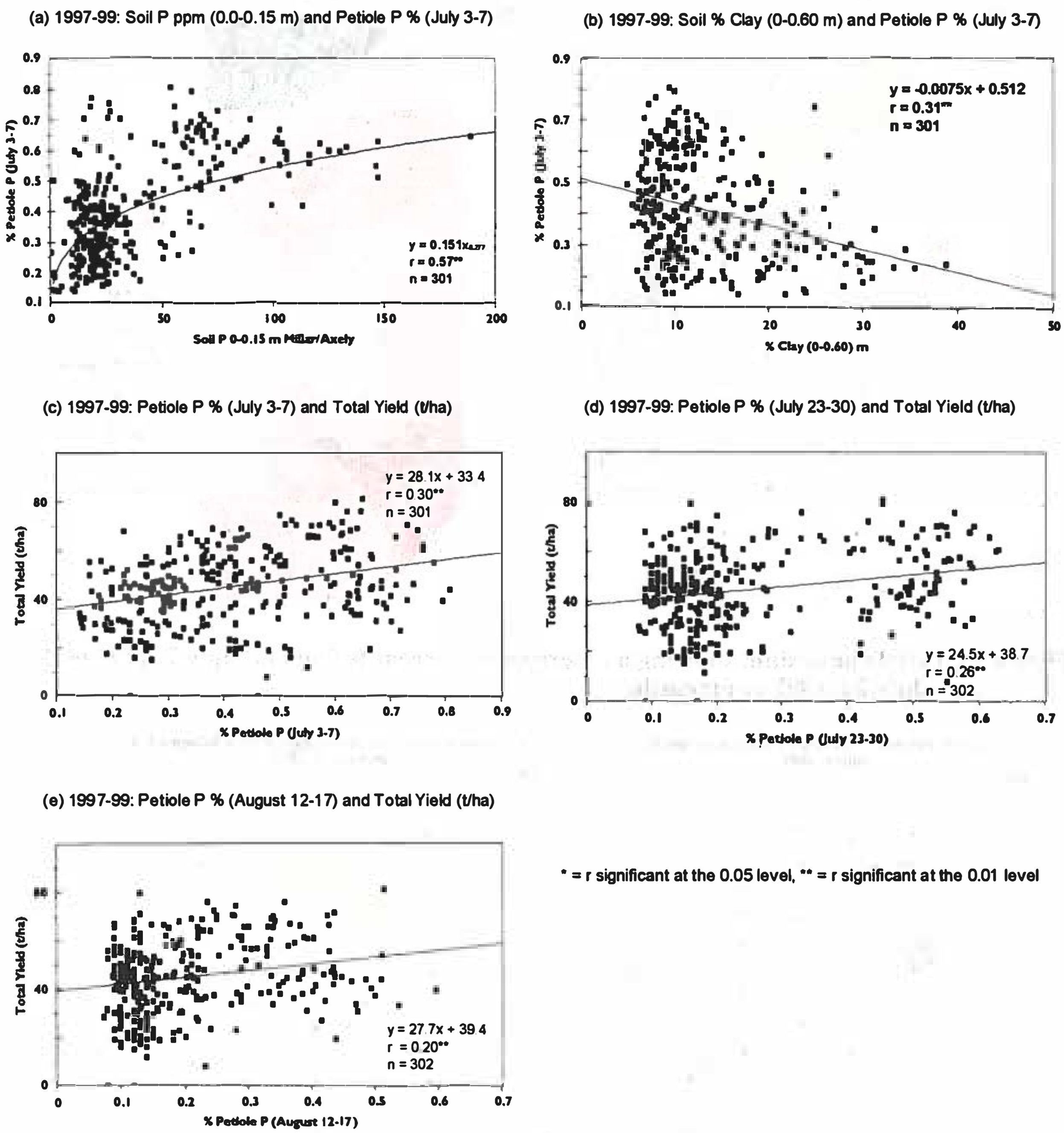


Figure 14. Correlation between potato petiole P and (a) soil PO_4-P, (b) soil clay and (c, d and e) total yield for 3 sampling dates at Hays and Fincastle for 1997-1999.

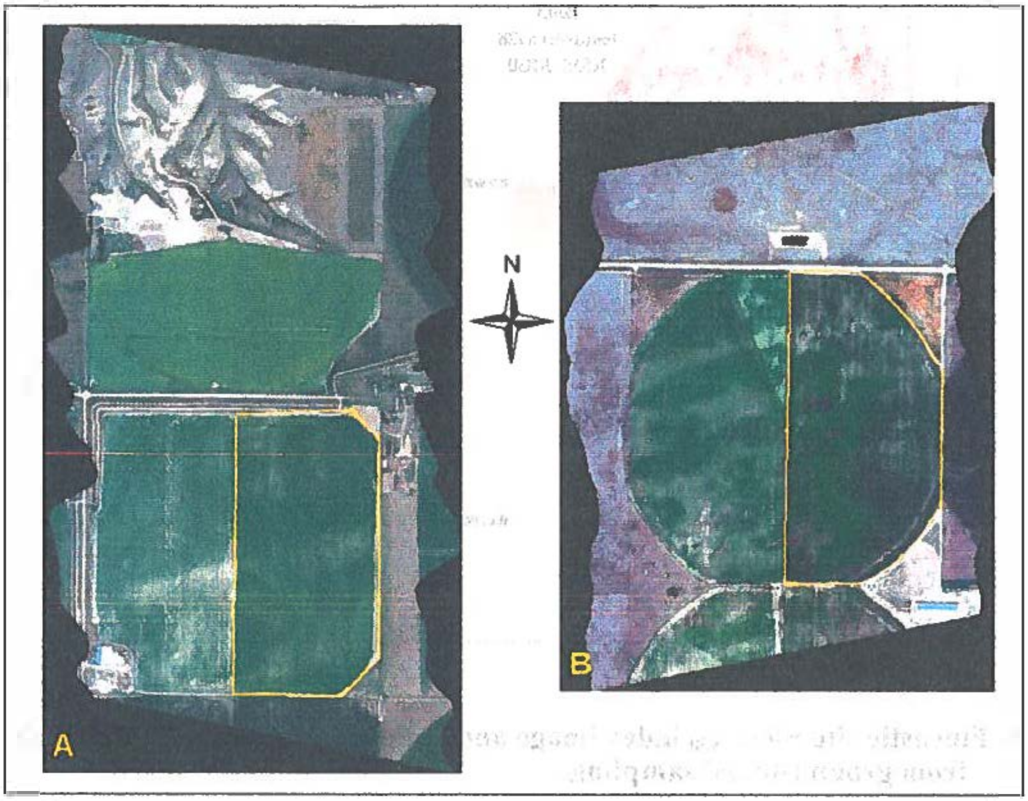


Figure 17. True colour composite images acquired July 28, 1999 at the (a) Fincastle and (b) Hays sites.

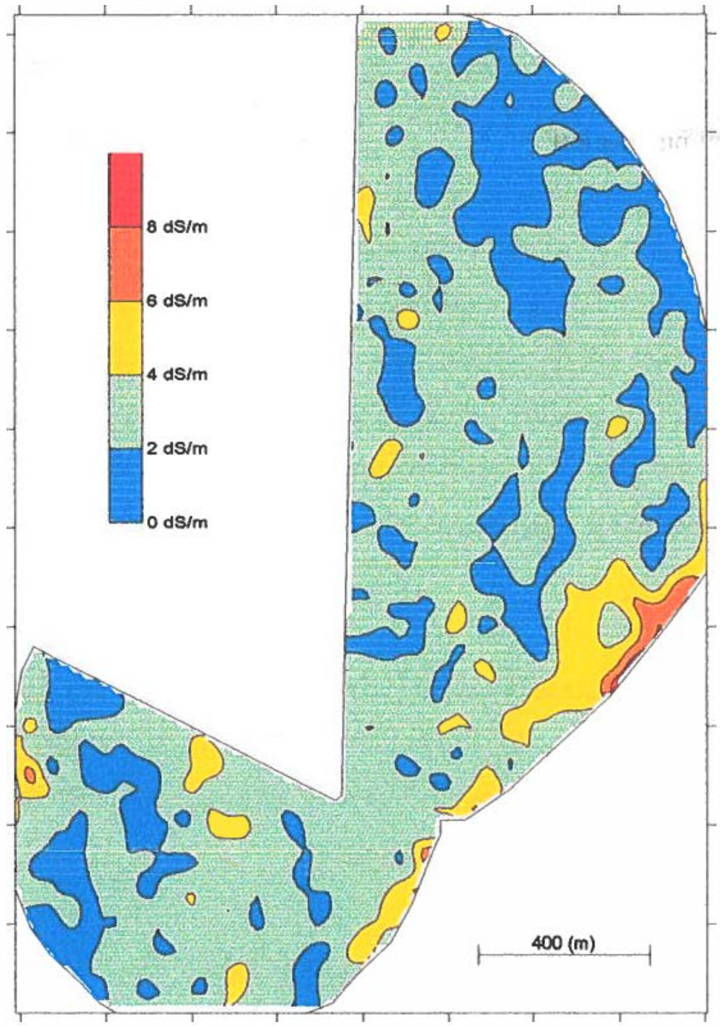


Figure 20. Soil salinity map (E.C. dS/m) for Vauxhall potatoes, April 1999.

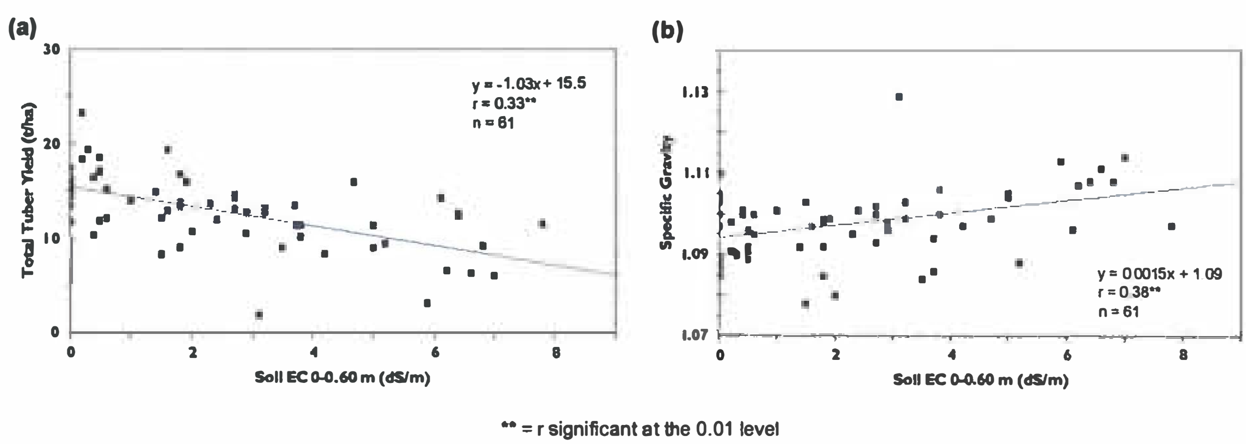


Figure 21. The effect of soil salinity on (a) tuber yield and (b) tuber specific gravity for Vauxhall potatoes 1999.

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J. Rodvang monitored ground water at a series of piezometer nests in 1997 and 1998 and prepared the related portion of this document, including the text and Figures 7-10.

A. Smith of Agriculture and Agri-Food Canada, Lethbridge interpreted the 1999 CASI data and prepared the related portion of this document, including the text, Tables.18-20 and Figure 17-19. A. Smith's full report also appears as an appendix in this document.

L. Hingley, technologist for the Soil and Water Agronomy Program, conducted yield monitoring, sample collection and data organization and he prepared the figures and appendices for this document.

The Precision Agriculture Project with Potatoes was operated by an Alberta Agriculture, Food and Rural Development (AAFRD) team. Soil moisture budgets were determined by R. Hohm and T. Harms. D. McKenzie, R. Skretting, B. winter, T. Dell, A. Harms, H. Harms and L. Wenger collected and processed samples. J. Panford organized measurement of tuber chipping and French fry scores. M. Eliason and D. McKay assisted with setting up yield monitoring equipment. C. Murray proofread the manuscript. Word processing of the manuscript was done by S. Day and M. Bunney.

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PGA
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April 28, 2005

Patricia McAllister
Seed Potato Program
Alberta Agriculture, Food and Rural Development
Crop Diversification Centre North
17507 Fort Road
Edmonton, AB T5Y 6H3

Re: "Post Harvest Test Evaluation Plot and Disease Identification School."

Dear Patricia

We are pleased to advise that the Board of the Potato Growers of Alberta has approved your application in the requested amount of $7,200.00. 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 to the potato industry.

Yours truly,

Vern Warkentin
Executive Director

March 6/07
Not done to date.
MB

Potato Growers of Alberta

Proposal application for Research funding 2005-2006

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. This application could use other sources of forms only if it will be presented to other funding consortiums.
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 presentations and result reports.

Confidentiality

This Proposal is confidential and the information contained in it may not be disclosed with other organizations or research groups. ☐

1. Research Team Information

Team Leader:Patricia McAllister		
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Team Member:Deb Hart		
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Team Member:		
Organization:	Section/Department:	
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Phone Number:	Fax Number:	

2. Project Information

Title:Post Harvest Test Evaluation Plot and Disease Identification School.
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 ☐Potato Fertility Plant ☐Nutrition/Soil management ☐Green House ☐Environment ☐Potato Marketing and Economics ☐Potato Cultural Management
Research Location (s): Ellerslie Research Farm, Edmonton, AB
Duration (Y):1 Start Date (YY/MM):04/05Ending Date (YY/MM):10/05

Is the project linked to other applications / Research projects Y ☒ N ☐
(Please identify related projects)

1.Project:Post Harvest Test Virus Survey - Hawaii
Team Leader:Deb Hart

Start Date:11/04

2.Project:
Team Leader:

Start Date:

Background.
(Max 2000 characters)

In 2003, the PGA voted in favour of making post harvest testing of lots E2 and lower mandatory. This more then doubled the number of Alberta seed lots that are winter tested on an annual basis and increased the profile of the winter test with Alberta's commercial growers.

Traditionally the PHT plot had been in Oceanside, California and results were avaiable in mid to late February. In 2001-02 we begain to investigate moving the trial site to Hawaii where warmer conditions would results in earlier field readings. In 2002-03 the site was moved to Hawaii.

Field readings are done more then a month earlier in Hawaii then they were in California but this year lab test results indicate that there were high levels of current season virus spread at the site. This has raised many questions about the accuracy of a field post harvest test and in consultation with seed growers this project was developed.

Objectives (Measurable-Deliverables)
(Please use Bullets) (Max 1000 characters)
The purpose of this trial is to evaluate the accuracy of the post harvest test results and to provide a virus identification training opportunity for growers and their staff.

Economical/Environmental Benefits
(Please mention how the results of this project will benefit potato production economically and environmentally.(Max. 1000 characters) .
Post harvest testing (PHT) has been mandatory in Alberta since the summer of 2003. Results from the 2004-05 winter test in Hawaii have raised questions about the accuracy of PHT and the best way of getting timely results.

This study will benefit the seed potato industry as it will provide information to help in decision making regarding PHT and it will help restore confidence in the process. Alberta needs to maintain its low disease presence and PHT is a useful tool in making that happen. Commercial growers benefit from disease free seed and discussing PHT and its importance should lead more growers to ask for results before they purchase seed.

POTATO GROWERS OF ALBERTA

Methodology Description

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

Seed growers will be asked to submit 400 tuber samples from lots that were grown in Hawaii in the 2004-05 winter grow-out. CFIA 2004 summer field readings and field and lab results from winter 2005 will accompany the samples. Samples will be received at CDC North where they will be labelled and sorted for planting.

Samples will be planted at the Ellerslie Research Farm and every two rows will be followed by a blank row which will serve as a pathway. The site will be treated with a pre-emergent herbicide and plots will be monitored for emergence. When emergence is complete accurate stand counts will be completed and diseased plants will be flagged as symptoms become apparent. Leaves will be collected from diseased or suspect plants and sent for confirmatory lab analysis. Accurate results will be compliled for each lot and will be provided to the seed grower comparing 2004 summer field readings, winter test readings and lab results.

In early to mid-July, a field tour(s) will be arranged where growers and their staff will be invited to walk the plot and observe the visible symptoms of virus. Lot identity will be kept confidential as the purpose of the tour is to improve virus identification skills. Growers who have submitted lots will be told which lot is theirs.

Once the field tour(s) are completed the plot will be destroyed. Chemicals will be applied to the plot as necessary for insect and fungal disease control.

Note: All costs for this trial are based on the assumption that the 39 growers that sent samples to Hawaii will submit a sample to this trial.

The materials section of the budget includes land rent at Ellerslie Research Farm, confirmatory virus testing costs and freight, fertilizer and chemical costs and other materials including stakes and pin flags.

Personnel includes labour costs for planting and maintaining the trial as well as the in-kind costs provided by AAFRD and the PGA.

Technology Transfer Plan.

(Please describe the proposed method to communicate findings and results) (Max. 1000 characters)

This trial site is to be used as a tool to evaluate the accuracy of the post harvest test readings in Hawaii and to serve as an virus identification educational tool for growers and their staff. Information collected from the plot will be used to assist growers in determining the best method for meeting their post harvest test obligations. Information will be presented to seed growers during training sessions held at the site and at the seed meeting held at CDC North in August.

3. Project Budget

		Year 1	Year 2	Year 3	**Total**
PGA	Cash	7200			7200
	In-Kind	1000			
	Total	7200			7200
Other					
AAFRD	Cash				
	In-Kind	6000			6000
	Total	6000			6000
Other					
	Cash				
	In-Kind				
	Total				
Other					
	Cash				
	In-Kind				
	Total				
Other					
	Cash				
	In-Kind				

	Total				

Total

14200			**13200**

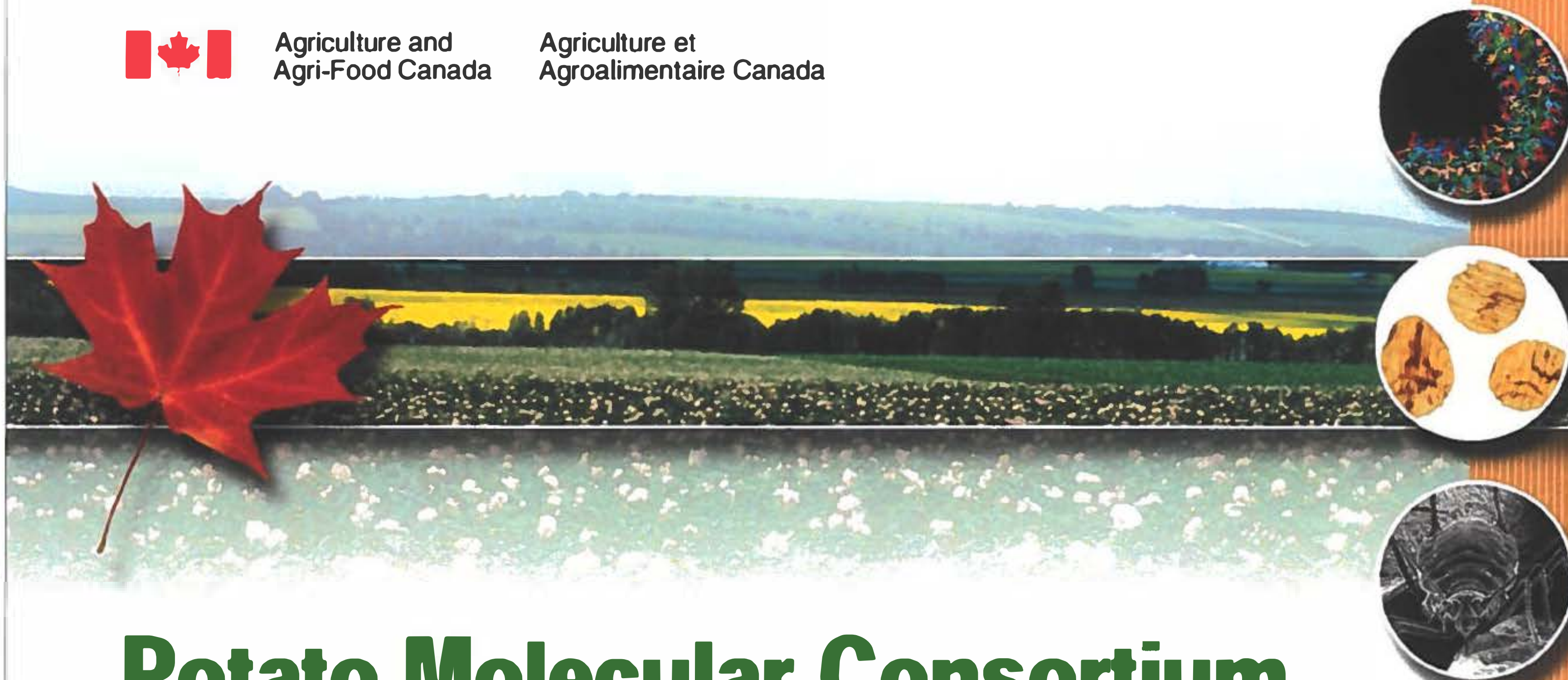
Project Cost Distribution	Year 1	Year 2	Year 3	Total
Personnel	8500			8500
Travel expenses	500			500
Capital goods				
Materials	5200			5200
TOT				
Overhead				
Total	**14200**			**14200**

*TOT (Transference of Technology)

Research Project Manager

Signature **Date**

Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada



Potato Molecular Consortium

Lawrence Kawchuk

Agriculture and Agri-Food Canada
Research Centre, Lethbridge, AB

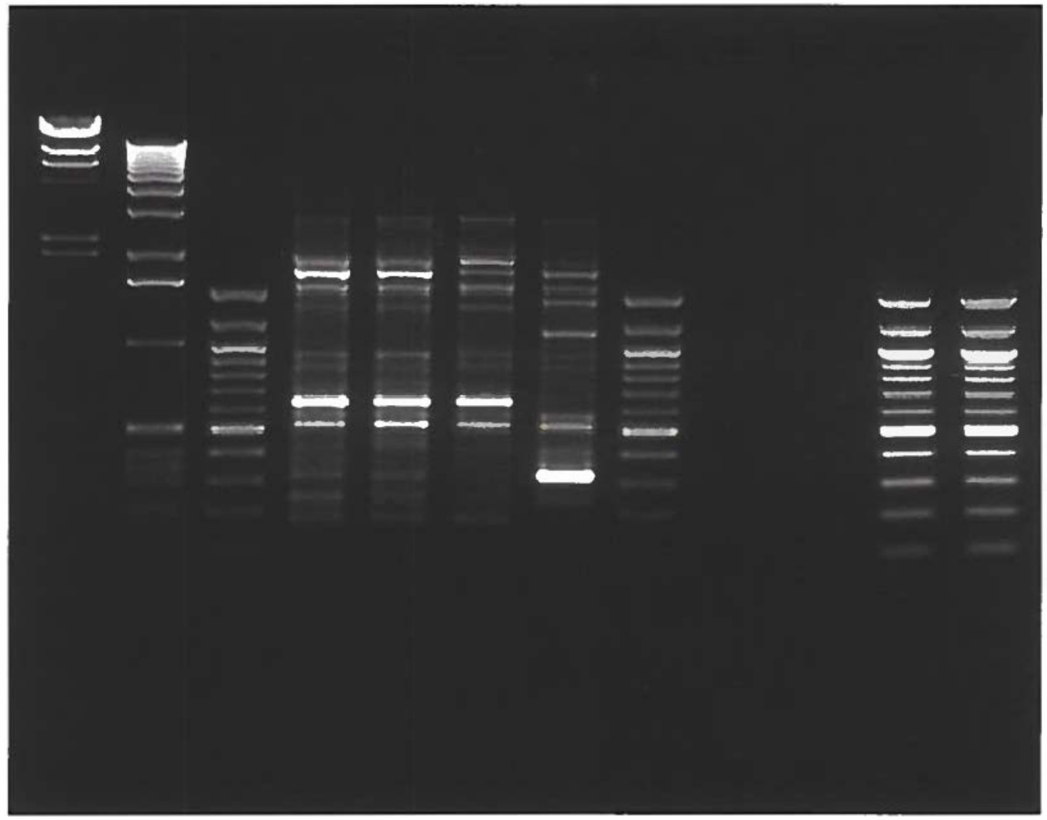
Canada

Variety DNA Fingerprinting 2009

CFIA

Seed producers

Processors

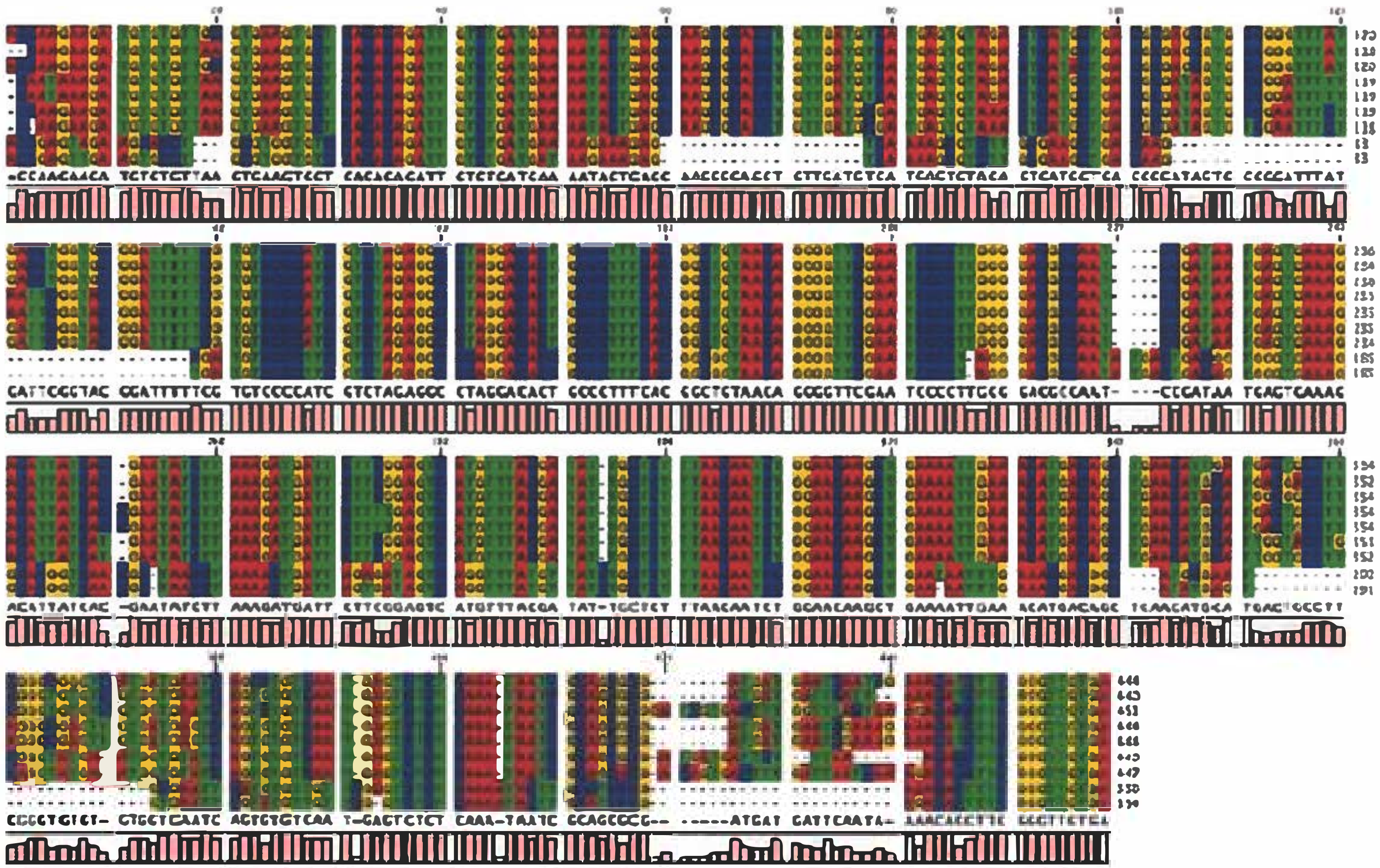


Any tissue and results available in a day.

Every variety is unique.

Barcoding DNA

Erwinia species rDNA ITS



The first 3 sequences represent *E. braziliensis*, the following 4 sequences are from *E. carotovora*, and the last 2 sequences are from *E. chrysanthemi*.

Marker assisted selection

Overall chipping ability

Verticillium wilt resistance

Late blight resistance

- Little disease development
- Effective against aggressive isolates
- Foliage not tubers
- Some LB isolates may infect

Potato plants survive inoculation with the aggressive isolate of US8.

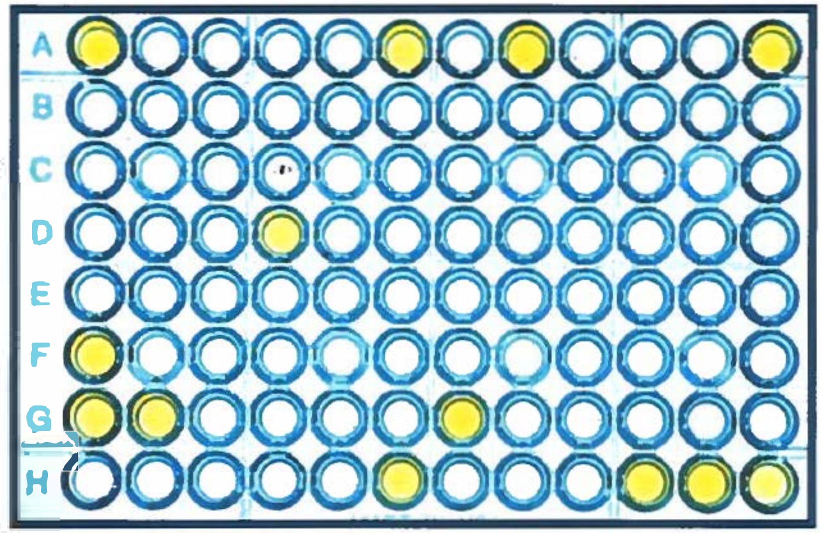
Early dying

Resistance protein selection

Soil probiotics

Virus diagnostics

- PLRV
- PVY
- PVX
- PVS
- other viruses



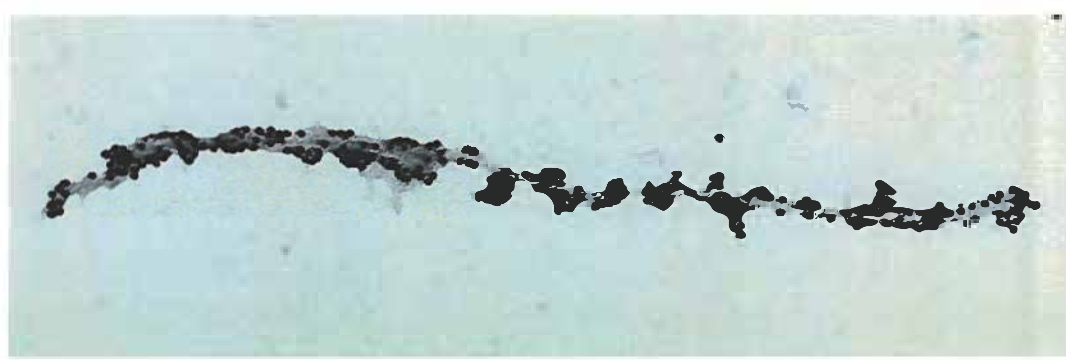
Quantatative TAS PLRV ELISA

Seed virus free status confirmed

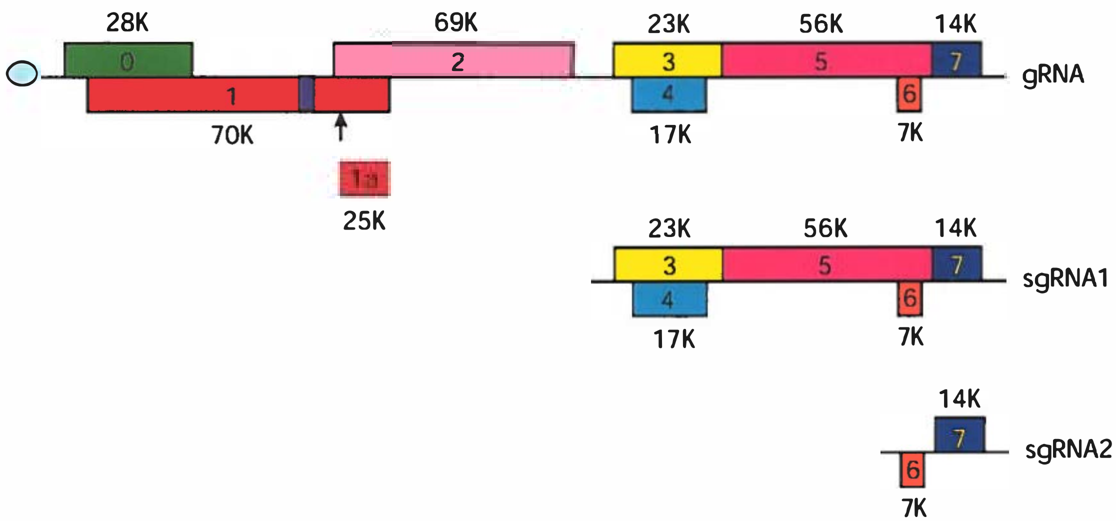
A regulatory misidentification resolved

New improved diagnostics developed

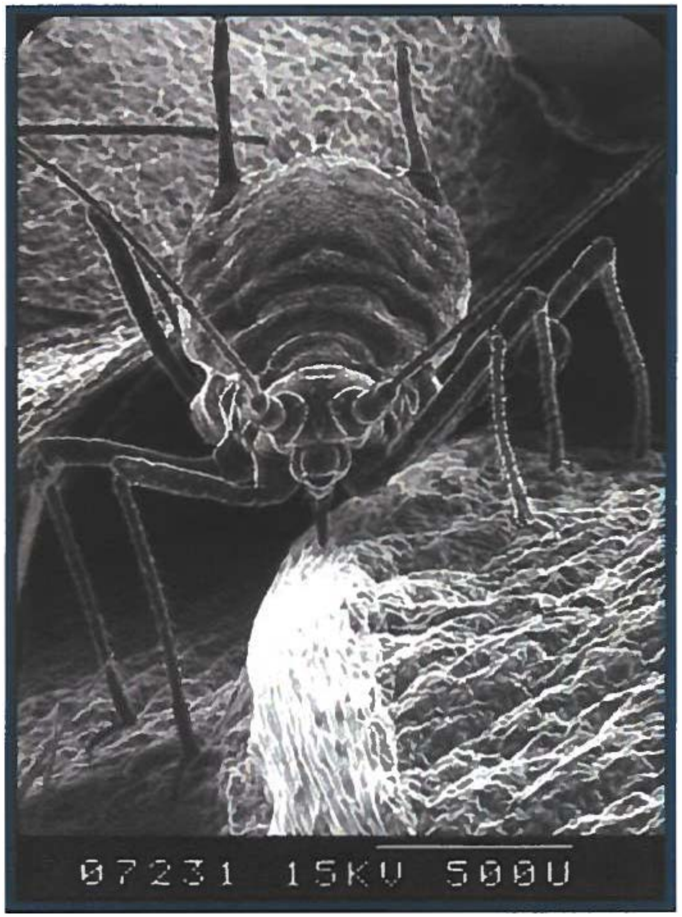
Electron photomicrograph of PVS



PLRV field assay

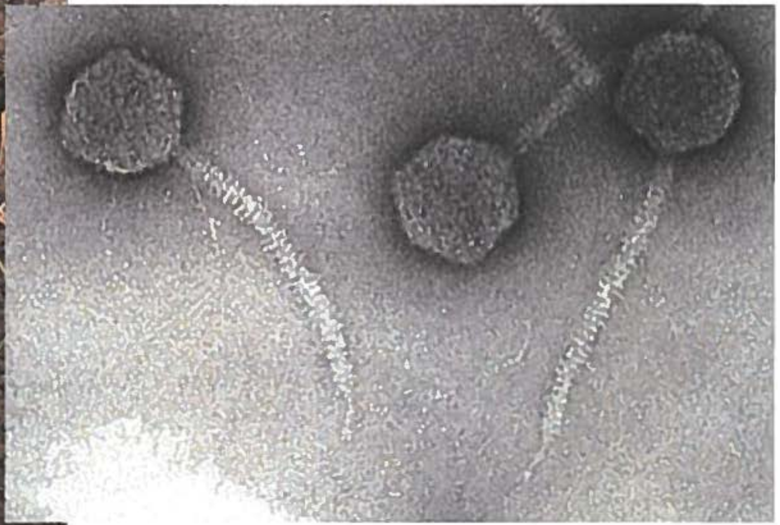


Myzus persicae



- PLRV + PLRV

Probiotics



- Seed 20 to 40 lbs request
- Blackleg or soft rot
- Field trials in AB, BC, SK, and MB
- PMRA approval and registration

Probiotic formulations

BRR foliar symptoms

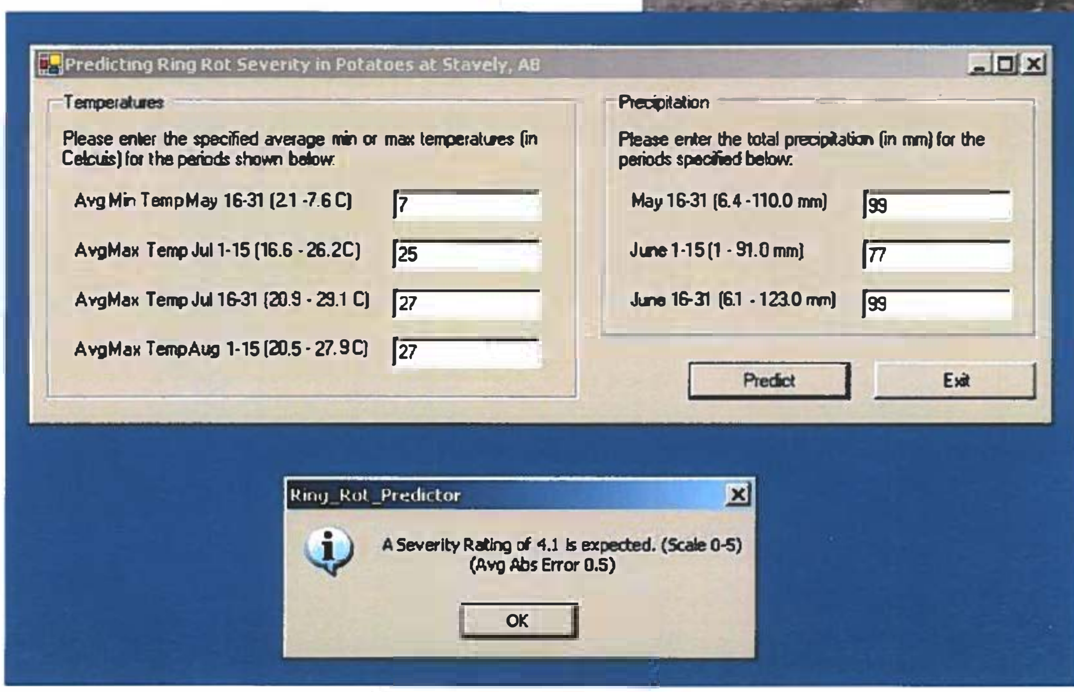
Blackleg

Blackleg+Probiotic

Soft rot / blackleg 24h assay

BRR severity

BRR AAFC



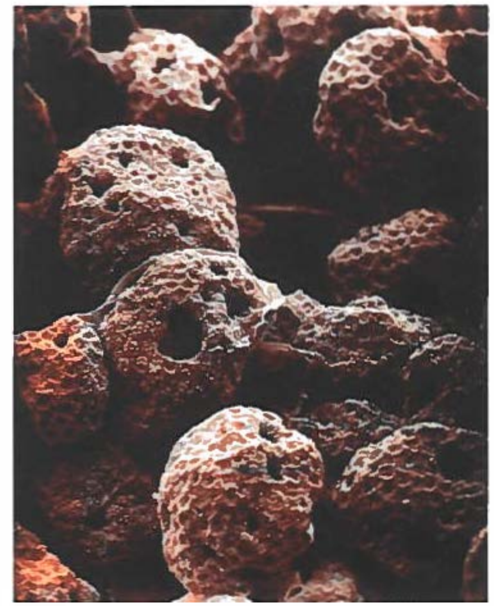
2008 severity high at 4.1

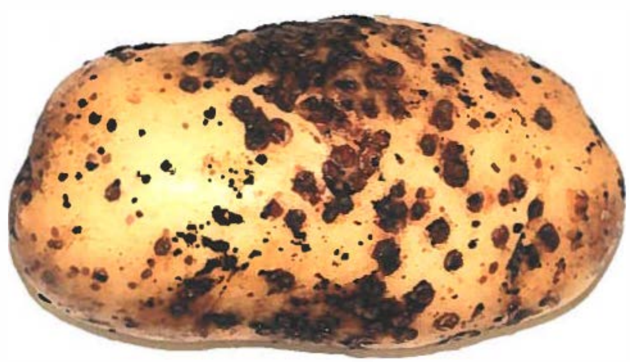
Clubroot

Related to powdery scab

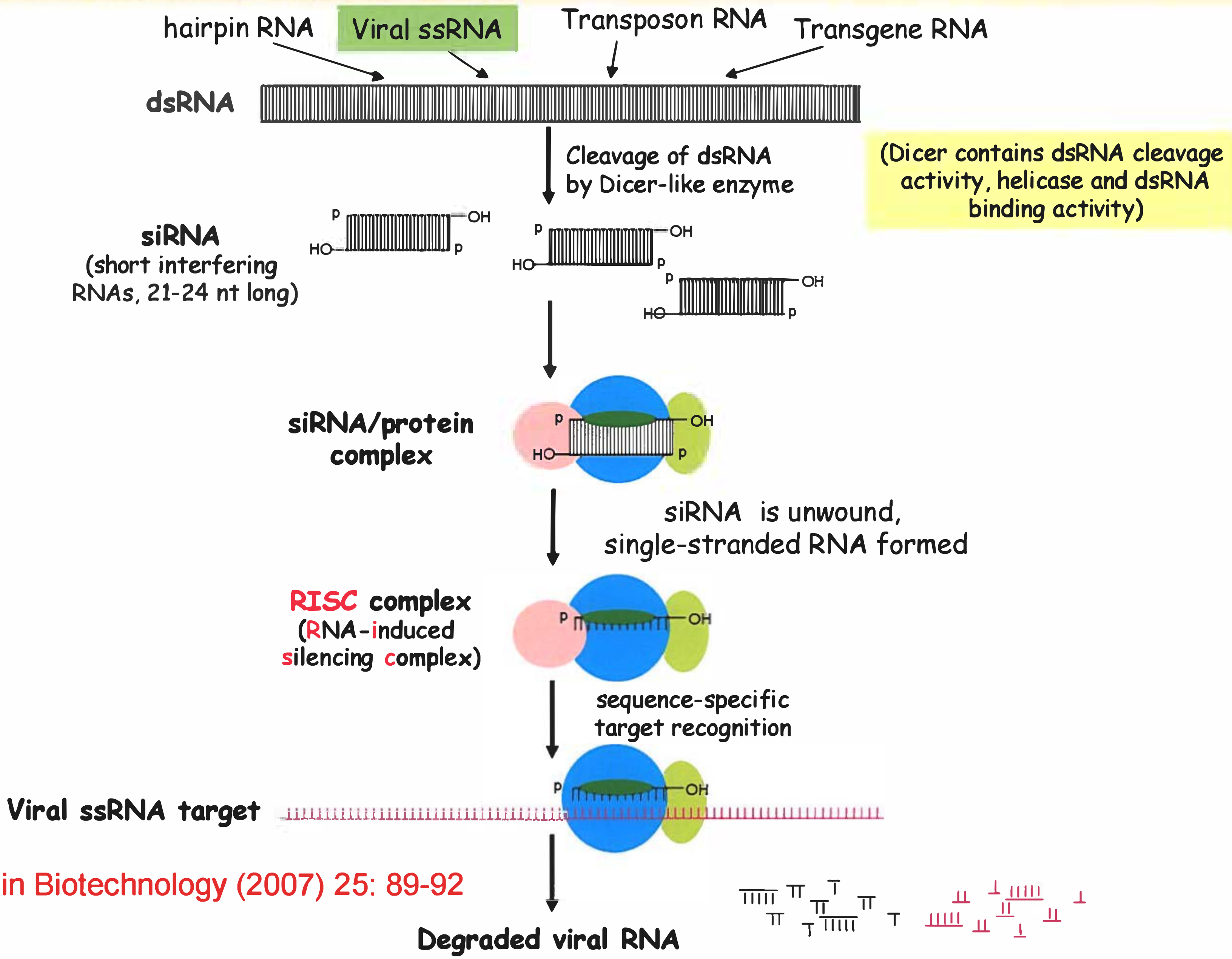
Trade impediment

Immunological diagnostics





RNA silencing pathway in plants - precision breeding



Trends in Biotechnology (2007) 25: 89-92

Late Blight – Foliar 2008

Cultivar or Line	CN #	Control	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Rating	Std Error
CV95122-3	CCN 102	0	0	0	0	1	0	0.2	0.22
CV96053-4	CCN 95	0	1	2	2	3	1	1.8	0.42
CV97108-1	CCN 115-37A	0	2	2	2	2	2	2.0	0.00
CV97050-3	CCN 117	0	0	0	1	1	0	0.4	0.27
CV97085-1	CCN 110-2	0	2	2	1	2	2	1.8	0.22
CV97112-6	CCN 111	0	1	2	2	2	3	2.0	0.36
CV97123-1	CCN 113	0	0	0	0	0	0	0.0	0.00
CV98270-1	CCN 136-3	0	1	2	2	3	1	1.8	0.42
V0318-1	CCN 55	0	1	1	2	1	1	1.2	0.22
V0370-2	CCN 56	0	2	2	2	2	2	2.0	0.00
V0360-2	CCN 123	0	0	0	0	0	0	0.0	0.00
V1102-1	CCN 104	0	1	1	2	2	1	1.4	0.27
WV5387-1	CCN 124	0	1	1	1	2	2	1.4	0.27
Sterling CP457	Check	0	0	0	0	0	1	0.2	0.22
Shepody CP633	Check	0	1	1	2	1	1	1.2	0.22
Russet Burbank CP453	Check	0	2	2	2	2	2	2.0	0.00

0 = no infection 5= 100% infection

Late Blight - Tuber 2008

Cultivar or Line	CN #	Control	0	1	2	3	4	5	Rating	Std Error
CW03305-1		0	0	0	[illegible]	4	4	1	3.5	0.28
CW98112-3		0	0	6	4	0	0	0	1.4	0.17
v1270-1		0	0	0	8	2	0	0	2.2	0.14
v1274-2		0	0	0	3	6	1	0	2.6	0.21
WA4295-1		0	0	0	[illegible]	3	6	0	3.5	0.24
CW98173-4		0	0	1	3	6	0	0	2.5	0.24
CW93011-2		0	0	0	0	4	5	1	3.7	0.22
WA4472-1		0	0	0	[illegible]	2	3	4	4.0	0.25
vHB1166-1		0	0	0	2	4	4	0	3.2	0.26
CW93089-2		0	0	0	2	2	4	2	3.6	0.26
CW93058-2		0	0	0	2	6	2	0	3.0	0.22
vHB0950-2		0	0	0	5	5	0	0	2.5	0.18
Russet Burbank	Check	0	0	0	0	4	4	4	4.6	1.10
Norland	Check	0	0	0	0	9	3	0	2.9	0.27
Shepody	Check	0	0	0	[illegible]	6	5	2	4.7	0.64
Sangre	Check	0	0	0	2	6	3	1	3.9	0.61

0 = no infection 5= 100% infection

Fusarium Dry Rot 2008

Test Line	Cultivar or Line	Checks	Control	0%	25%	50%	75%	100%	Rating	Std Error
1	CV03085-1		0	0	0	0	4	6	4.6	0.172133
2	CV05112-3		0	0	0	0	2	8	4.8	0.105409
3	V1270-1		0	0	0	0	5	5	4.5	0.175682
4	V1274-2		0	0	0	0	6	4	4.4	0.172133
5	WV4293-1		0	0	0	0	2	8	4.8	0.105409
6	CV05173-4		0	0	0	0	4	6	4.6	0.172133
7	CV03011-2		0	0	0	0	0	10	5	0
8	WV4473-1		0	0	0	0	3	7	4.7	0.161015
9	V-B1196-1		0	0	0	0	0	10	5	0
10	CV02088-2		0	0	0	0	0	10	5	0
11	CV02058-2		0	0	0	0	2	5	3.3	0.195505
12	V-B0580-2		0	0	0	0	5	5	4.5	0.175682
13	Russet Burbank	Check	0	0	0	0	9	1	4.1	0.105409
14	Ranger Russet	Check	0	0	0	2	2	6	4.4	0.221108
15	Shepody	Check	0	0	0	4	4	2	3.8	0.252237
16	Atlantic	Check	0	0	1	2	4	3	3.9	0.321473

0 = no infection   5= 100% infection

BRR 2008

Foliar Symptoms

Incidence

Treatment	with BRR	total hills	% infection
Alpha	**0**	**14**	**0**
Russet Burbank	15	15	100
Norland	15	15	100
Red Pontiac	15	15	100
CV98022-3	14	15	93
CV98053-4	11	15	73
CV97065-1	15	15	100
CV97112-5	11	13	85
CV97192-1	14	14	100
FV12486-2	15	15	100
V1002-2	15	15	100
V1102-1	15	15	100

Severity

MeanRep 1	MeanRep 2	MeanRep 3	Mean	Std Dev
* **0.00**	**0.00**	**0.00**	**0.00**	**0.00**
2.80	2.40	2.20	2.47	0.31
4.00	3.80	3.40	3.73	0.31
4.80	4.60	4.00	4.47	0.42
2.00	2.20	1.80	2.00	0.20
1.60	1.20	1.00	1.27	0.31
3.40	3.00	3.80	3.40	0.40
2.25	1.80	1.75	1.92	0.28
4.00	4.40	4.80	4.43	0.40
4.00	3.20	4.00	3.73	0.46
4.20	4.00	4.00	4.07	0.12
2.80	2.40	2.60	2.60	0.20

Tuber Symptoms

Incidence

Treatment	MeanR1	MeanR2	MeanR3	Mean	Std Dev	S.E.ofMean
Alpha	**4.1**	**0.0**	**2.9**	**2.33**	**0.703**	**0.406**
Russet Burbank	7.0	33.3	13.3	17.87	4.577	2.643
Norland	10.2	38.2	28.1	25.50	4.727	2.729
Red Pontiac	50.0	68.2	35.1	51.10	5.526	3.190
CV98022-3	13.6	17.4	15.2	15.40	0.636	0.367
CV98053-4	14.3	15.2	5.0	11.50	1.882	1.087
CV97065-1	15.2	5.1	7.0	9.10	1.789	1.033
CV97112-5	**3.0**	**3.2**	**0.0**	**2.07**	**0.598**	**0.345**
CV97192-1	21.1	42.9	43.5	35.83	4.254	2.456
FV12486-2	6.3	23.9	11.1	13.77	3.033	1.751
V1002-2	23.9	45.0	17.0	28.63	4.863	2.807
V1102-1	16.7	7.1	6.5	10.10	1.908	1.102

Severity

Avr Sev	Std Dev	S.E.ofAvr Sev
* **0.23**	**0.21**	**0.12**
2.77	2.16	1.25
4.48	2.47	1.42
8.65	2.51	1.45
1.76	0.23	0.13
1.42	0.58	0.34
1.28	0.75	0.43
* **0.21**	**0.18**	**0.10**
7.31	3.83	2.21
1.83	1.06	0.61
4.93	3.12	1.80
1.08	0.51	0.30

Alpha = symptomless carrier

Genome Canada - Potato 2020

A $10M project and 1 of 27 selected from 58 invited proposals for Toronto

GenomeCanada

free BCfresh Recipes

KPPA
Keystone Potato Producers Association

PGA

SSPGA

ConAgra Foods
Specialty Potato Products
Lamb Weston

MAPLE LEAF

SAATZUCHT FRITZ LANGE

AARI
Alberta Agricultural Research Institute

GenomeAlberta

Agriculture and Agri-Food Canada

Acknowledgements

- ***Canada***

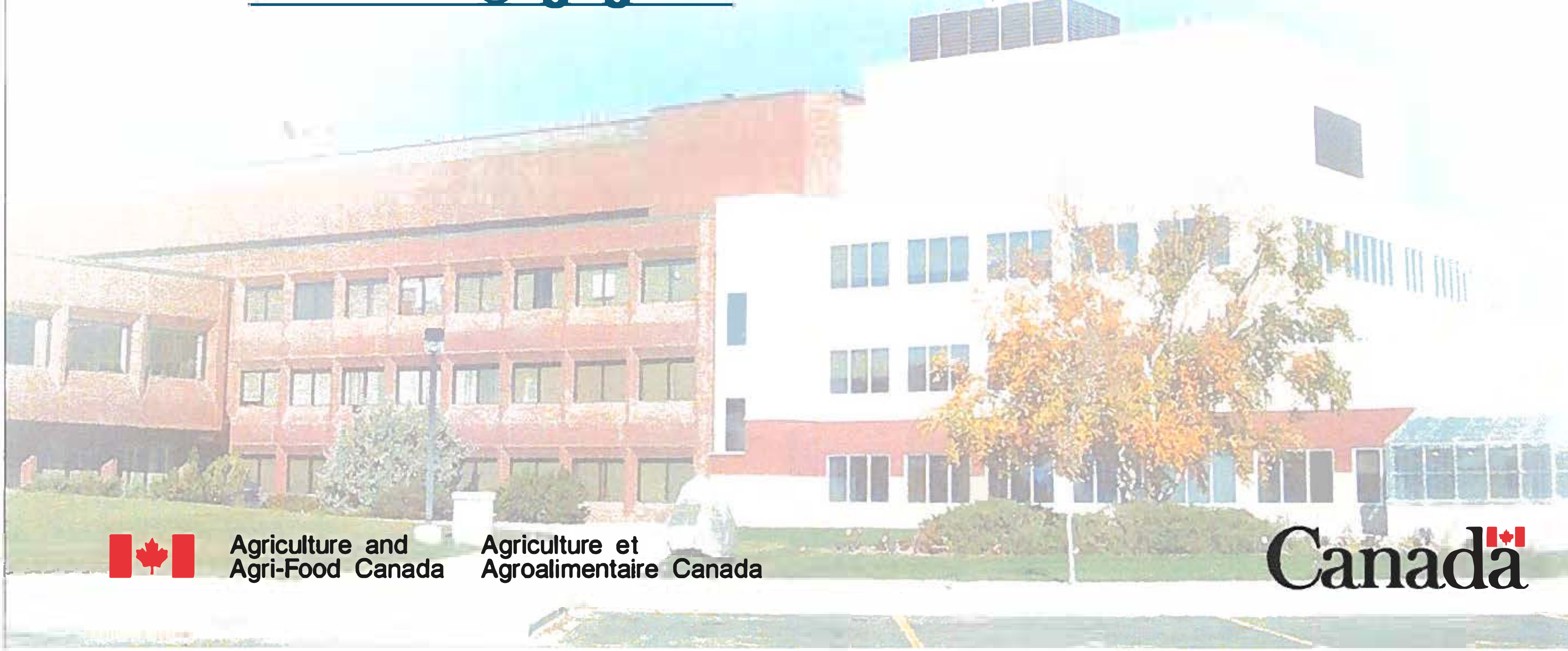
- BC Potato & Vegetable Growers Association
- Conagra Limited, Lamb-Weston Division
- Keystone Vegetable Producers Association Inc.
- Maple Leaf Potatoes
- Potato Growers of Alberta
- Saskatchewan Seed Potato Growers Association
- Agriculture and Agri-Food Canada

- ***Europe***

- Saatzucht-Vertrieb Lange KG

Agriculture and Agri-Food Canada
Lethbridge, Alberta, Canada
5403 – 1st Avenue South
Lethbridge, AB T1J 4B1

Tel (403) 317-2271
Fax (403) 382-3156
Email kawchukl@agr.gc.ca



PCA POTATO GROWERS OF ALBERTA

6008 46th Avenue
Taber, AB T1G 2B1
Tel: (403) 223-2262
Fax: (403) 223-2268

ATB FINANCIAL
5317 - 48 AVE.
TABER, ALTA. T1G 1S7

008183

DATE 0 7 2 6 2 0 1 1
M M D D Y Y Y Y

PAY ******Five Thousand and 00/100

$ **5,000.00

POTATO GROWERS OF ALBERTA
General Account

TO THE ORDER OF
Receiver General for Canada
Agriculture & Agri-Food Canada
Revenue Management
960 Carling Avenue
Building 74, Room 206D, CED
Ottawa, ON K1A 0C6

PER ________ AUTHORIZED SIGNATURE

PER ________ AUTHORIZED SIGNATURE

MEMO Western Potato Consortium B -Pymt #5

⑈008183⑈ ⑆08829⑉219⑆ 9912592⑉ 01⑈

POTATO GROWERS OF ALBERTA

008183

Receiver General for Canada 7/26/2011

Date	Type	Reference	Original Amt.	Balance Due	Discount	Payment
07/26/2011	Bill	83016150	5,000.00	5,000.00		5,000.00
				Cheque Amount		5,000.00

ATB Main Account Western Potato Consortium B -Pymt #5 5,000.00

POTATO GROWERS OF ALBERTA

008183

Receiver General for Canada 7/26/2011

Date	Type	Reference	Original Amt.	Balance Due	Discount	Payment
07/26/2011	Bill	83016150	5,000.00	5,000.00		5,000.00
				Cheque Amount		5,000.00

ATB Main Account Western Potato Consortium B -Pymt #5 5,000.00

MMDDYYYY 26 2011

**5,000

...voice - Facture

...e Canada

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Date: 07/13/2011

Customer Reference Référence du client
820269 - T.1206.UA

Customer No. N° du client
100311
Business No. N° d'entreprise

ATTN: Edzo Kok
Potato Growers of Alberta
6008-46th Avenue
TABER AB T1G 2B1
CANADA

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Due on Receipt Dû à la réception

If payment is not received by 08/12/2011 interest is charged on overdue amounts at the average Bank of Canada rate for the previous month plus 3%, compounded monthly.

Originator-Expéditeur
Lethbridge Research Centre
Lethbridge, AB
ATTN: KATHLEEN MCLEAN
TEL: (403) 317-3386

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Description	Quantity	Unit Price	Amount
Western Potato Consortium - B "Introduction of Variety Production Tools for Potato and Other Crops" with Dr. Larry Kawchuk.			
NVR Collaborative agreements research	1 EA	5,000.00	5,000.00
Payment #5 as per executed agreement for project listed above.			
Sub-Total (CAD)			5,000.00
Total (CAD)			5,000.00

POSTED

Canada

Date	Type	Reference	Original Amt.	Balance Due	Discount	Payment
07/26/2011	Bill	83016150	5,000.00	5,000.00		5,000.00
					Cheque Amount	5,000.00

Called Aug 16/11 ~ advise had cleared bank - ? re: late fee

Cheque cashed before payment due date of Aug 12/11
Invoice # 83016150
why 90 days past due?
Please reverse late fees. Thank you