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).

Filella J. and J. Peñuelas. 1994. The red edge position and shape as indicators of plant chlorophyll content, biomass and hydric status. International Journal of Remote Sensing 15:1459-1470.

Gamon J.A., J. Peñuelas and C.B. Field. 1992. A narrow-waveband spectral index that tracks diurnal changes in photosynthetic efficiency. Remote Sensing of Environment 41:35-44.

Gitelson A. and M.N. Merzlyak. 1994. Spectral reflectance changes associated with autumn senescence of Aesculus hippocastanum L. and Acer platanoides L. leaves. Spectral features and relation to chlorophyll estimation. Journal Photochemical and Photobiology B.: Biol 22:247-252.

Gitelson A.A. and M.N. Merzlyak. 1996. Signature analysis of leaf reflectance spectra: Algorithm development for remote sensing of chlorophyll. Journal of Plant Physiology 148:494-500.

Gitelson A.A., C. Buschmann and H.K. Lichtenthaler. 1999. The chlorophyll fluorescence ratio F735/F700 as an accurate measure of chlorophyll contents in plants. Remote Sensing of Environment 69:296-302.

Haboudane D., J.R. Miller, N. Tremblay, P.J. Zarco-Tejada and L. Dextraze. 2002. Integrated narrow-band vegetation indices for prediction of crop chlorophyll content for application to precision agriculture. Remote Sensing of Enviornment 81-416-426.

Leblon B. , J. McRobert, V. Vanderbilt and S. Thériault. 2001. Defining hyperspectral reflectacen ratios for assessing potato crop nitrogen and chlorophyll status. Proceedings 23rd Canadian Symposium on Remote Sensing, August 21-24. Sainte-Foy Québec, Canada. Pp.271-277.

Lichtenthaler H.K., A. Gitelson and M. Lang. 1996. Non-destructive determination of chlorophyll content f leaves of a green and an aurea mutant of tobacco by reflectance measurements. Journal of Plant Physiology 148:483-489.

Merzlyak, M.N., Gitelson, A.A., Chivkunova, O.B. and Y.R. Rakitin. 1999. Non-destructive optical detection of pigment changes during leaf senescence and fruit ripening, Physiologia Plantarum, 106:135-141.

Peñuelas J., J.A. Gamon, A.L. Fredeen, J. Merino and C.B. Field. 1994. Reflectance indices associated with physiological changes in nitrogen- and water-limited sunflower leaves. Remote Sensing of Environment 48:135-146.

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

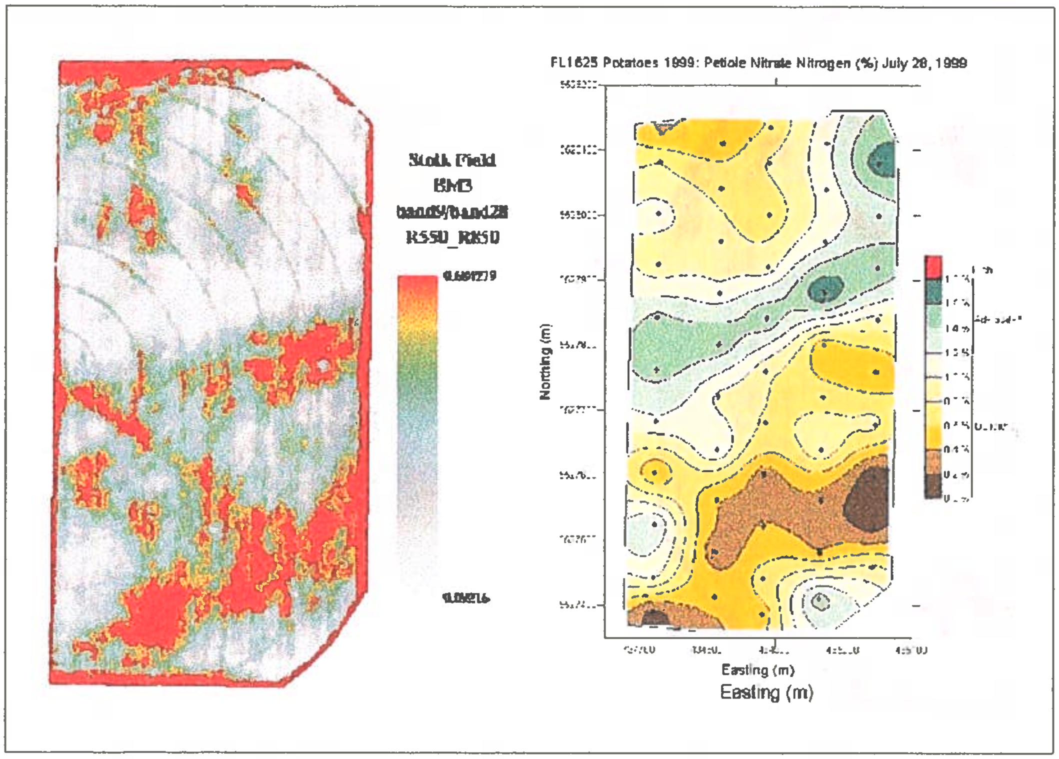

FIGURE 2. FINCASTLE SITE: SR_{550_850} INDEX IMAGE AND PETIOLE-N MAPS DERIVED FROM GROUND-BASED SAMPLING

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

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)*			
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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).