Yield Response of Two Potato Culivars to Supplemental Irrigation and N Fertilization in New Brunswick

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ABSTRACT

Nitrogen and water are important factors influencing potato production, and crop response to these two factors may vary with cultivars. The yield response of two potato cultivars (Russet Burbank and Shepody) to six rates of N fertilization (0-250 kg N ha^{-1}) with and without supplemental irrigation was studied at four on-farm sites in each of three years, 1995 to 1997, in the upper St-John River Valley of New Brunswick, Canada. On average, irrigation increased total yield from 31.9 t ha^{-1} without irrigation to 38.4 t ha^{-1} with irrigation and marketable yield from 25.6 t ha^{-1} without irrigation to 30.7 t ha^{-1} with irrigation. Potato yields were increased by irrigation at nine out of the 12 sites, and the irrigation response was similar for both cultivars. Nitrogen fertilization significantly increased both total and marketable yields at all sites except one. The yield response to N fertilization was greater with irrigation. The N fertilization rate (Nmax) required to reach maximum total and marketable yield, however, was similar with and without irrigation. A large variation in Nmax was observed among sites. With irrigation, Nmax varied between 158 and 233 kgN ha^{-1} for total yield, and between 151 and 250 kg N ha^{-1} for marketable yield. There was no interaction between N fertilization and potato cultivar for both total and marketable yields. The two cultivars had similar total yields (35 t ha^{-1}). Shepody, however, had a greater marketable yield (28.9 t ha^{-1}) than Russet Burbank (27.4 t ha^{-1}). Our results indicate that the response to two of the most significant factors of potato production, irrigation and N fertilization, varies greatly with sites and climatic conditions, and that field specific recommendations are required for the optimum management of N and irrigation.

RESUMEN

El nitrógeno y el agua son factores importantes que influyen en la producción de la papa, y la reacción de la cosecha antes estos dos factores puede variar con diferentes cultivares. La reacción de rendimiento de dos cultivares de papa (Russet Burbank y Shepody) antes seis medidas de fertilizante N (0-250 kg N Ha^{-1}) con y sin irrigación suplementaria se estudió en dos lotes en granja durante cada uno de los tres años, 1995-1997, en la parte superior del Valle del Río St-John en New Brunswick, Canadá. En un p romedio, la irrigación aumentó el rendimiento total de 31.9 t ha^{-1} sin irrigación a 38.4 t ha^{-1} con irrigación y al rendimiento comerciable de 25.6 t ha^{-1} sin irrigación a 30.7 t ha^{-1} con irrigación. Los rendimientos de la papa aumentaron a causa de la irrigación en 9 de los 12 lotes, y el resultado de la irrigación fue similar para los dos cultivares. La fertilización con nitrógeno aumentó notablemente tanto los rendimientos totales y comerciables en todos los lotes menos uno. El rendimiento ante la fertilización N fue mayor con irrigación. La tasa de fertilización N (Nmax) que es necesaria para alcanzar el rendimiento total y comerciable, sin embargo, fue similar con y sin irrigación. Se observó una gran variación en Nmax en los lotes. Con irrigación, Nmax varió entre 158 y 233 kg N ha^{-1} en el rendimiento total, y entre 151 y 250 kg N ha^{-1} en el rendimiento comerciable. No había ninguna interacción entre la fertilización N y el cultivar de la papa para los rendimientos tanto totales como comerciables. Los dos cultivares tuvieron rendimientos totales similares 35 t ha^{-1}). Shepody, sin embargo, tuvo un rendimiento comerciable mayor (28.9 t ha^{-1}) que Russet Burbank (27.4 t ha^{-1}). Nuestros resultados indican que la respuesta a dos de los factores más significativos en la producción de la papa, la irrigación y la fertilización N, varía mucho entre lotes y condiciones climáticas, y que unas recomendaciones de campo específicas son necesarias para el manejo óptimo de N y de la irrigación.

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ADDITIONAL KEY WORDS: *Solanum tuberosum* L., N fertilizer, irrigation, Marketable yield, Russet Burbank, Shepody.

INTRODUCTION

Water and nitrogen (N) are important factors influencing potato (*Solanum tuberosum* L.) tuber growth, development, quality, and yield (Westermann and Kleinkopf, 1985; Ojala *et al.*, 1990; Vos, 1997). Irrigation is essential for potato production in areas of inadequate or infrequent precipitation, and on soils with low water holding capacity (Ojala *et al.*, 1990). Studies have reported the importance of irrigation for potato production in northern California (Meyer and Marcum, 1998,) Wisconsin (Bundy *et al.*, 1986), Michigan (Silva *et al.*, 1991) and Alberta (Lynch and Tai, 1989). In New Brunswick, annual precipitation exceeds evapotranspiration but water deficits may occur in midsummer with crops grown on soils with low water holding capacity. Therefore, supplemental irrigation to potatoes may be required for optimum production. However, very little information is available about the effects of supplemental irrigation on potato yield under New Brunswick growing conditions.

Potatoes are highly responsive to N fertilization and N is usually the most limiting essential nutrient for potato growth, especially on sandy soils (Errebhi *et al.*, 1998). Annual fertilizer N rates for irrigated potatoes commonly range from 30 to 350 kg N ha^{-1} worldwide (Williams and Maier, 1990). Nitrogen deficiency usually results in poor growth and low yield while excessive N can lead to poor tuber quality, delayed crop maturity, and excessive nitrate leaching (Harris, 1992). Thus, N management for potatoes is important from both production and environmental standpoints.

The interaction between irrigation and N fertilization is an important consideration toward achieving optimum yields and quality. Harris (1992) concluded that, although the response to N fertilization may be enhanced by irrigation, there was little evidence to suggest that the maximum N rate needed to be increased. Potato tuber yield is also affected by cultivars (Gavlak *et al.*, 1993; Porter and Sisson, 1993; De la Morena *et al.*, 1994).

The objective of this study was to determine the effects of supplemental irrigation and N fertilization on total and marketable tuber yields of Shepody and Russet Burbank, two potato cultivars widely grown in New Brunswick.

MATERIALS AND METHODS

The study was conducted at four on-farm sites in each of three years, 1995 to 1997, in the upper St-John River Valley of New Brunswick, Canada. The sites are referred as S1 to S4 in 1995, S5 to S8 in 1996, and S9 to S12 in 1997 (Table 1). Two potato (*Solanum tuberosum* L.) cultivars were used with a row spacing of 0.75 m and in-row plant spacings of 0.30 m

TABLE 1.—*Soil chemical and physical properties to a 0.15 m depth at each site, and other experimental details.*

	1995				1996				1997			
Sites	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Soil series[1]	Caribou	Carleton	Carleton	Carleton	Carleton	Undine	Holmesville	St-Amand	Caribou	Carleton	Holmesville	Seigas
O.M. (mg kg^{-1})	26	27	30	28	41	31	28	26	28	30	30	27
pH (water)	5.1	5.8	5.5	5.5	6.0	6.4	6.0	5.8	5.1	6.3	6.0	6.0
CEC (meq $100g^{-1}$ soil)	14.3	16.0	14.4	17.6	18.1	18.4	15.2	15.2	16.2	18.0	15.6	14.2
P (mg kg^{-1})	272	392	194	380	292	367	259	-	335	285	389	272
K (mg kg^{-1})	194	199	213	261	64	168	77	-	320	228	162	208
Ca (mg kg^{-1})	590	1410	899	1329	1706	1704	1238	1200	877	2008	1428	1055
N (mg kg^{-1})	1.5	1.4	1.7	1.5	2.4	1.7	1.5	1.3	1.5	1.6	1.4	1.3
NO_3-N[2] (kg ha^{-1})	42	75	65	107	22	13	54	7	34	46	25	26
Particle size distribution (%)												
Sand	26	21	29	31	31	34	36	34	28	33	38	36
Silt	49	52	48	48	45	45	45	46	48	43	43	43
Clay	25	27	23	21	24	21	19	20	24	24	19	21
Previous crop	grain	forage	grain	forage	forage	clover	clover	clover	grain	clover	grain	clover
Planting date	2 June	20 May	1 June	28 May	18 May	26 May	28 May	29 May	6 June	1June	5 June	30 May
Harvest date	4 Oct.	13 Oct.	3 Oct.	14 Oct.	4 Oct.	7 Oct.	8 Oct.	17 Oct.	8 Oct.	5 Oct.	7 Oct.	4 Oct.
Rainfall[3] (mm)	186	225	196	224	339	337	333	369	273	233	243	243
Temperature[4] (C)	14	19	15	16	18	16	17	17	16	18	17	17
PET[5] (mm)	404	442	415	406	340	327	359	370	344	406	344	405

[1]Langmaid *et al.*, 1976; Stobbe and Aalund, 1944; Millette and Langmaid, 1964.
[2]Measured to a 0.3 m depth.
[3]Cumulative rainfall from planting to harvest.
[4]Average air temperature calculated from planting to harvest.
[5]Cumulative potential evapotranspiration from planting to harvest.

for Shepody and 0.46 m for Russet Burbank. Potato seed pieces were planted by hand and covered with tractor-mounted closing disks. Nitrogen as ammonium nitrate was applied at planting with a modified Wintersteiger plot planter adapted for potatoes at 0, 50, 100, 150, 200, and 250 kg N ha^{-1}. Phosphorus (165 kg P_2O_5 ha^{-1}) and potassium (165 kg K_2O ha^{-1}) were surface broadcast prior to planting as a 0-15-15 blend. At each site, the experiment consisted of two large blocks (irrigated and non-irrigated). Within each block, a split plot arrangement of the experimental treatments was used with cultivars as main plots and N fertilization rates as sub-plots with four replications. Individual plots consisted of 6 rows each 7.6 m in length. There were 1.5 m between plots within a block and 24.3 m between the irrigated and non-irrigated blocks. Planting dates ranged from 18 May to 6 June (Table 1). Recommended weed, disease and insect control measures for potatoes in Atlantic Canada were used at all sites (Bernard *et al.*, 1993).

Irrigation applications were scheduled using the Wisdom© computer software program (IPM Software, Madison, WI). The program utilizes a water budget approach to schedule irrigation (Curwen and Massie, 1984). Crop water use calculations based on potential evapotranspiration were used to estimate soil moisture levels. The potential evapotranspiration (PET) was calculated using a modified Priestly-Taylor equation and was adjusted for canopy cover. The calculation required daily net solar radiation and mean air temperature data. The soil water holding capacity (WHC) was characterized for a 0.3-m rooting depth by measuring the moisture difference between 0.01 (0.03 in 1995) and 1.5 MPa using a pressure plate extractor apparatus. Water was applied when soil moisture reserves were reduced to 65% of the soil water holding capacity. The allowable soil moisture depletion (WHC - (0.65 x WHC)) among sites was determined to range from 16 to 33 mm. The amount of irrigation was adjusted to compensate for expected PET. Some irrigation applications were reduced to less than those quantities required to restore theoretical moisture deficits to compensate for expected rainfall events. Irrigation was applied at a rate of 0.68 cm h^{-1} with a portable overhead irrigation system operated at a nominal pressure at the sprinkler heads of 0.34 MPa. Sprinklers were installed on a 18 m x 18 m grid. The irrigation block extended approximately 10 m beyond the plot boundaries in all directions. Among the four sites per year, supplemental irrigation ranged from 148 to 217 mm in 1995, 50 to 70 mm in 1996, and 76 to 121 mm in 1997 (Table 3).

At each site, a monthly water balance (WB) was calculated by subtracting PET from rainfall. A positive WB indicated excess water whereas a negative WB indicated a water deficit. The seasonal WB for each site was also calculated by adding monthly WB from May to September. The response to irrigation at each site was quantified by calculating the difference between the yield with and without irrigation. A relationship between this yield difference, and WB for the whole season and the month of July was established. The month of July under New Brunswick conditions corresponds to the stage of tuber initiation and early to mid-bulking, stages at which potatoes are known to be influenced by a water deficit (Ojala *et al.*, 1990).

At harvest, the middle two rows of each plot were harvested to determine total tuber yield. Marketable tuber yield was calculated as total tuber yield minus small tubers and defects. Defects consisted of roughs and tubers with hollow heart, brown center, stem-end discoloration, insect and wireworm damage, sunburn and rot. Harvest dates ranged from 4 October to 19 October (Table 1).

One composite soil sample was collected to a 0.15 m depth at each site immediately prior to planting. The soil was air dried, ground, and passed through a 2-mm sieve. The soil was analyzed for soil pH (1:1 water), organic matter content by wet oxidation (Tiessen and Moir, 1993), particle size distribution by the hydrometer method following organic matter destruction (Sheldrick and Wang, 1993) and total N concentration by dry combustion (McGill and Figueiredo, 1993). Soil K and Ca concentrations were determined by atomic absorption spectroscopy following their extraction with 0.1 M $BaCl_2$ (Hendershot and Duquette, 1986). The cation exchange capacity (CEC) was determined following an extraction with $BaCl_2$ (Hendershot *et al.*, 1993). Soil P was extracted with 0.03 M NH_4F in 0.025 M HCl (Bray 2). At each site, a composite soil sample was collected to a 30 cm depth and inorganic N was extracted using a 10:1 ratio of 2 M KCl to air dry soil. The extract was filtered and then analyzed for NO_3-N using a colorimetric hydrazine-reduction method (Tel and Heseltine, 1990). Soil physical and chemical properties, and other experimental details are presented in Table 1.

Statistical Analyses

The analyses of variance were carried out using the general linear model of SAS (Statistical Analysis System Institute, Inc. 1996). All experimental error variances were tested for homogeneity using Bartlett's test (Steel and Torrie, 1980). Orthogonal contrasts were performed to determine linear and quadratic responses to N fertilization rates. The following polynomial equation was used to describe the yield response as a function of N fertilization rates:

$$Y = a + bX + cX^2 \qquad (1)$$

where Y is the tuber yield in t ha^{-1} (total and marketable), X the N fertilization rate in kg N ha^{-1}, and a, b, and c are parameters estimated by multiple linear regression. Parameter "a" from the model was used to estimate total and marketable tuber yields with no N applied. The fertilizer rate (Nmax) required to reach maximum yield was calculated by setting the first partial derivative of the N response curve equal to zero:

$$dY/dX = b + 2cX = 0 \qquad (2)$$

and solving for X. Therefore, Nmax (kg N ha^{-1}) is calculated as:

$$Nmax = -b/2c \qquad (3)$$

No Nmax values was calculated when the fitted parameter "c" had a positive value (Colwell, 1994). When the Nmax values were greater that 250 kg N ha^{-1}, a value of 250 was used.

RESULTS AND DISCUSSION

Response to Irrigation

Irrigation significantly ($P< 0.001$) affected both total and marketable yields (Table 2). On average, irrigation improved total yield by 6.5 t ha^{-1}; from 31.9 t ha^{-1} without irrigation to 38.4 t ha^{-1} with irrigation (Table 3). Marketable yield was also improved by irrigation; from 25.6 t ha^{-1} without irrigation to 30.7 t ha^{-1} with irrigation. A positive response to irrigation was observed at nine out of the 12 sites (Table 3).

A neutral to negative response to irrigation was observed at three of the 12 sites (S6, S7, and S8). These all occurred in the 1996 crop year. Moisture deficits for the 1996 crop year were low (Table 3), with rainfall greater than in 1995 and 1997 (Table 1). The need for supplemental irrigation was therefore minimal. Only site S5 showed a positive response to irrigation in 1996 (Table 3). However, we suspect that this was as much the result of observed waterlogging in the non-irrigated block as to irrigation in the irrigated block. At site S8, total and marketable tuber yields were higher without than with irrigation (Table 3). In this case, we suspect that waterlogging in the irrigated block was the primary cause for observed yield differences. We therefore conclude that the field data from 1996 provides little insight into the response of potato to drought relief through supplemental irrigation. It does provide, however, an indication of the practical importance of good field drainage, especially when supplemental irrigation is practised in temperate climates.

The positive response to irrigation in 1995 and 1997 is in agreement with other studies reporting that irrigation of potatoes is essential to reach maximum yield in areas of inadequate or infrequent precipitation, and on soils with low water holding capacity (Clutterbuck and Simpson, 1978; Ojala *et al.*, 1990). The importance of supplemental irrigation to achieve maximum total and marketable yields was also supported by the significant ($P<0.05$) linear regression between the yield difference due to irrigation and WB (Fig. 1). Since a greater proportion of the variability in the yield difference was explained by WB in July than WB for the whole season, only the relationship with WB in July is presented. The site response to irrigation can be classified into three groups. In the first group (S5, S6, S7, and S8), WB in July was positive (5-83 mm) indicating excess water and the yield difference due to irrigation was very low, and even negative at some sites. Gregory and Simmonds (1992) also indicated that, in wet years, yield may not respond to irrigation or the response may be negative. In the second group (S1, S2, S9, and S12), the yield difference was greater than 9 t ha^{-1}, therefore providing evidence that irrigation can increase total and marketable yields in New Brunswick.

The third group (S3, S4, S10, and S11) was characterized by a negative WB (-76 to -105 mm) similar to the second

TABLE 2.—*Analysis of variance for potato tuber yield (total and marketable) as affected by irrigation, cultivar, N rate and site.*

Source of variation	d.f.	Mean square values Total	Marketable
Replications (R)	3	209.8	231.0
Irrigation	1	12271.1***	7285.3***
R*Irrigation (Error A)	3	27.4	17.1
Cultivar	1	51.7	610.4***
Irrigation * Cultivar	1	89.3	15.4
R*Irrigation*Cultivar (Error B)	3	23.8	40.8
Nitrogen rate (N)	5	2148.5***	1610.4***
Irrigation * N	5	116.1**	94.2*
Irrigation * Cultivar * N	5	10.4	8.2
Site	11	4089.4***	3637.7***
Site * Cultivar	11	145.8***	346.6***
Site * N	55	73.3***	42.8
Cultivar * N	5	24.3	7.8
Site * Irrigation	11	888.3***	725.7***
Residual (Error C)	1031	31.0	33.8
Contrast			
N Linear	1	8444.6***	6798.3***
N Quadratic	1	2026.5***	1047.9***
N Linear * Irrigation	1	328.7**	253.1**
N Quadratic * Irrigation	1	205.3**	194.9*
N Linear * Cultivar	1	84.7	1.9
N Quadratic * Cultivar	1	25.9	8.7

*, **, *** Significant at $P<0.05$, $P<0.01$ and $P<0.001$, respectively.

TABLE 3.—*Effect of irrigation on total and marketable tuber yields averaged over N rates and cultivars.*

		Total yield ($t\ ha^{-1}$)		Marketable yield ($t\ ha^{-1}$)			
Sites	Year	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigation (mm)	Seasonal water balance[1] (mm)
S1	1995	39.56	25.98	31.91	21.91	208	-218
S2	1995	46.61	30.25	34.25	24.76	217	-217
S3	1995	31.66	25.97	23.74	21.91	148	-219
S4	1995	31.22	26.01	26.40	21.87	160	-182
S5	1996	33.33	29.35	22.93	21.65	69	-1
S6	1996	32.27	32.34	24.87	25.54	50	10
S7	1996	49.01	48.78	38.06	38.57	70	-26
S8	1996	36.85	39.56	25.39	27.68	52	-1
S9	1997	33.41	24.10	27.43	14.82	76	-71
S10	1997	45.30	39.57	41.58	35.75	121	-173
S11	1997	43.72	38.05	37.81	34.22	94	-101
S12	1997	37.92	22.59	33.57	19.04	93	-162
Mean		38.40	31.88	30.66	25.64		

[1]Calculated from planting to harvest as potential evapotranspiration minus rainfall.

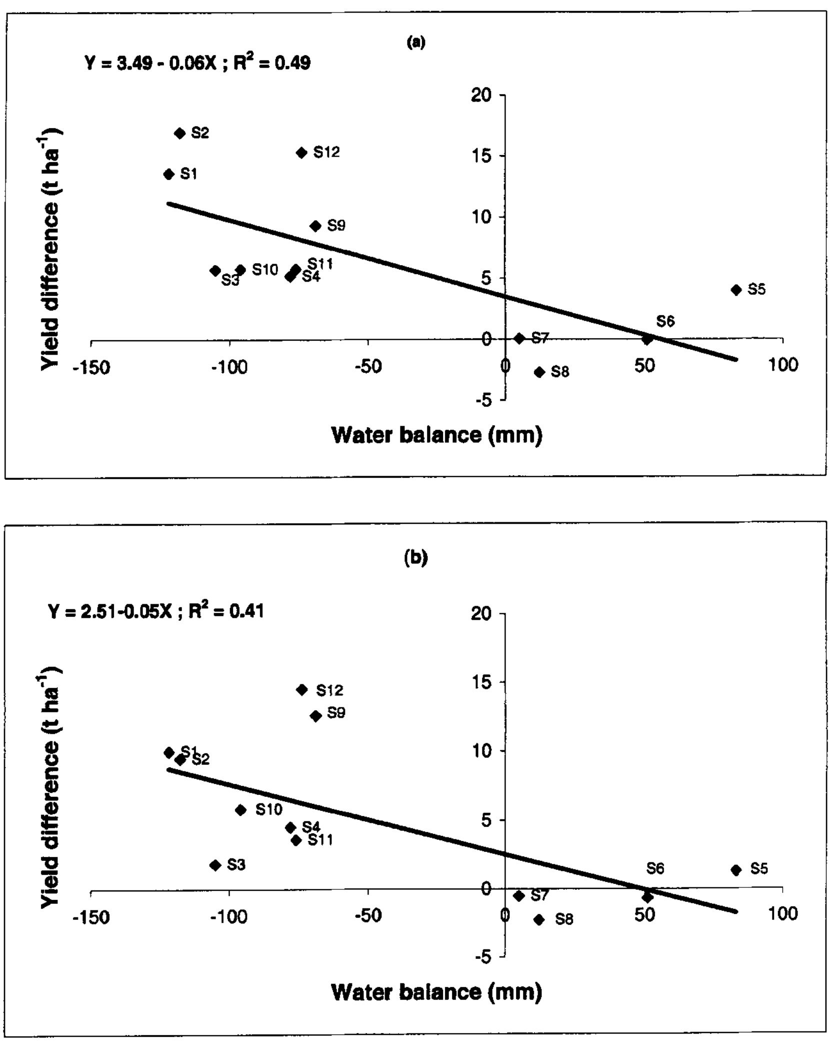

FIGURE 1.
Relationship between the yield difference due to irrigation for total (a) and marketable yield (b), and the water balance in July. Lines represent the linear regression and site numbers are presented beside each data point.

group but a lower yield difference (approximately 5 t ha^{-1}) was obtained. Possible reasons for this limited response could be a poorly aerated, compacted root zone with a high soil bulk density causing irrigation water to run off rather than penetrate the soil profile. The low tuber yield of sites S3 and S4 compared to the other sites (Table 3) provide indirect evidence of such limited growth conditions at sites S3 and S4. The limited response to irrigation of the third group of sites, however, cannot be explained in a fully satisfactory manner. Further research is required to gain a greater understanding of the variability in the response to irrigation under New Brunswick soil and water conditions.

No interaction between irrigation and cultivar was noted (Table 2), indicating that the effect of irrigation was the same for both cultivars. In Alberta, however, Lynch and Tai (1989) reported an interaction between water stress and six cultivars including Russet Burbank and Shepody.

On average, total tuber yield was 34.9 t ha^{-1} for Russet Burbank and 35.4 t ha^{-1} for Shepody but the difference was not statistically significant. Marketable yield, however, was significantly less for Russet Burbank (27.4 t ha^{-1}) than for Shepody (28.9 t ha^{-1}). Lynch and Tai (1989) also reported a greater marketable yield of Shepody compared with Russet Burbank.

Response to Applied N

Nitrogen fertilization significantly ($P< 0.001$) increased both total and marketable yields (Table 2; Figs. 2, 3, 4). Linear

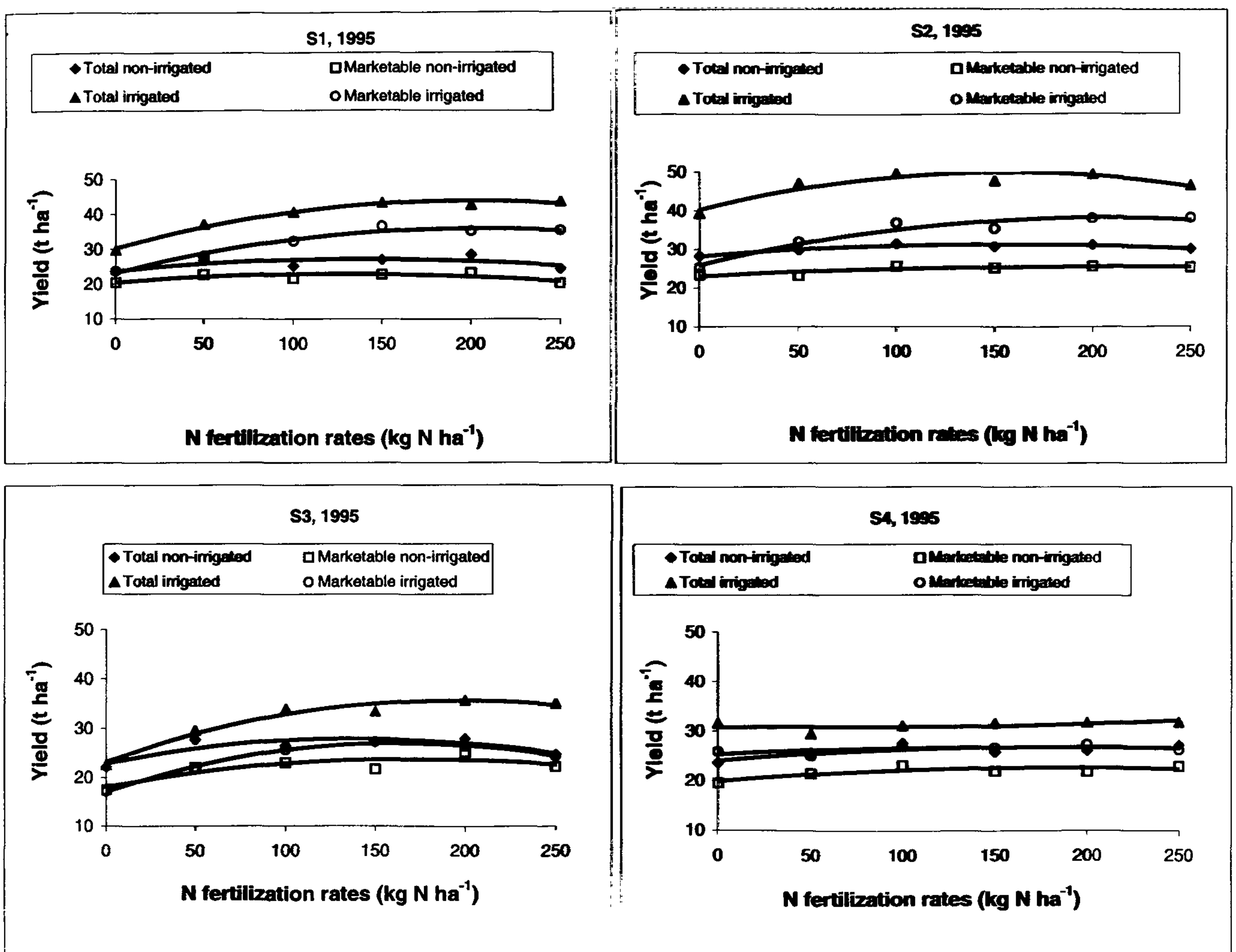

FIGURE 2.

Effect of N fertilization rates with and without irrigation on total and marketable tuber yields of potatoes at four sites in 1995. Lines represent the fitted polynomial curves and the corresponding parameters are presented in Table 4.

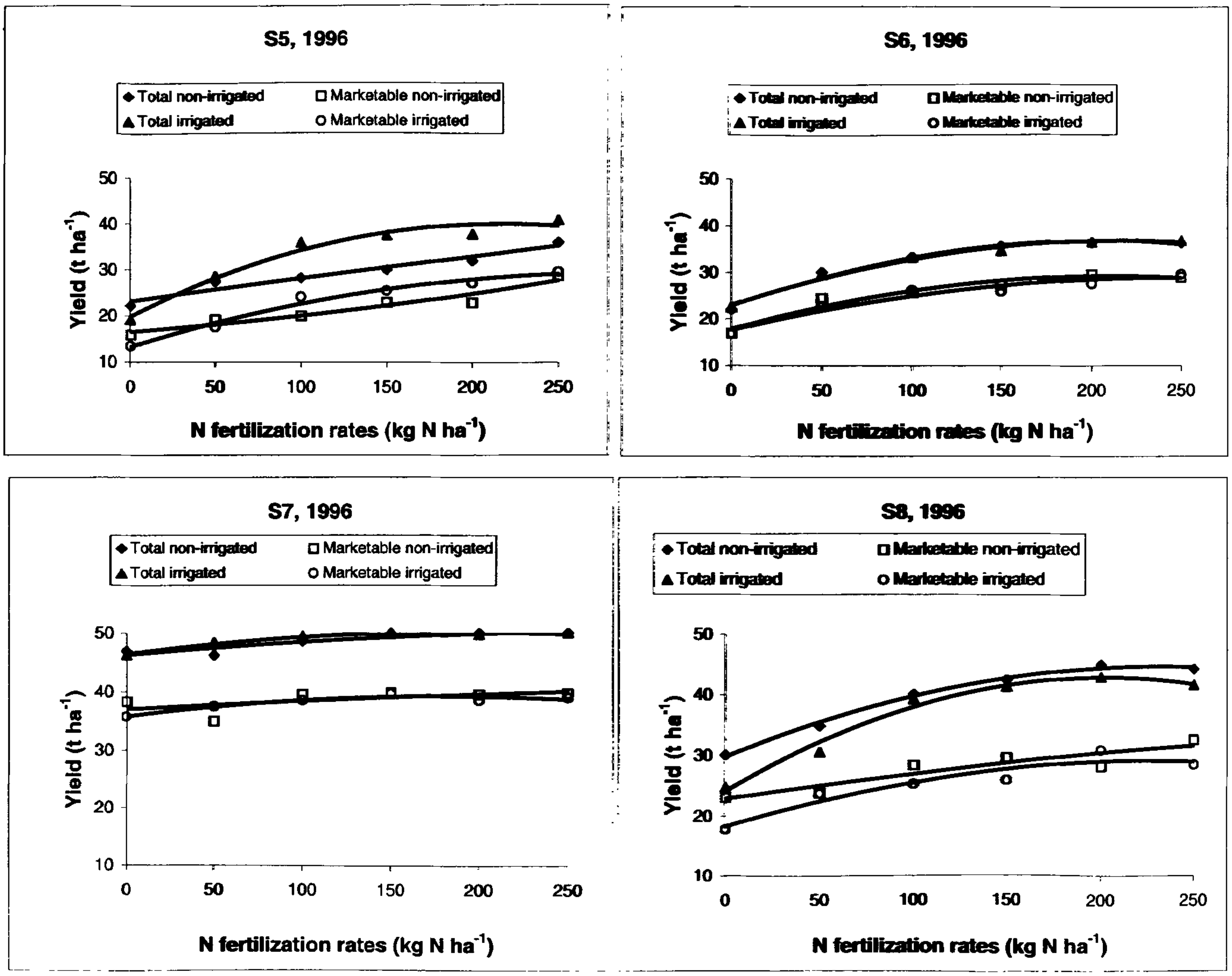

FIGURE 3.

Effect of N fertilization rates with and without irrigation on total and marketable tuber yields of potatoes at four sites in 1996. Lines represent the fitted polynomial curves and the corresponding parameters are presented in Table 4.

and quadratic contrasts for applied N were significant ($P<0.001$) for both total and marketable yields, indicating that near maximum yield was achieved (Table 2). The increase of potato tuber yield by N fertilization has been reported in many studies (Westermann and Kleinkopf, 1985; Joern and Vitosh, 1995; Vos, 1997; Meyer and Marcum, 1998). A positive response to N fertilization rates was observed at all sites except at S4. The absence of a yield response at that site can be attributed to the combined effect of a previous forage crop and the large amount of soil (0-30 cm) NO_3-N in spring (107 kg ha^{-1}) (Table 1). The yield response to N fertilization is often limited following a legume crop (Baldock *et al.*, 1981; Paré *et al.*, 1992; Feibert *et al.*, 1998).

A significant irrigation by N rate interaction on total and marketable yields was obtained (Table 2). Simpson (1962) noted the effects of applied N and soil moisture and their positive interaction on growth and yield of potatoes. In our study, however, 60% of the sites had no interaction between irrigation and N fertilization (data not shown). This may be partly explained by the above normal rainfall during the 1996 growing season (Table 1). No interaction between irrigation and N fertilization was observed at three of the four sites in 1996.

The N rate required to reach maximum yield (Nmax) was calculated for total and marketable yields at each site using a

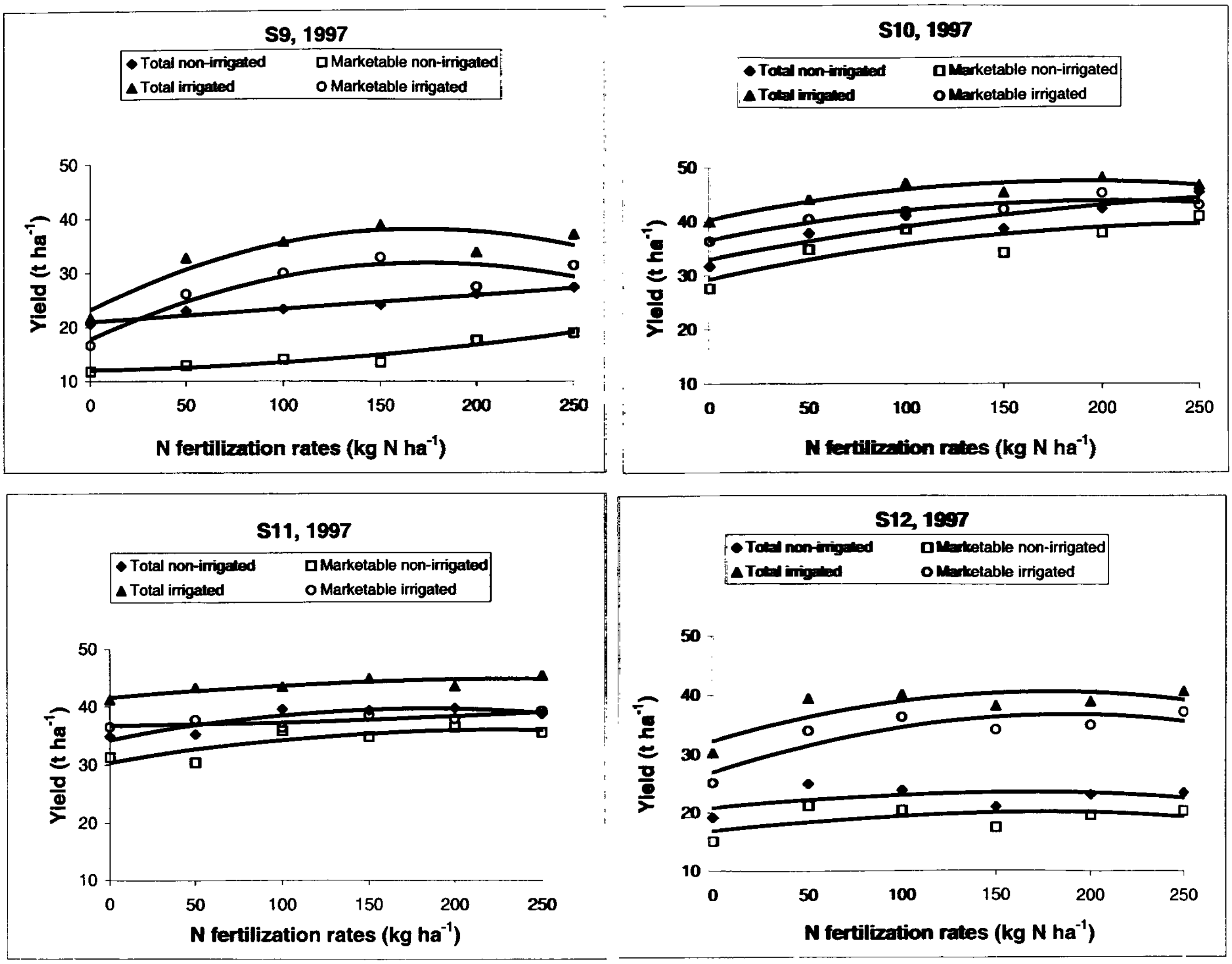

FIGURE 4.

Effect of N fertilization rates with and without irrigation on total and marketable tuber yields of potatoes at four sites in 1997. Lines represent the fitted polynomial curves and the corresponding parameters are presented in Table 4.

quadratic function (Table 4). The average calculated Nmax over sites for total yield with irrigation (198 kg N ha^{-1}) was similar to that without irrigation (189 kg N ha^{-1}). The average calculated Nmax for marketable yield was 194 kg N ha^{-1} with irrigation and 203 kg N ha^{-1} without irrigation. Harris (1992) concluded that while the response to N fertilization might be enhanced by irrigation, there was little evidence to suggest that Nmax needed to be increased. The interaction between irrigation and N fertilization is complex and reflects the effects of water on N leaching, crop N uptake, and soil N mineralization, the latter not estimated in this study.

A large variation in Nmax was observed among sites. With irrigation, Nmax varied between 158 and 233 kg N ha^{-1} for total yield, and between 151 and 250 kg N ha^{-1} for marketable yield (Table 4). Similarly, the total yield with no N applied corresponding to parameter "a" ranged from 19.87 to 46.49 t ha^{-1}, and the marketable yield ranged from 13.31 to 36.71 t ha^{-1}. Comparable variation was obtained without irrigation. The large difference among sites in yields obtained without N application cannot be explained only by the soil NO_3-N concentration in the spring. For instance, with soil concentrations in spring of 65 kg NO_3-N ha^{-1} at S3 and 54

TABLE 4.—*Parameters of the polynomial equation of non-irrigated and irrigated tuber yield (total and marketable) as a function of N application rates (X) [$Y = a + bX + cX^2$] and the N fertilizer rate (Nmax) required to reach maximum yield.*

Sites	a	b	c (x 10^{-3})	R^2	Nmax (kg N ha^{-1})	a	b	c (x10^{-3})	R^2	Nmax (kg N ha^{-1})
	Non-irrigated					Irrigated				
	Total					Total				
S1	23.77	0.048	-0.200	0.49	120	30.23	0.136	-0.30	0.98	226
S2	28.21	0.040	-0.100	0.91	200	40.22	0.127	-0.40	0.88	159
S3	22.84	0.072	-0.300	0.74	120	23.15	0.129	-0.30	0.96	215
S4	23.99	0.032	-0.090	0.63	178	30.74	-0.001	0.03	0.34	-[1]
S5	23.18	0.050	-0.010	0.95	250	19.87	0.186	-0.40	0.97	232
S6	22.67	0.144	-0.400	0.98	180	23.04	0.128	-0.30	0.98	213
S7	46.23	0.031	-0.060	0.76	250	46.49	0.037	-0.10	0.95	185
S8	29.78	0.130	-0.300	0.99	217	24.12	0.187	-0.50	0.98	187
S9	20.99	0.024	0.004	0.96	-[1]	23.20	0.175	-0.50	0.86	175
S10	32.97	0.070	-0.100	0.85	250	40.34	0.079	-0.20	0.88	197
S11	34.23	0.060	-0.200	0.84	150	41.59	0.028	-0.06	0.77	233
S12	20.82	0.033	-0.100	0.21	165	32.27	0.095	-0.30	0.67	158
	Marketable					Marketable				
S1	20.52	0.037	-0.100	0.61	185	23.23	0.125	-0.30	0.97	208
S2	23.04	0.026	-0.070	0.75	186	25.94	0.123	-0.30	0.93	205
S3	18.05	0.066	-0.200	0.74	165	17.06	0.121	-0.40	0.99	151
S4	19.87	0.032	-0.090	0.73	178	25.29	0.019	-0.06	0.44	158
S5	16.56	0.028	0.060	0.93	-[1]	13.31	0.113	-0.20	0.98	250
S6	17.85	0.110	-0.300	0.95	183	17.64	0.090	-0.20	0.94	225
S7	37.08	0.010	-0.010	0.33	250	35.86	0.036	-0.10	0.90	180
S8	22.90	0.047	-0.050	0.84	250	18.34	0.094	-0.20	0.91	235
S9	12.06	0.006	0.090	0.92	-[1]	17.77	0.160	-0.50	0.84	160
S10	29.28	0.080	-0.200	0.73	200	36.53	0.075	-0.20	0.92	187
S11	30.36	0.052	-0.100	0.73	250	36.71	0.006	0.01	0.65	-[1]
S12	16.86	0.037	-0.100	0.27	185	26.93	0.106	-0.30	0.75	176

[1]The Nmax value was not calculated when the fitted parameter "c" had a positive value.

kg NO_3-N ha^{-1} at S7, the total yield with irrigation was 23.15 t ha^{-1} at S3 and 46.49 t ha^{-1} at S7. It is likely that mineralization played a significant role after planting, and this might be a function of the previous crop. A grain crop preceded potatoes at S3 whereas clover was the previous crop at S7. Similar year and location variation in the yield response to N fertilization rates was observed in many studies (Joern and Vitosh, 1995; Meyer and Marcum, 1998).

Fertilizer recommendations are typically developed for a large geographic area represented by numerous differences in soil and microclimates. In Atlantic Canada, the existing recommendations for N fertilization are based on trials conducted at many sites, and from which an average response was calculated. As a result, N fertilization recommendations do not consider site-to-site variation in yield response to N fertilization. Hence, the large variations in the yield response to N fertilization as illustrated in our study might cause an excess or a deficiency of N when the existing recommendations are used. Excess N results in N losses to the environment through leaching and denitrification whereas N deficiency results in yield losses.

The Nmax values represent the N fertilization rates required to reach maximum yield and were calculated to characterize the response to N fertilization at different sites. They do not take into account any economic considerations such as the cost of fertilizer and the value of the crop. Hence, they should not be used for recommendations to growers. Although the quadratic equation adequately described the relationship between yield and N rates, it might not be appropriate to estimate the economic optimum N rates used for recommendations to growers (Cerrato and Blackmer, 1990). Further research on potatoes is required to establish the best model to use for that purpose.

There was no interaction between N fertilization rates and potato cultivars for both total and marketable tuber yields, indicating that the effect of N fertilization rates was the same for both cultivars. A significant cultivar by N interaction was only obtained at S5. Our results are in agreement with those of Feibert *et al.* (1998) which included Russet Burbank and Shepody in Oregon, Gavlak *et al.* (1993) in Alaska, and Munro *et al.* (1977) on Prince Edward Island who reported no cultivar by N interaction. In Atlantic Canada, lower rates of N fertilization are recommended for Shepody (130-150 kg N ha^{-1}) than for Russet Burbank (150-180 kg N ha^{-1}) (Bernard *et al.* 1993). Our results do not support this recommendation.

Our results indicate clearly that the response to two of the most significant factors of potato production, irrigation and N fertilization, varies greatly with site. The variation in the yield response to irrigation among the 12 sites could not be explained entirely by the level of water deficiency. Similarly, spring soil NO_3-N concentration could not explain all the variation in the yield response to N fertilization. Hence, other factors not measured in our study affected the response to irrigation and N fertilization. Furthermore, under non-limiting water and N conditions, yields at all sites were expected to be similar, and close to the potential yield. This was not the case as the maximum total yield varied from 30.7 to 50.3 t ha^{-1}. Since weeds, diseases and insects were adequately controlled, we speculate that abiotic factors such as soil depth, soil bulk density, and soil aeration status were responsible for this variability in maximum total yield. Our results suggest that the potential commercial yield in New Brunswick is approximately 50 t ha^{-1}.

The response to irrigation and N fertilization is highly site and year specific. Hence, further research should aim at developing field specific recommendations rather than the conventional general recommendations. To achieve this, a greater understanding of the effects of water and N deficiencies, and their interaction with other production factors is required.

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LITERATURE CITED

Baldock, J.O., L.R. Higgs, W.H. Paulson, J.A. Jacobs, and W.D. Schrader. 1981. Legume and mineral N effects on crop yields in several crop sequences in the upper Mississipi Valley. Agron J 73:885-890.

Bernard, G., S.K. Asiedu, and P. Boswall. (eds.). 1993. Atlantic Canada potato guide. Publ. 1300/87. Published by authority of the Atlantic Provinces Agricultural Services Coordinating Committee. 60 pages. Available from the New Brunswick Department of Agriculture and Rural Development, Fredericton, NB.

Bundy, L.G., R.P. Wolkowski, and G.G. Weis. 1986. Nitrogen source evaluation for potato production on irrigated sandy soils. Am Potato J 63:385-397.

Cerrato, M.E. and A.M. Blackmer. 1990. Comparison of models for describing corn yield response to nitrogen fertilizer. Agron.J 82:138-143.

Clutterbuck, B.J. and K. Simpson. 1978. The interactions of water and fertilizer nitrogen in effects on growth pattern and yield of potatoes. J Agric Sci Camb 91:161-171.

Colwell, J.D. 1994. Estimating Fertilizer Requirements. A Quantitative Approach. UK: Cab International. 262 p.

Curwen, D. and L.R. Massie. 1984. Potato irrigation scheduling in Wisconsin. Am Potato J 61:235-241.

De la Morena, I., A. Guillén, and I.F. Garcia del Moral. 1994. Yield development in potatoes as influenced by cultivar and the timing and level of nitrogen fertilization. Am Potato J 71:165-172.

Errebhi, M., C.J. Rosen, S.C. Gupta, and D.E. Birong. 1998. Potato yield response and nitrate leaching as influenced by nitrogen management. Agron J 90:10-15.

Feibert, E.B.G., C.C. Shock, and L.D. Saunders. 1998. Nitrogen fertilizer requirements of potatoes using carefully scheduled sprinkler irrigation. Hort Sci 33:262-265.

Gavlak, R.G., W.L. Campbell, J.L. Walworth, C.L. Johnson, J.E. Muniz, and T.A. Tindall. 1993. Nitrogen fertilization of irrigated Russet potatoes in southcentral Alaska. Am Potato J 70:571-578.

Gregory, P.J. and L.P. Simmonds. 1992. Water relations and growth of potatoes. Pages 214-246 *In:* The Potato Crop, The Scientific Basis For Improvement, ed. P. Harris, Chapman & Hall, London, UK.

Harris, P. 1992. Mineral nutrition. Pages 162-213 *In:* The Potato Crop, The Scientific Basis For Improvement, ed. P. Harris, Chapman & Hall, London, UK.

Hendershot, W.H. and M. Duquette. 1986. A simple barium chloride method for determining cation exchange capacity and exchangeable cations. Soil Sci Soc Am J 50:605-608.

Hendershot, W.H., H. Lalande, and M. Duquette. 1993. Ion exchange and exchangeable cations. Pages 167-176 *In:* Soil sampling and methods of analyses, ed. M.R. Carter, Lewis Publishers, Boca Raton, FL.

Joern, B.C. and M.L. Vitosh. 1995. Influence of applied nitrogen on potato Part I: Yield, quality, and nitrogen uptake. Am Potato J 72:53-63.

Langmaid, K.K., J.K. MacMillan, and J.G. Losier. 1976. Soils of Northern Victoria County, New Brunswick. Seventh Report of the New Brunswick Soil Survey. Copies available from the New

Brunswick Department of Agriculture and Rural Development. P.O. Box 6000, Fredericton, NB E3B 5H1.

Lynch, D.R. and G.C.C. Tai. 1989. Yield and yield component response of eight potato genotypes to water stress. Crop Sci 29:1207-1211.

McGill, W.B. and C.T. Figueiredo. 1993. Total nitrogen. Pages 201-211 *In:* Soil sampling and methods of analyses, ed. M. R. Carter, Lewis Publishers, Boca Raton, FL.

Meyer, R.D. and D.B Marcum. 1998. Potato yield, petiole nitrogen, and soil nitrogen response to water and nitrogen. Agron J 90:420-429.

Millette, J.F.G. and K.K. Langmaid. 1964. Soil survey of the Andover-Plaster Rock area of New Brunswick. Fifth Report of the New Brunswick Soil Survey. Copies available from the New Brunswick Department of Agriculture and Rural Development. P.O. Box 6000, Fredericton, NB E3B 5H1.

Munro D.C, R.P. White, and J.B. Sanderson. 1977. Effects of applied nitrogen on yields, tuber sizes, and specific gravities of two potato cultivars. Can J Plant Sci 57:803-810.

Ojala, J.C., J.C. Stark, and G.E. Kleinkopf. 1990. Influence of irrigation and nitrogen management on potato yield and quality. Am Potato J.67:29-43.

Paré, T., F.P. Chalifour, J. Bourassa, and H. Antoun. 1992. Forage-corn dry matter yields and N uptake as affected by previous legumes and nitrogen fertilizer. Can J Plant Sci 72:699-712.

Porter, G.A. and J.A. Sisson. 1993. Yield, market quality and petiole nitrate concentration of non-irrigated Russet Burbank and Shepody potatoes in response to side dressed nitrogen. Am Potato J 70: 101-116.

Sheldrick, B.H. and C. Wang. 1993. Particle size distribution. Pages 499-511 *In:* Soil sampling and methods of analysis, ed. M.R. Carter, Lewis Publishers, Boca Raton, FL.

Silva, G.H., R.W. Chase, R. Hammerschmidt, M.L. Vitosh, and R.B. Kitchen. 1991. Irrigation, nitrogen and gypsum effects on specific gravity and internal defects of Atlantic potatoes. Am Potato J 68:751-765.

Simpson, K. 1962. Effects of soil-moisture tension and fertilizers on the yield, growth and phosphorus uptake of potatoes. Journal of the Science of Food and Agriculture 13:236-248.

Statistical Analysis System Institute. Inc. 1996. Statistics. 6 th ed., SAS Institute Inc., Cary, NC.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics: A biometrical approach. McGraw-Hill Publishing Co. NY.

Stobbe, P.C. and H. Aalund. 1944. Soil survey of the Woodstock area of New Brunswick. Second Report of the New Brunswick Soil Survey. Copies available from the New Brunswick Department of Agriculture and Rural Development. P.O. Box 6000, Fredericton, NB E3B 5H1.

Tel, D.A. and C. Heseltine. 1990. The analyses of KCl soil extracts for nitrate, nitrite and ammonium using a TRAACS 800 analyzer. Commun Soil Sci Plant Anal 21:981-1688.

Tiessen, H. and J.O. Moir. 1993. Total and organic carbon. Pages 187-199 *In:* Soil sampling and methods of analyses, ed. M.R. Carter, Lewis Publishers, Boca Raton, FL.

Vos, J. 1997. The nitrogen response of potato (*Solanum tuberosum* L.) in the field: nitrogen uptake and yield, harvest index and nitrogen concentration. Potato Research 40:237-248.

Westermann, D.T. and G.E. Kleinkopf. 1985. Nitrogen requirements of potatoes. Agron J 77:616-621.

Williams, C.M.J and N.A. Maier. 1990. Determination of the nitrogen status of irrigated potato crops. I. Critical nutrient ranges for nitrate-nitrogen in petioles. J Plant Nutr 13(8):971-984.