for the first harvest and practically eliminated BER development for the second harvest of mature green fruit. The NH4 treatments without Ca spray reduced the number of fruit on the plants at the second harvest.

These experiments show that NH4-N produced a marked reduction of Ca and Mg absorption by tomatoes and sweetcorn seedlings. NH4-N applied during fruiting of tomatoes resulted in rapid development of BER, which was likely due to the influence of NH4-N on reduction of Ca absorption by the plant. It is conceivable that NH4 induced Ca or Mg deficiency can be a factor whenever NH4 becomes a major portion of the N supply to these plants. NH4 is likely to become the major source of N supply where supplemental programs of N fertilization are used during plant growth. Situations where high levels of NH4-N are maintained in the soil, as in cold or acid soils with reduced nitrification rates are peculiarly vulnerable to Ca or Mg deficiency.

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Effects of N, P, and K Fertilizer on Leaf Composition, Yield, and Fruit Quality of Bearing 'Ben Lear' Cranberries[1]

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Abstract. Data from a 3-yr experiment on 'Ben Lear' cranberries (*Vaccinium macrocarpon* Ait), by multiple stepwise regression at the 1% level, showed that N, P, and K applications increased their respective tissue levels. Tissue Ca and Mn were decreased by N applications in 1969; 1970 tissue Ca was decreased by applications of both N and P. Nitrogen, P, and K applications all tended to decrease 1969 tissue Mg.

Yield was increased by N applications in 1971. A cubic effect of N applications was noted in 1970 anthocyanin and soluble solids contents. Pooled data for 1970 and 1971 were fitted to linear and quadratic equations relating tissue levels to fertilizer applications and yield and quality measurements to tissue levels. Desirable tissue levels of N, P, K, Ca, Mg, Fe, and Mn are suggested.

A number of studies have been made to determine cranberry fertilizer requirements and the effects of fertilizer applications on yield and fruit quality (1, 3, 4, 8, 9, 10). However, little study has been made on effects of fertilizers on mineral composition of cranberry tissue and to relate leaf tissue composition to fruit quality and yield.

To recommend a single optimum cranberry fertilizer application would be impractical due to the variability in bogs, grower operations, and other environmental factors (1, 4).

Several workers (3, 9, 16) have reported excessive vine growth and reduction in yield and fruit quality with applications of too much N. In order to sustain cranberry yields, the balance between optimum vine growth and reproductive development must be maintained (5). This balance is maintained only when an adequate supply of N is available. In a study of the effect of 3 levels of N applications on 6 bogs of similar age and soil background, Eck (11) found that N applications increased leaf tissue N, the number of runners per unit of bog area, and the length of both fruiting and non-fruiting uprights. Torio and Eck (17) applied high and low levels of N, P, K, and S to cranberries in a greenhouse sand culture experiment. High N or S increased runner growth, high P increased runner length and dry wt, and K application increased the number of uprights. Sulfur applications increased runner production only with joint applications of high N.

Eck (10) in a study of several major and minor elements applied to cranberry bogs of varying organic matter contents, found that applications of P at 13 lb. per acre increased berry wt, but decreased the number of berries per sq ft. Fisher (12) in

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[3]Rates represent 0, 10, 20 and 30 lb. N/acre and 0, 30 and 60 lb./acre of either P or K.

a study of Washington bogs found lack of K reduced yield. Doehlert (7) found no effect of K on yield in New Jersey.

Francis and Atwood (13) found a decrease in pigment with increased levels of a complete fertilizer. Eaton (8) found in a mature bog that N, P, or K applications increased the respective tissue levels. Applications of N and P increased yield, yellowness and lightness, but decreased fruit redness. Potassium applications modified effects of both N and P applications. Eaton (9) found high rates of N reduced yield in a young bog and that applications of N and P decreased fruit redness. Tissue Mn was decreased by N applications.

The present study was undertaken to learn the effects of NPK fertilizer applications on the leaf mineral composition, yield, and fruit quality of mature cranberry plants grown on acid sphagum peat in the field. It continues into the mature plant stage, a study begun on a young bog (9).

Materials and Methods

We used a commercial planting of bearing 'Ben Lear' cranberries, established in the spring of 1965, on acid sphagnum peat. Results for the non-bearing experiment carried out at this location were published (9). The bearing plant experiment was a 4 x 3 x 3 factorial in each of 2 complete blocks. Since bearing bogs usually receive less fertilizer applications than non-bearing bogs, the experimental rates were decreased in 1969. During June of 1969, 1970, and 1971, the 36 possible treatment combinations were applied to each block. The treatments were 0, 11, 22, and 34 kg N/ha, as NH_4 NO_3; 0, 15, and 29 kg P/ha as treble superphosphate; and 0, 28, and 56 kg K/ha[3] as muriate of potash.

In early August of each year, leaf samples were taken for mineral analyses by clipping entire uprights of both fruiting and non-fruiting, current season growth. When oven dry, stem tissue was discarded, and the remaining leaf tissue was analyzed. The samples were digested for chemical analysis for all elements except N using the wet-ashing method of Chapman and Pratt (2). Samples were analyzed for N by the semi-micro Kjeldahl method, for P by the phosphomolybdate colorimetry method of Dickman and Bray (6), for K by flame emission photometry, and for Ca, Mg, Fe, and Mn by atomic absorption spectroscopy.

Two samples were handpicked from each plot for yield data in 1970 and 1971. Each sample consisted of the fruits in a quadrat 400 cm^2 in area, randomly placed within each plot. Berry numbers and fruit wt were recorded. The fruit samples were then frozen. Soluble solids content was determined and fruit color was evaluated by measuring total anthocyanin content of the thawed fruit, according to the method described by Fulecki (14).

Data for the 3 years were first analyzed separately. Main effects and interactions in 1969, 1970, and 1971 mineral analyses and in 1970 and 1971 yield and fruit quality data were subdivided into individual degrees of freedom, namely linear (-3, -1, 1, 3), quadratic (1, -1, -1, 1), and cubic (-1, 3, -3, 1) effects of N application rates; linear (-1, 0, 1) and quadratic (1, -2, 1) effects of P and K rates; and the possible interactions among them. The separate analyses were followed by a similar analysis on the pooled data for 1970 and 1971. All statistical analyses were carried out using stepwise multiple regression at the 1% level for the separate analyses and the 5% level for the pooled analyses. This method of statistical analysis identifies the major sources of variability among treatments and assigns them to specific hypotheses designed by the experimenter.

Table 1. Data for final multiple regression equations for mineral analyses, yield, and quality measurements in response to fertilizer treatments, 1969-1971.

	Dependent Variables										
	N %	P %	K %	Ca %	Mg %	Fe ppm	Mn ppm	Berries/plot = $\overline{x}$ no.	Yield kg/ha	Anthocyanin mg/100gm	Soluble solids %
1969 Independent variables											
Constant term	0.9298	0.1207	0.4150	0.4326	0.3211	96.18	174.5				
N-linear	0.0356	–	–	-0.0145	-0.0065	–	-23.31				
P-linear	–	0.0438	–	–	0.0179	–	–				
K-linear	–	–	0.0731	–	-0.0207	–	–				
K-quadratic	–	–	–	–	0.0073	–	–				
2 factor interactions											
N-linear x P-linear	–	–	–	–	0.0070	–	–				
N-cubic x P-linear	0.0253	–	–	–	–	–	–				
N-cubic x K-linear	–	–	–	–	–	-6.783	–				
Multiple R^2	0.32	0.47	0.50	0.56	0.51	0.10	0.59				
Error degrees of freedom	69	70	70	70	66	70	70				
Standard error of estimate	0.14	0.04	0.06	0.04	0.03	37	44				
1970 Independent variables											
Constant term	1.0250	0.1468	0.3864	0.5932	0.3283	74.54	182.5068	85.05	25,960.	34.24	8.879
N-linear	0.0308	–	0.0062	–	-0.0087	–	-20.42	–	–	–	–
N-quadratic	0.0289	-0.0120	–	–	-0.0110	–	–	-10.48	–	–	–
N-cubic	–	–	–	–	–	–	–	–	–	0.7842	0.0645
P-linear	–	0.0483	0.0262	–	–	–	–	–	–	–	–
K-linear	–	–	0.0462	–	–	–	–	–	–	–	–
K-quadratic	–	–	-0.0116	–	–	–	–	–	–	–	–
2 factor interactions											
N-linear x K-linear	–	–	–	–	-0.0062	–	–	–	–	–	–
N-quadratic x K-linear	–	–	–	–	–	–	–	10.98	–	–	–
3 factor interaction											
N-cubic x P-quadratic x K-linear	–	–	–	–	–	–	6.899	–	–	–	–
Multiple R^2	0.46	0.68	0.66	N.S.	0.46	N.S.	0.45	0.28	N.S.	0.11	0.09
Error degrees of freedom	69	69	67		68		69	69		70	70
Standard error of estimate	0.08	0.04	0.04		0.03		55.	27.		5.0	0.45
1971 Independent variables											
Constant term	1.153	0.1969	0.3611	0.6655	0.2538	145.6	204.2	65.84	19,990.0	29.46	7.665
N-linear	–	–	–	-0.0193	–	–	-14.19	6.040	183.6	–	–
P-linear	–	0.0670	–	-0.0617	–	–	–	–	–	-	–
K-linear	–	–	0.0469	–	–	–	–	–	–	–	–
2 factor interaction											
P-quadratic x K-quadratic	–	–	–	–	–	–	8.073	–	–	–	–
Multiple R^2	N.S.	0.59	0.33	0.25	N.S.	N.S.	0.35	0.15	0.15	N.S.	N.S.
Error degrees of freedom		70	70	69			69	70	70		
Standard error estimate		0.05	0.06	0.12			50.	33.	9908.		

Table 2. Effect of N, P, and K application upon tissue mineral composition, adjusted means.

	Tissue mineral content			
Applied N (kg/ha)	0	11	22	34
1970 leaf N (pct)	.96	.97	1.03	1.15
1969 leaf Ca (pct)	.48	.45	.42	.39
1969 leaf Mn (ppm)	224.	198.	151.	105.
Applied P (kg/ha)	0	15	29	
1969 leaf P (pct)	.077	.103	.165	
1971 leaf P (pct)	.130	.197	.264	
Applied K (kg/ha)	0	28	56	
1969 leaf K (pct)	.34	.42	.49	
1971 leaf K (pct)	.31	.36	.41	

Table 4. Effect of N and K fertilizer applications on tissue mineral composition, adjusted means.

		Applied N(kg/ha)			
		0	11	22	34
Applied K(kg/ha)	1970 tissue Mg (pct)				
0		.32	.34	.34	.31
28		.34	.35	.33	.29
56		.36	.35	.32	.28
	1969 tissue Fe (ppm)				
0		89	117	76	103
28		96	96	96	96
56		103	76	117	89

Nonsignificant effects are largely omitted from the resulting summary of results. Error degrees of freedom are increased from the 35 of the analysis of variance to 65 or more (Table 1).

Results

The significant findings of the separate analyses for each year are completely summarized in Table 1. Tables 2 through 7 inclusive are illustrative values fitted from the appropriate equations presented in Table 1. The data for the final multiple regression equations, of the form of $Y = a + b_1X_1 + b_2X_2 + \ldots b_nX_n$, for the variables measured are presented in Table 1. For each dependent variable, the constant term (a) and the coefficients (b) for the significant independent variables are given. The X in the multiple regression equation refers to the corresponding individual degree of freedom multiplier for a specific treatment or treatment combination. For example, 1969 leaf tissue Mn can be represented as:

$$1969 \text{ ppm Mn} = 174.5 - 23.31\ (X_1)$$

The adjusted mean for the linear effect of 11 kg N/ha on 1969 leaf Mn, as shown in Table 2, can be calculated from this equation in the following manner:

Table 3. Effect of N and P fertilizer applications on tissue mineral composition, adjusted means.

		Tissue mineral content (pct)								
		1969 tissue N			1970 tissue P			1971 tissue Ca		
Applied N (kg/ha)	Applied P (kg/ha)	0	15	29	0	15	29	0	15	29
0		.85	.82	.80	.087	.135	.183	.79	.72	.66
11		.82	.89	.97	.110	.159	.207	.75	.68	.62
22		1.04	.97	.89	.110	.159	.207	.71	.64	.58
34		1.01	1.04	1.06	.087	.135	.183	.67	.61	.54

$$1969 \text{ ppm Mn} = 174.5 - 23.31\ (-1) = 197.8$$

Applications of N fertilizer increased 1970 leaf tissue N composition (Table 2). This was also true in 1969 but there was also a cubic effect which was modified by applications of P (Table 3).

The effect of P and K applications on their respective elements in the tissue acted similarly in 1969 and 1971. Applications of P increased tissue P in a linear manner for both years (Table 2). In a similar manner, increasing applications of K increased tissue K in both 1969 and 1971 (Table 2).

Table 5. Effect of N, P, and K applications on tissue mineral composition, adjusted means.

		Applied P(kg/ha)								
		0			15			29		
	Applied K (kg/ha)	0	28	56	0	28	56	0	28	56
Tissue mineral content	Applied N kg/ha									
1970 tissue K (pct)	0	.28	.36	.38	.31	.39	.40	.34	.42	.43
"	11	.30	.38	.39	.32	.40	.41	.35	.43	.44
"	22	.31	.39	.40	.33	.42	.43	.36	.44	.45
"	34	.32	.40	.41	.35	.43	.44	.37	.45	.47
1969 tissue Mg (pct)	0	.37	.33	.33	.37	.33	.33	.37	.32	.32
"	11	.34	.30	.30	.34	.31	.31	.37	.32	.32
"	22	.32	.28	.28	.34	.30	.30	.37	.32	.33
"	34	.29	.25	.25	.33	.29	.29	.37	.32	.33
1970 tissue Mn (ppm)	0	251	244	237	230	244	258	251	244	237
"	11	182	203	224	244	203	162	182	203	224
"	22	183	162	141	121	162	203	183	162	141
"	34	114	121	128	135	121	107	114	121	128
1971 tissue Mn (ppm)	0	255	231	255	231	279	231	255	231	255
"	11	226	202	226	202	251	202	226	202	226
"	22	198	174	198	174	222	174	198	174	198
"	34	170	145	170	145	194	145	170	145	170

Table 6. Effect of N and K applications on number of berries per 400 cm^2, 1970 adjusted means.

Applied K (kg/ha)	Applied N (kg/ha) 0	11	22	34
0	64	107	107	64
28	75	96	96	75
56	86	85	85	86

Table 7. Effects of N application on 1970 anthocyanin and soluble solids content and 1971 berry number and kg/ha, adjusted means.

	Applied N(kg/ha) 0	11	22	34
Anthocyanin (mg/100gm)	33	37	32	35
Soluble solids (%)	8.8	9.1	8.7	8.9
Berries per 400 cm^2	48	60	72	84
Yield (metric tons/ha)	14.50	18.16	21.82	25.48

An N-quadratic X P-linear interaction affected 1970 leaf P (Table 3). At any rate of applied N, applying P fertilizer increased tissue P levels. However, P levels were lower when control or 34 kg N/ha was applied when compared to the leaf P content when 11 or 22 kg N/ha was applied.

N, P, and K-linear and K-quadratic effects were noted in 1970 tissue K levels (Table 5). The greater the amount of K supplied, within any N-P combination, the greater the increase in K composition. Similarily, increasing N applications under any P-K combination and increasing P applications under any N-K combination, increased tissue K levels. This effect was due to the separate main effects of N, P, and K; there was no interaction.

In both 1969 and 1971, the general effect of N applications was to decrease Ca tissue levels (Tables 2, 3). This effect was further modified by P applications in 1971 (Table 3) where leaf Ca composition was further decreased with increasing P applications at each rate of applied N. No fertilizer applications affected 1970 leaf tissue Ca.

Leaf tissue Mg was affected in 1969 by main effects of N, P, and K and a N x P interaction (Table 5). At 0 and 15 kg P/ha and all rates of applied N, applications of K decreased tissue Mg in comparison to the control. This general tendancy held true at the highest rate of applied P also, although slight differences between adjusted means for 28 and 56 kg K/ha were noted.

Negative linear and quadratic effects of N and a linear N x K interaction affected 1970 tissue Mg (Table 4). At 0 and 11 kg N/ha, increasing applications of K increased tissue Mg content while at 22 and 34 kg N/ha tissue Mg levels were decreased with increased K applications.

An N-cubic x K-linear interaction modified 1969 Fe levels. At 0 and 22 kg N/ha, K applications tended to increase tissue Fe content while 11 and 34 kg N/ha, K applications decreased Fe levels (Table 4).

Tissue Mn levels in 1969 and 1971 were decreased with increasing applications of N fertilizer (Table 2, 5). Leaf Mn was further modified in 1971 by a quadratic P x K interaction. In 1970, Mn levels decreased when N rates were increased and K was applied at 28 kg/ha. 1970 tissue Mn was also affected by an N-cubic x P-quadratic x K-linear interaction, making interpretation very difficult.

At 0 and 34 kg N/ha increasing amounts of K fertilizer increased the average number of berries per 400 cm^2 sample in 1970 (Table 6). However, when 11 or 22 kg N/ha was applied, applications K decreased the number of berries.

In 1971 increasing applications of N at every rate increased both berry number and yield as kg/ha (Table 7). In 1970, there was an N-cubic effect on both anthocyanin and soluble solids content of the berries (Table 7).

Simple linear and quadratic equations in one independent variable were also fitted by stepwise regressions to the pooled data of 1970 and 1971, and the significant ($P = .05$) results presented in Table 8. Yield and quality measurements were not recorded in 1969. The results relate tissue levels of N, Ca, Mg, and Mn to applications of N; tissue levels of P, K, and Ca to applied P; tissue levels of K and Ca to applied K. Soluble solids increased with tissue K and Mg but decreased with N, P, Ca, Fe, and Mn. Anthocyanin increased with tissue Mg but decreased with N, P, and Fe. Yield increased with tissue Ca and Mg but decreased with K. Although some of these equations have a theoretical min or max, the corresponding values of the independent variable were generally outside its observed range.

Discussion

Our results indicate that N, P, or K deficiency problems

Table 8. Equations of the form $Y = a + bX + cX^2$ fitted to the pooled data for 1970 and 1971.

Dependent variable (Y)	Independent variable (X)	a	b	c	100 R^2	Std. error of estimate	Mean (Y)	Std. deviation (Y)	Optimum (X)	Min or max (Y)
Tissue N (pct)	applied N (kg/ha)	1.014	' ..0034	0	5.6	.233	1.089	.239		
Tissue Ca (pct)	applied N (kg/ha)	.686	-.0025	0	6.3	.162	.630	.167		
Tissue Mg (pct)	applied N (kg/ha)	.304	-.00060	0	3.7	.051	.291	.052		
Tissue Mn (ppm)	applied N (kg/ha)	245	-2.310	0	32.6	56	193.	68		
Tissue P (pct)	applied P (kg/ha)	.114	.0019	0	42.5	.055	.172	.073		
Tissue K (pct)	applied P (kg/ha)	.351	.00076	0	7.5	.065	.374	.068	57.83	MAX
Tissue Ca (pct)	applied P (kg/ha)	.678	-.0016	0	5.7	.163	.630	.167		
Tissue K (pct)	applied K (kg/ha)	.319	.0032	-.00028	34.9	.055	.374	.068		
Tissue Ca (pct)	applied K (kg/ha)	.666	-.0012	0	3.2	.165	.630	.167		
Anthocyanin (mg/100g)	tissue N (pct)	48.97	-23.95	7.2	6.2	6.0	31.9	6.2	1.658	MIN
Anthocyanin (mg/100g)	tissue P (pct)	39.96	-80.86	166.7	7.5	6.0	31.9	6.2	.243	MIN
Anthocyanin (mg/100g)	tissue Mg (pct)	22.36	32.65	0	7.5	6.0	31.9	6.2		
Anthocyanin (mg/100g)	tissue Fe (ppm)	35.29	-.0312	0	6.1	6.0	31.9	6.2		
Soluble solids (pct)	tissue N (pct)	11.17	-3.66	0.87	12.1	.71	8.2	0.76	2.108	MIN
Soluble solids (pct)	tissue P (pct)	8.74	-2.80	0	7.2	.73	8.2	0.76		
Soluble solids (pct)	tissue K (pct)	7.39	2.31	0	4.3	.74	8.2	0.76		
Soluble solids (pct)	tissue Ca (pct)	8.82	-0.89	0	3.9	.74	8.2	0.76		
Soluble solids (pct)	tissue Mg (pct)	5.89	8.16	0	31.4	.63	8.2	0.76		
Soluble solids (pct)	tissue Fe (ppm)	10.03	-.0216	.000042	41.0	.58	8.2	0.76	256	MIN
Soluble solids (pct)	tissue Mn (ppm)	9.09	-.0086	.00020	3.8	.74	8.2	0.76	216	MIN
Yield (metric T/ha)	tissue K (pct)	33.40	-28.03	0	3.3	10.3	22.9	10.5		
Yield (metric T/ha)	tissue Ca (pct)	15.96	11.05	0	3.1	10.3	22.9	10.5		
Yield (metric T/ha)	tissue Mg (pct)	-8.05	81.91	0	16.5	9.6	22.9	10.5		

could be alleviated by direct applications of fertilizer. This agrees with the findings of other experimenters (8, 9, 10, 11). Moreover our equations (Table 8) can provide an indication of fertilizer levels required to supply specified tissue levels of certain elements. If one were interested in only a single dependent variable, say yield, the suggestion of a fertilizer application from our results would not be difficult; but, as quality is also important, one should probably choose a fertilizer application which would be an economical compromise between yield and quality. We did not find consistent yearly relationships among yield, tissue N, and applied N. However, we suggest that 22 kg/ha be a max N application since high levels of N induced low Ca and Mg tissue levels, which in turn were associated with low yields. We suggest that 1.0% be a max tissue N level since above this level soluble solids and anthocyanins both decreased. We suggest that 0.10% is a max desirable level of tissue P since both soluble solids and anthocyanin decreased steadily as this level was exceeded. This level would be marginally low for the growth of young vines (15). Since soluble solids increased slightly and yield decreased slightly between K levels of .34 and .40%, the preferred K level is probably in this range. Since soluble solids decreased and yield increased between Ca levels of .60 and .70%, the preferred Ca level is probably in this range. Since yield, soluble solids, and anthocyanin each increased with Mg tissue levels between .27 and .31 without any evidence of a max being reached, the optimum Mg level may be above this range. Fe levels, while not associated with yield, were associated with steady decreases in both soluble solids and anthocyanin as the Fe level increased from 50 to 100 ppm. The optimum Fe level is, therefore, probably below 50 ppm. Tissue Mn was related to soluble solids, and suggests a preferred tissue level below 150 ppm. Since Fe levels above 50 ppm and Mn levels above 150 ppm are very commonly found in cranberry, luxury consumption of these elements may be more important in cranberry nutrition than has previously been supposed.

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