SOME EFFECTS OF WATER TABLE, pH, AND AMMONIUM AND NITRATE NITROGEN UPON THE GROWTH AND COMPOSITION OF HIGHBUSH BLUEBERRY

by

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ABSTRACT

Frequent drainage and aeration problems occur in blueberry plantings on acid peats (pH 3.0 to pH 4.2) of British Columbia during a part of the growing season.

The effect of waterlogging, pH, and form of N were studied under greenhouse conditions. Using one year old plants of Bluecrop blueberry, a split plot design was employed with two water tables for main plots and a factorial combination of 4 pH levels and 3 levels each of ammonium and nitrate N (20, 40, and 60 lbs. N/acre). An unfertilized check treatment was also included as a treatment.

Growth records and leaf analysis showed that poor aeration under waterlogged conditions exhibited characters symptomatic of poor nutrition. Sparse leaf growth, smaller leaves with severe yellowing and premature leaf abscission were observed in the high water table treatments. Leaf analysis revealed highly significant differences in foliar N, P, K, Ca, Mg, and Fe levels.

There was also a greater growth response to ammonium N and nitrate N. Higher levels of nitrate N (40, and 60 lbs. N/acre) caused severe leaf scorch. Although higher levels of ammonium N (40, and 60 lbs. N/acre) gave better growth response, growth was prolonged and fall leaf drop and wood maturation were delayed. Plants receiving 60 lbs. N/acre as ammonium N showed symptoms of dieback in the following spring.

Although pH had very little effect on leaf nutrient composition, growth appeared to be better at a pH level of around 4.2.

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I. INTRODUCTION

The highbush blueberry, (*Vaccinium corymbosum* L.) is cultivated under a wide range of soil and climatic conditions in the south, west, and northeastern regions of the North American continent. It is commercially popular as a horticultural crop in eastern North Carolina, southern New England, western New York, southern Michigan and western Oregon and Washington. The highbush blueberry is also cultivated on a commercial scale in the southeastern region of Canada and to a limited extent on the western coastal region of British Columbia. Climatically, successful cultivation is limited to the regions mentioned above due to the specific chilling requirements of the highbush blueberry.

From the edaphic aspect, the most important factor in the soil appears to be the pH. Due to peculiar nutrient requirements of the highbush blueberry, ecological adaptation appears to depend to a large measure on its soil requirements. If the natural flora in a particular region where it is to be grown contains related plants of the *Ericaceae*, it is a good indication that the highbush blueberry will succeed. In order to adjust the soil pH to the optimum range, corrective measures have been adopted in many areas either by the addition of dolomitic lime to raise the pH, or by the addition of ground S to lower pH. Mineral soils as well as soils of organic origin can be utilized for growing blueberries.

Most commercial highbush blueberry plantings in the lower Fraser Valley delta region have been established on acid peat and muck soils. The pH in these soils ranges from pH 3.0 to pH 4.2. Wherever the surface layer of peat has been exploited the remaining layer of decomposed organic material may range from a little over a foot in thickness to a few feet overlying sand or sandy clay. Due to the nature of the flat terrain, the delta region has a very high water table inundating blueberry fields for periods sufficient to create waterlogged conditions. Although drainage facilities have been provided in these fields, the water table often goes above the 14 to 30 inch level which is considered to be ideal for blueberries (20).

The nutrient supply of these peats does not seem to be sufficient for successful cropping. Under such acid conditions microbial activity and mineralization of the organic N would be very slow. Poor drainage and low soil pH would reduce the uptake and availability of P, basic cations, and some trace elements like Cu and Mo.

A preliminary survey of blueberry leaf nutrient status was carried out in the summer of 1965 to obtain some guidelines which would serve as a basis for the initiation of a comprehensive program of research leading to the establishment of critical nutrient levels and to establish criteria for making fertilizer recommendations for highbush blueberry. A closely related objective of that preliminary survey was to evolve a reliable precedure for collecting leaf

samples. Since the survey revealed possible "hidden hunger" levels for N and P according to the estimated deficiency levels presented in Table (1) (Cain and Eck, 14), the present experiment was designed to study the effects of two sources of N at different pH levels maintained under waterlogged and free-drained conditions.

II. LITERATURE REVIEW

A. Soil Reaction

Early work of Chandler (15) showed increase in yields with application of lime at the rate of 8 tons per acre to lowbush blueberry fields. The high dose of lime used did not seem to have adverse effects on the crop. Although these initial studies were conducted on lowbush blueberries, the response to liming, as indicated by better growth and higher yield, prompted further study extending to the highbush blueberry. Cain and Galletta (12) found the range of pH 4.5 to pH 4.8 to be best suited to successful commercial production of highbush blueberries. Johnston (34) reported that pH was more critical than any other soil factor. Merril (39) found that pH 3.2 or lower was too acid, often causing detrimental effects to plants, perhaps because at such low pH levels most nutrients were limiting. These results were in accord with those obtained by Stene, (44) who submitted that true acidity was not the ultimate criterion blueberry survival was dependent upon, but rather the level of nutrition they were able to derive from such a nutrient environment. Even at higher pH levels blueberries thrived, provided the balance of supply of nutrients was maintained. Kramer and Schrader (36) suggested that the reason why blueberries thrived in acid soils was due to their low cation requirements. They found as a rule most acid soils were low in exchangeable cations, and the blueberry absorbed excessive quantities of anions other than the

phosphate. They also theorized that Fe deficiency might result in the plant if available Fe in the reduced form were oxidized by the anions. Bailey et al (7) in their investigations observed similar trends which indicated further that foliar levels of P, K, Ca, and Mg were lower in blueberry than in most fruit crops.

Using Rubel highbush blueberry plants, Doelhert and Shive (25) demonstrated that optimum growth was obtained from treatments high in N and low in K. A drop in the pH of these nutrient solutions also indicated that the ammonium ion was taken up more than the nitrate ion. This trend was observed more at higher pH levels. Cain (11) also suggested that ammonium sulphate gave better results in soils above pH 5.5. Willis and Carreo (45) produced chlorosis in rice with several forms of nitrate N. They suggested that an unassimilable ion caused precipitation of Fe within the plant resulting in chlorosis.

In experiments conducted by Cain (11), varying Ca content in the nutrient solution, typical Fe deficiency symptoms in high Ca treatments were obtained where the source of N was calcium nitrate. It was also found that as Ca in the foliage increased, N, P, Mg and Fe decreased. From these studies he made the following generalizations:

1. The supply of ammonium N determined the ultimate levels of foliar N and Fe.
2. Plants which were chlorotic at high Ca levels, had a high Fe content.

3. Iron deficiency symptoms were not necessarily related to soil pH, Ca content or Fe content in the foliage, since healthy plants had more Ca and less Fe than those showing acute chlorosis.

The experiments of Cain (11) were conducted at pH 5.5 and it was apparent that ammonium N was influencing both Fe metabolism and growth. In later experiments Cain (13) showed that Fe deficiency symptoms were closely linked with the pH of the leaf tissue. Neutralization of free organic acids would mark the point at which these symptoms appear. Considerable speculation as to the role of the free basic amino acid arginine arose from this work. At the point where deficiency symptoms appeared, the level of arginine increased with a corresponding decrease in protein N. This indicated a very close relationship between N, Fe, and leaf pH.

A chlorotic condition that appeared in the midsummer of 1966 in most blueberry fields in the lower mainland of British Columbia was similar to that described by Bailey (4). These symptoms were more evident in heavy bearing plantings. Iljin (32) found similar trends and in addition he noticed that the chlorotic condition was associated with a higher content of organic acids. Cain (13) also found that a higher soil pH induced a greater uptake of basic cations. These findings resulted in more organic acids getting neutralized, giving the higher leaf pH values he observed. He further found a large proportion of citrate in chlorotic leaves. These conditions would decrease the solubility of Fe and inactivate the enzymes that depend on Fe as a co-factor.

It would thus appear that organic acid metabolism, N metabolism and chlorophyll synthesis are closely related to the Fe dependent enzyme action as suggested by Cain. Oertli (40) also reported similar interdependent relationships between N metabolism and soil pH in connection with the role of Fe in the plant. Bailey and Everson (6) demonstrated chlorotic symptoms, and possibly Fe deficiency by adding rates of lime ranging from 5-40 grams per crock. After nearly 14 months the pH values ranged from 4.2 to 6.4. This experiment was apparently done with mineral soil.

By varying growth media and pH, Hall et al (29) showed that the lowbush blueberry, like the highbush varieties, grows best in a range of pH 4 to pH 5. Although Bailey (5) pointed out that the addition of peat partially alleviated the effect of lime induced chlorosis, Hall et al (29) failed to show this effect by an interaction of pH with media. There was, however, a high negative correlation between stem length and soil pH, a condition which could not be shown under field conditions.

Since pH values of peats in British Columbia are much lower than the optimum range reported in the above investigations, the effect of different rates of liming on the growth of the highbush blueberry grown on low pH peat soils, needs further study. Although it has not been conclusively established, it was observed during the preliminary survey of 1965 that plantings which were receiving regular lime applications appeared to have better growth. Some growers also claimed that plots regularly limed tended to give

higher yields. Soil pH levels in such mature plantings were slightly higher than in newly established fields.

B. Source of Nitrogen

The effect of nitrate and ammonium N have been studied in a series of experiments by Colgrove and Roberts (18) on the growth and development of chlorosis in the Azalea, which like the highbush blueberry,is also a member of the family Ericaceae. Citing the findings of Cain (11) on the preferential uptake of ammonium N and its influence on Fe metabolism in the blueberry, they worked on chlorosis by making a comparative study of ammonium and nitrate N under different environmental conditions, of light intensity and pH in the presence and absence of chloride and sulphate ions in the nutrient solution. These experiments they conducted were in sand culture. Their findings demonstrated an antagonism of ammonium ions with basic cations, a greater uptake of the former reducing uptake of the latter. This brought about a reduction of plant tissue pH. Nitrate on the other hand increased base absorption, and Fe was "inactivated" in the plant as a result of the higher tissue pH. An influence of nitrate on absorption of bases like Ca, Mg, and K has also been demonstrated by Sideris and Young, in pineapple (43), and by Holley, Pickett and Dulen (31), in cotton.

From the diverse studies cited it appears that close relationships may exist between soil pH, form of N desired and common symptoms like chlorosis. It is imperative to clarify the combination of ammonium and nitrate N with differing soil reactions and amounts of N that would

give the most favourable response.

C. Soil Aeration

In most areas on the lower mainland where the highbush blueberry is grown, peat soils are often poorly drained. The water table remains a few inches from the surface during a greater part of the autumn, winter and spring. At times flooding may occur in prolonged wet weather. Even though many farms are drained, rain water percolates very slowly in peat, with the result that fields remain flooded long enough to cause adverse conditions in the root zone. If plants grow under these conditions for too long, the blueberry develops a matty root system on the surface and around the collar, thus raising above the fluctuating water table. This phenomenon is popularly called "hilling" by growers.[1] By this unique adaptation it appears that older plants are able to survive even if the deeper roots are subject to a low redox potential brought about by poor aeration, if complete inundation does not cause irreparable damage. There is no doubt, however, that growth can be retarded under such conditions (14). In mineral soils, Kender and Brightwell (35) have reported that poorly drained conditions have detrimental effects on blueberry plant growth. The highbush blueberry does not tolerate standing water for long periods during the growing season. Building of mounds and ridges on lowland soils has been a common practice to promote root growth above the reach

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[1] Eaton, G.W., and H.M.E. Herath, Unpublished survey of leaf nutrient status in highbush blueberry plantings in British Columbia 1966.

of the water table. Waterlogged plants on mineral soils were found to be less productive than plants in well-drained locations. The slow growth and occasional death of newly set plants in locations frequently subjected to waterlogging, could well be due to the inability to generate sufficient roots near the surface. The high water retentive capacity of peat may also create a situation where air spaces are displaced by water. Peat can retain as much as twenty times its weight in water.

The root system of the highbush blueberry is devoid of root hairs (19). This may be an ecological adaptation. The much branched and fine root system is in intimate contact with the soil solution and the need for a specialized absorbing region becomes redundant. No studies have so far been carried out to determine the extent to which highbush blueberry plants can stand excess water in peat without seriously affecting normal physiological processes and depressing growth.

D. Leaf Analysis as a Diagnostic Tool in Blueberry Fertilizer Programs

Many techniques are available today for the study of plant nutrition in agricultural research. The use of a specific organ or tissue warrants justification.

Leaf analysis has been successfully used in fertilizer programs for perennial crops as a supplement to the more conventional technique of soil analysis (9, 42). It helps in studying more closely the nutrient requirements of plants in relation to higher yields and quality production. Evaluation of the nutrient requirements of a crop is based on the assumption that the leaf acts as an indicator tissue and reflects

the utilization of essential elements at any time during the life of the plant((42).

There are various reasons for selecting the leaf as an indicator tissue. Primarily the leaf acts as the site for the synthesis of raw materials out of which various plant tissues are composed. Although other tissues in the plant may be suitable for detecting a nutritional disorder, the leaf tissue has been widely used due to its accessibility, sensitivity (for most elements), and homogeneity. For physiological and practical considerations, the leaf tissue has therefore been accepted as the most convenient plant organ to study nutritional disorders. Variability in sampling can also be minimized if morphologically homologous tissue of comparable physiological maturity is used for analysis (42).

The level of nutrients in the leaf, as in most tissues of the plant, appears to have a high correlation with metabolic indices such as growth and yield. The sensitivity of the leaf is such that when the vigour of the plant is impaired by any abnormality in the nutrient or physical environment, it registers a characteristic symptom. In the field, however, difficulties arise in diagnosing certain symptoms due to the multiplicity of factors that interact and affect growth. It is at this stage that leaf analysis proves valuable as a diagnostic tool in detecting hidden or latent symptoms that cannot be found out by soil analysis. A soil test is still the primary means by which fertilizer requirements are determined for crops (42). The method of soil analysis if used as the sole means of diagnosis has its drawbacks too. The availability of

soil nutrients or the extent to which a perennial fruit crop could derive from a soil various nutrients at different depths cannot be accurately estimated from a conventional soil test. Since the ultimate effect is on the plant, nutritional disorders may go undetected in a soil test which could easily be found by tissue analysis. It could also be beneficial in assessing responses to a fertilizer or differentiating a mineral deficiency symptom caused by a nutrient disorder from that of a non-nutrient cause (9).

The leaf analysis technique has been effectively used to establish fertilizer programs for the highbush blueberry in other areas on the North American continent. Table I gives the consolidated data obtained by various workers. The results of a sampling survey conducted in the lower Fraser Valley of British Columbia in 1965 have also been included for comparison.[1] Median shoot leaves and basal leaves from shoots subtending a fruit cluster were sampled from two varieties during the months of August and September. The results of this survey for the varieties Dixi and Rancocas, and also for the variety Bluecrop from the work of 1966, included in Table I comprise the grand mean for each element from the statistical analysis.

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[1] Eaton, G.W., and H.M.E. Herath, Unpublished survey of leaf nutrient status in commercial highbush blueberry plantings in British Columbia 1966.

Table I. Foliar Mineral Element levels of Highbush Blueberry varieties[1]

Source	Variety	% N	% P	% K	% Ca	% Mg	Fe ppm
Bailey et al	Rubel	1.9-2.0	0.13-0.18	0.53-0.68	0.2-0.4	0.12-0.22	---
Mikkelsen et al	Jersey	---	0.18-0.32	0.40-0.87	0.3-0.5	0.14-0.21	60-84
Mikkelsen et al	Jersey	---	0.28-0.32	1.2	0.2-0.3	0.14-0.19	70-
Mikkelsen et al	Jersey	---	0.26-0.27	0.80-1.2	0.18-0.3	0.22-0.24	60-70
Ballinger et al	---	2.0-	0.16	0.53	0.74	0.28	150
Ballinger et al	---	1.5	0.07	0.40	0.30	0.09	60
Tukey et al	---	2.2	0.22	0.74	0.47	0.24	290
Popenoe	Rancocas	---	0.14-0.18	0.42-0.56	0.2-0.3	0.09-0.25	---
Cain	Jersey	1.9-2.6	0.11-0.16	1.2-1.8	0.4-1.2	0.10-0.15	72-170
Cain	Rubel	1.8-2.4	0.07-0.09	0.43-0.78	0.5-0.7	0.13-0.17	60-85
Cain	Rubel	1.1-1.2	0.04-0.07	0.61-0.97	0.33-0.6	0.09-0.24	67-144
Cain	Rubel	1.4-2.3	0.07-0.09	0.37-0.43	0.5-0.7	0.03-0.08	---
Eaton and Herath[2]	Rancocas	1.36	0.09	0.34	0.28		61
Eaton and Herath[2]	Dixi	1.57	0.09	0.43	0.31		65
Eaton and Herath[2]	Bluecrop	1.56	0.09	0.28	0.21	0.43	95
Estimated deficiency	All	1.8	0.07	0.40	0.30	0.08	60

[1] Information obtained from Childers' Fruit Nutrition cited by Cain and Eck (14)

[2] Unpublished.

III. MATERIALS AND METHODS

The plant materials used in this experiment were one year old rooted cuttings of the Bluecrop variety of highbush blueberry obtained from a commercial nursery. The rooted cuttings were selected from a large population for uniformity of size of top and root system. As far as possible roots were washed clean of extraneous matter and the tops of plants consisted of a single stem with two to three short side shoots. The Bluecrop variety was selected for these studies due to its increasing popularity as a mid-season variety in British Columbia as well as elsewhere. Summer growth had already commenced when the plants were set in the greenhouse.

Peat for the growth medium was obtained from the Northern Peat Company, Richmond, British Columbia. The pH of the peat before adjustment varied from pH 3.0 to pH 3.5. In order to ascertain the amount of hydrated lime required to adjust pH to predetermined levels, weighed quantities of the peat were incubated with known amounts of lime. The wet peat thus treated was gently agitated for seventy two hours in a mechanical shaker and the pH recorded. At the end of one week the readings were taken again and the resultant values were plotted against amounts of lime added, and this buffer curve was used to estimate the required amounts of lime to adjust the pH to three levels above the original level of 3.4. Although it was the intention to adjust levels increasing by one unit, the ultimate values obtained were close to 3.4, 4.3, 5.2, and 6.0.

Eight-inch glazed crocks with drainage holes in the side were prepared in the following manner. Treatments receiving a high water

table were sealed with tight fitting rubber stoppers through which a bent glass "sight tube" was inserted to serve as an indicator of the water table in the crock. With this device it was possible to regulate the water table in the crock to any desired level along the height of the peat column and create artificially the conditions of a waterlogged soil.

Two blocks in the experiment received this treatment. The other two blocks were maintained under free drained conditions giving ample water to keep the peat moist all the time. These four blocks were randomized on two greenhouse benches. Each block comprised 28 crocks with seven treatments at each pH level. The seven treatments were as follows. Three levels equivalent to 20, 40, and 60 lbs. N per acre were given in the form of ammonium sulphate and sodium nitrate. In addition to these six treatments an unfertilized check was included for each pH level. Treatments were randomized within each block. The degrees of freedom for the analysis of variance for growth measurements and chemical analysis of foliage are presented in Table 2. Randomization within blocks was changed periodically to evenly distribute bias due to position.

Plants were set three weeks after liming. The fertilizer treatments were given when the plants were well established. The water level treatments were maintained throughout the growing season. The two blocks receiving the high water table treatment had water three inches from the surface. Over-irrigation of the treatments maintained

Table 2. Analysis of variance for growth records and chemical analysis

Shoot Length		Shoot Number		Leaf Number		Leaf Area		Flower Clusters CL/Pl		Flower Clusters FL/CL		Chemical Analysis Single Date		Chemical Analysis Combined Date	
Source	df	Source	df	Source	df	Source	df	Source	df	Source	df	Source	df	Source	df
W	1	W	1	W	1	W	1	W	1	W	1	W	1	W	1
B/W	2	B/W	2	B/W	2	B/W	2	B/W	2	B/W	2	pH-W	3	pH-W	3
pH	3	pH	3	pH	3	pH	3	pH	3	pH	3	Tr	6	Tr	6
pH-W	3	pH-W	3	pH-W	3	pH-W	3	pH-W	3	pH-W	3	pH-Tr	18	pH-Tr	18
Tr	6	Tr	6	Tr	6	Tr	6	Tr	6	Tr	6	Error	139	Error(A)	27
Tr-W	6	Tr-W	6	Tr-W	6	Tr-W	6	Tr-W	6	Tr-W	6			Date	2
Tr-pH	18	Tr-pH	18	Tr-pH	18	Tr-pH	18	Tr-pH	18	Tr-pH	18			D-pH	6
Tr-pH-W	18	Tr-pH-W	18	Tr-pH-W	18	Tr-pH-W	18	Tr-pH-W	18	Tr-pH-W	18			D-Tr	12
Error	54	Error	54	Error	54	Error	54	Residual Error	154 336	Residual Error	154 112			Error(B)	56
TOTAL	111	TOTAL	111	TOTAL	111	TOTAL	111	TOTAL	447	TOTAL	223	TOTAL	167	TOTAL	167

W - water B/W - Blocks within water table Tr - Treatment D - Date

under free drained conditions was avoided to minimize leaching of N fertilizer from the crocks.

A month after application of fertilizer, the first leaf samples were taken. As in field experiments, leaves were sampled from the mid-shoot region. In order to minimize the effect of leaf removal, only about four leaves were removed from each crock. Subsequent samplings carried out at monthly intervals were obtained in similar fashion using leaves of comparable physiological age to reduce leaf variability due to leaf age differences. Leaf disc sampling which is at times followed in greenhouse experiments of this nature in which leaf removal may set back growth, was not found necessary here as there were sufficient leaves per plant, after removal of these few leaves for mineral analysis,for normal growth. A composite sample from the two blocks of each treatment was used for chemical analysis. Since the experiment commenced in July the three sampling dates were in August, September and October. Growth continued into the end of November when artificial heating in the greenhouse was discontinued to allow plants to winter properly. No casualties were observed during the course of the experiment, although severe stunting and lesions occurred due to certain treatments. Light intensity appeared to be sufficient in the greenhouse although slightly higher day temperatures accelerated growth considerably in comparison with field grown plants. During the day the mean maximum temperature was always a few degrees higher in the greenhouse than outside.

Growth records were taken at the end of the growing season. The records included total leaf number, mean leaf area, shoot number and total shoot length. Flowering records were taken in the spring of 1967. Soil pH readings were recorded periodically during the growing season.

A. Leaf Area Measurements

Mean leaf area was measured by selecting the first four mature leaves in the terminal region of a shoot on each plant. Shoots were selected at random. The method for the estimation of leaf area was as follows: In order to obtain the closest correlation of a linear measurement to actual leaf area, a regression equation was derived. A sample of forty leaves were sampled at random ranging from the smallest to the largest. Ozalid paper was then used to obtain leaf impressions. The greatest length and width of each leaf was then measured after which the paper impressions were weighed and leaf area calculated. Regression of these measurements in all possible combinations with actual area was carried out. The best correlation (r-0,999) was obtained between area and the product of length X width. The linear relationship obtained is presented in Figure 1 and Table 3 and indicates a stronger association than any reported by Ackley et al (1) or by Jain and Misra (33) on Ricinus communis. The linear measurements and the regression coefficient for the actual area was calculated from leaf samples of the experiment.

B. Chemical Analysis

The leaf samples were subjected to chemical analysis. Total N was analysed by the semi-micro kjeldahl procedure, P was determined

Fig. 1 REGRESSION OF LEAF AREA ON LINEAR MEASUREMENTS IN HIGHBUSH BLUEBERRY 1966

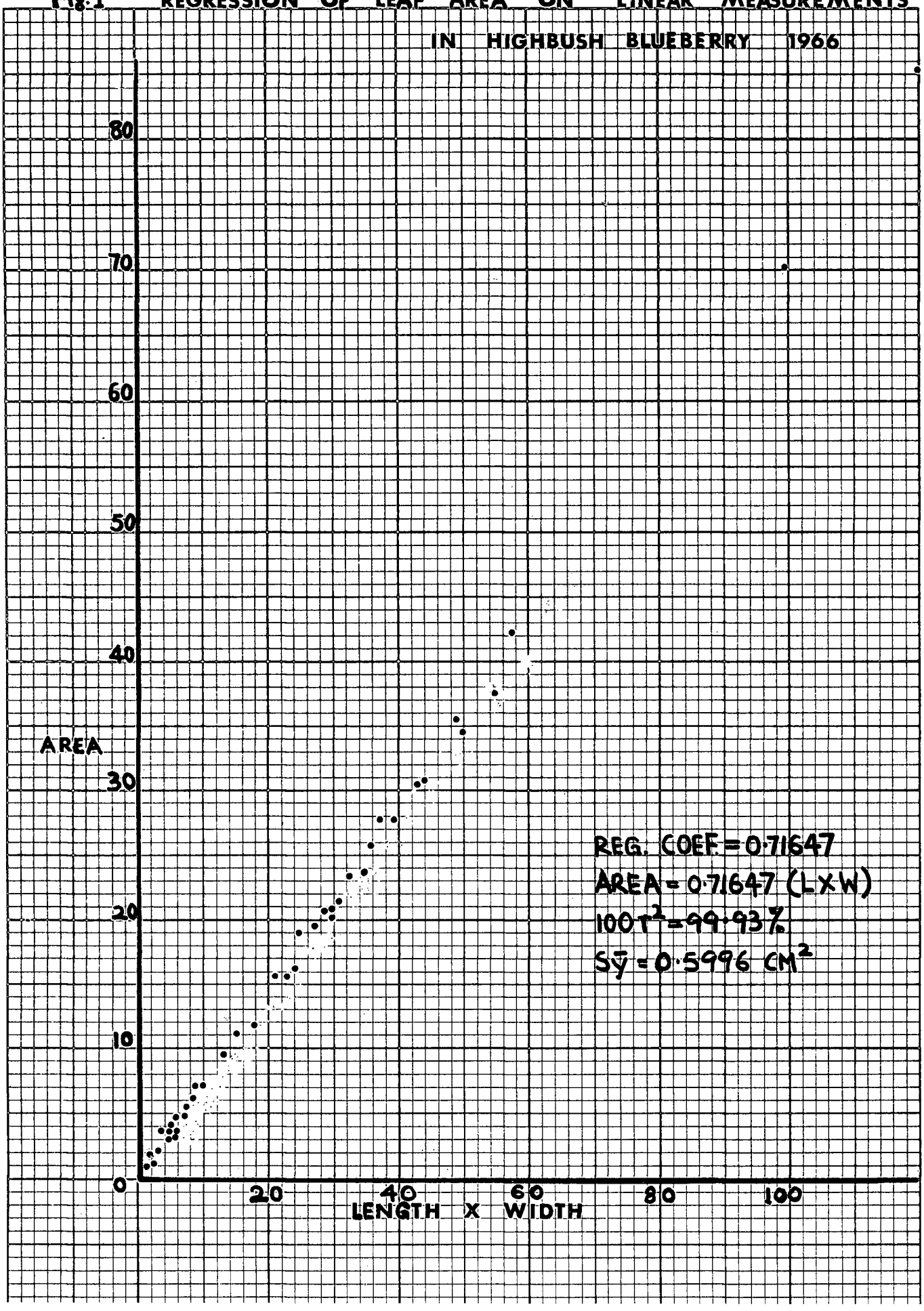

Table 3. Correlation coefficients for matrix involving leaf linear measurements and leaf area.

	Length	Width	Length X Width	Length/Width
Area	0.9495	0.9766	0.9991	-0.1675
Length	--	0.9794	0.9775	0.0164
Width	--	--	0.9503	-0.1587
Length X Width	--	--	--	-0.1675

colorimetrically by the phospho-molybdate method of Dickman and Bray (22). Atomic absorption spectrophotometry was used for the determination of Ca, Mg, and Fe. Using the same instrument (Model 140 EEL Atomic Absorption spectrophotometer) with an emmission adaptor, K was analysed by flame emmission.

1. Method of Preparation of Samples for Mineral Analysis

The wet digestion method of Chapman and Pratt (16) was used for the preparation of the mineral extracts. When leaf samples were brought in from the field, they were immediately placed in a 70°C forced air oven for a minimum of 72 hours. Before grinding they were transferred to a 105°C oven for seven hours. A porcelain mortar grinder was then used for grinding the samples until they were fine enough to pass a 20 mesh seive. Approximate grinding time for each sample was seven minutes. No metal contamination occurred as no moving parts inside this grinder are made of any metal that might con-

taminate the samples. The dried and ground samples were then stored in glass containers and placed in desiccators until the mineral extracts were made. Since the drying technique used was thorough, no attempt was made to make additional corrections for moisture. From the results of the work done in 1965 it was apparent that this technique was very reliable.[1] No duplicate determinations were carried out on any of the 1966-1967 samples because the duplicate determinations done in the previous year agreed within one percent error, and because only the means of observations were of interest.

From the tissue samples thus prepared, close to one gram of sample was weighed for wet digestion. A digestion mixture consisting of nitric, sulphuric and perchloric acids in the ratio of 750 ml. concentrated nitric acid, 150 ml. of concentrated sulphuric acid and 300 ml. of 60% perchloric acid was prepared according to the method described by Chapman and Pratt (16) and 10 ml. of this mixture was added to each sample of tissue. This was heated gently for a few minutes and the temperature raised until the fumes of nitrogen dioxide first disappeared, followed by perchloric and sulphuric acids. Taking care not to allow complete drying, the solution volume was reduced to about 2-5 ml. (P would

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[1] Eaton, G.W., and H.M.E. Herath, Unpublished survey of leaf nutrient status in commercial highbush blueberry plantings in British Columbia 1966.

be lost if taken to complete dryness). After digestion was complete, hot distilled water was added to the beaker and the extract filtered through acid washed filter paper into a volumetric flask. The filter paper was washed with more hot distilled water to ensure the removal of all the extract and the solution was made to 100 ml. volume with distilled water. All the acids used in the extraction procedure were redistilled from a glass still, since minor elements were to be analysed. The extracts thus prepared were transferred to "Nalgene" containers, using aliquots of this when required for various determinations.

2. Analytical methods

Atomic absorption spectrophotometry

Analyses for Ca, Mg, and Fe were done by Atomic absorption. The Atomic absorption method uses the "ground state" atoms which do not acquire sufficient energy from the burner flame to emit light. Since there is a greater proportion of these so-called "ground state" atoms the absorption technique is more sensitive and accurate than emission spectrophotometry, especially for metals occurring in minute quantities as in extracts of plants. The absorption of light at the specific "resonance" wavelength for each metal is proportional to its concentration in the sample solution. A monochromator wavelength selector is used in combination with a hollow cathode source lamp to generate the 'resonance' wavelength for each element to be determined (27). Zero absorbance is obtained when the light source of hollow cathode lamp passes unobstructed through the monochromator from where an electrical signal equivalent to the amount of absorption is amplified by the photomultiplier. When a sample is introduced the meter reading drops corres-

ponding to the amount of light absorbed. The advantage in this method lies in the fact that sensitivity could be increased or decreased depending on the range in which a particular element occurs in a sample. If the sample concentration is too low, special organic solvents or extraction methods could be used. If the range of standards selected shows a linear relationship with absorbance, any unknown sample could be directly read off by comparison with the curve obtained from the standards, provided the sample concentration falls within the range of standards used. If the relationship is not linear, a log transformation facilitates accurate reading.

Instrumental parameters

When the Atomic absorption method was used various instrumental parameters were considered, including the following:

1. Finding the optimum analytical absorption line for each element analysed.
2. Best slit width for the monochromator.
3. Optimum lamp current for the hollow cathode lamp.
4. Various optimum flame parameters depending on whether absorption is best in a high or low flame or whether it gives maximum absorption in an oxidizing or reducing flame. The sensitivity of the instrument can thus be adjusted by controlling fuel supply to alter flame height and quality. Other parameters such as the rate of sample uptake and range of absorption were given due consideration as per methods described by A.O.A.C. techniques on atomic absorption spectro-

photometry for minor element determinations (2). The facility provided for burner rotation afforded additional flexibility in the use of the instrument.

No serious interferences were observed during the analysis of any of the elements to justify the use of alternate methods. There were no interferences from phosphate or sulphate when Mg was analysed. Even for Ca the phosphate interference at 40 ppm was negligible. Discernible interference was only shown at lower concentrations around 10 ppm. Since most of the samples had values above 30 ppm, La or Sr were not used in the standards or samples.

An Evans Electroselenium Ltd. atomic absorption spectrophotometer model 140 was used with a Texas Instruments Servo recorder model PSO1WGA. A distinct advantage in the use of such an arrangement was the greater speed at which samples could be analysed. The chart also made it easy to check with the standards periodically in order to see whether the instrument was steady throughout the run. All readings were corrected from the readings obtained from the blanks. At approximately every 50th sample, sets of standards were taken for the computation of a least squares fitted curve.

Standards as well as samples were run only after the instrument stabilized without any baseline drift. This usually occurs due to poor adjustment of the monochromator, a block in the atomizer or when the hollow cathode lamp has not been conditioned enough. (Figure 2). Although it is claimed by the manufacturers that the lamp has to be heated for only 30 minutes it was found necessary to heat it for a minimum of three hours prior to use. When Ca was being analysed, the

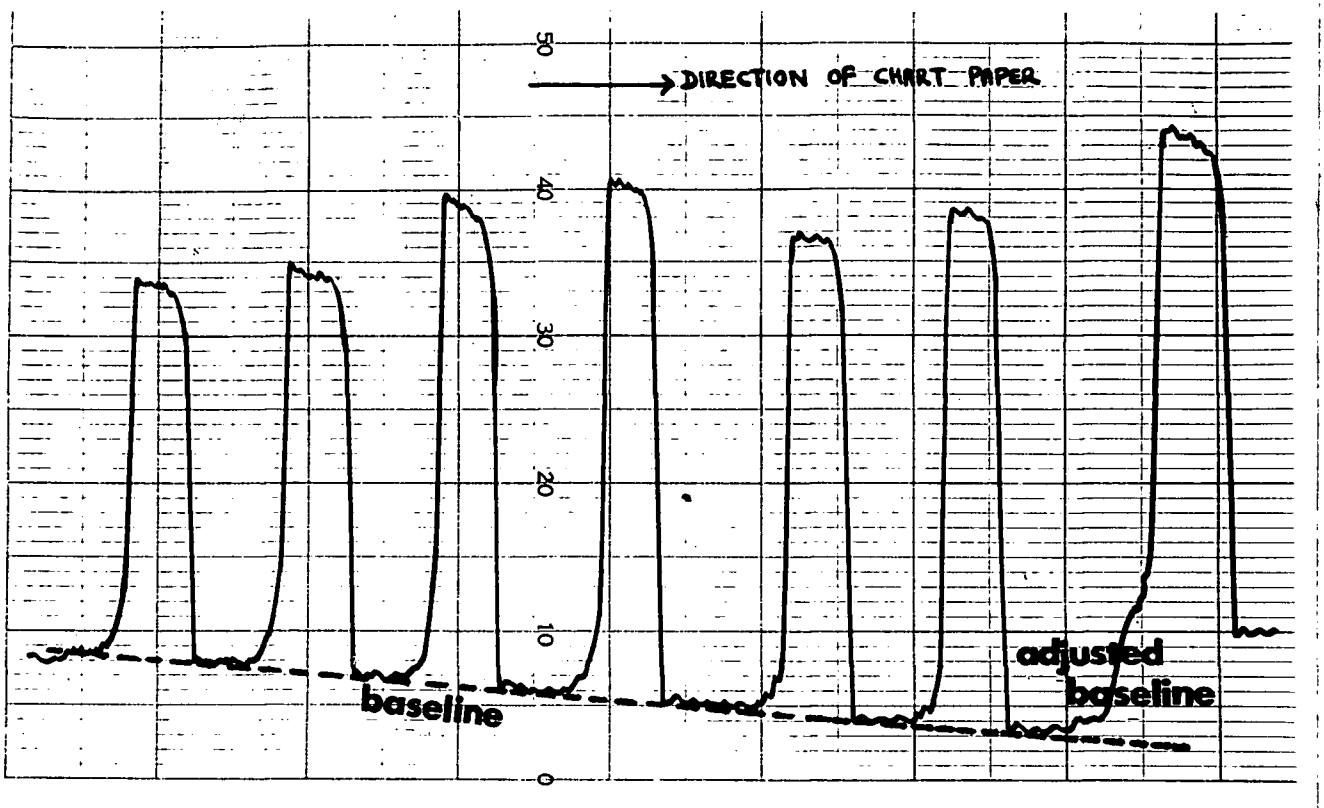

Fig2 DRIFTING BASELINE DUE TO INSUFFICIENT CATHODE LAMP CONDITIONING

burner was rotated to give the desired sensitivity and range since higher concentrations were present in the samples. Since the resolution was poor at high concentrations the range selected for Mg was from 0.5 up to 6 ppm. Therefore all samples were diluted 2500 times before they were used on the instrument.

Interpretation of Data from Chart

Sets of readings for standards and for the elements Ca, Mg, and Fe as read on chart paper are shown in Figures 3-5. It was observed from these charts that the absorbance lines for a particular sample could easily be read with the minimum of error if the baseline is steady. During the course of a run, a little solid impurity in the samples could block the atomizer assembly. This would result in a jagged line at the base as well as at the peak (Figure 6). As soon as this was observed, the atomizer unit was cleaned by inserting a tiny wire through the aspirator. The atomizer could also be cleaned by boiling the unit in water. This was usually carried out as a routine preventive measure at the end of the day when the instrument has been used for a long time. To cite an example to justify this procedure, it was found that the Ca in the samples even at low dilution of 1 in 100 caused a white encrustation of calcium carbonate all along the aspirator assembly if the instrument had been used for a few days without proper cleaning. A better cleaning procedure was to dip the atomizer for about five minutes in a very weak solution of hydrochloric acid and subsequently boiled in water for at least ten minutes. In this way the atomizer can be cleaned and kept ready for the next run.

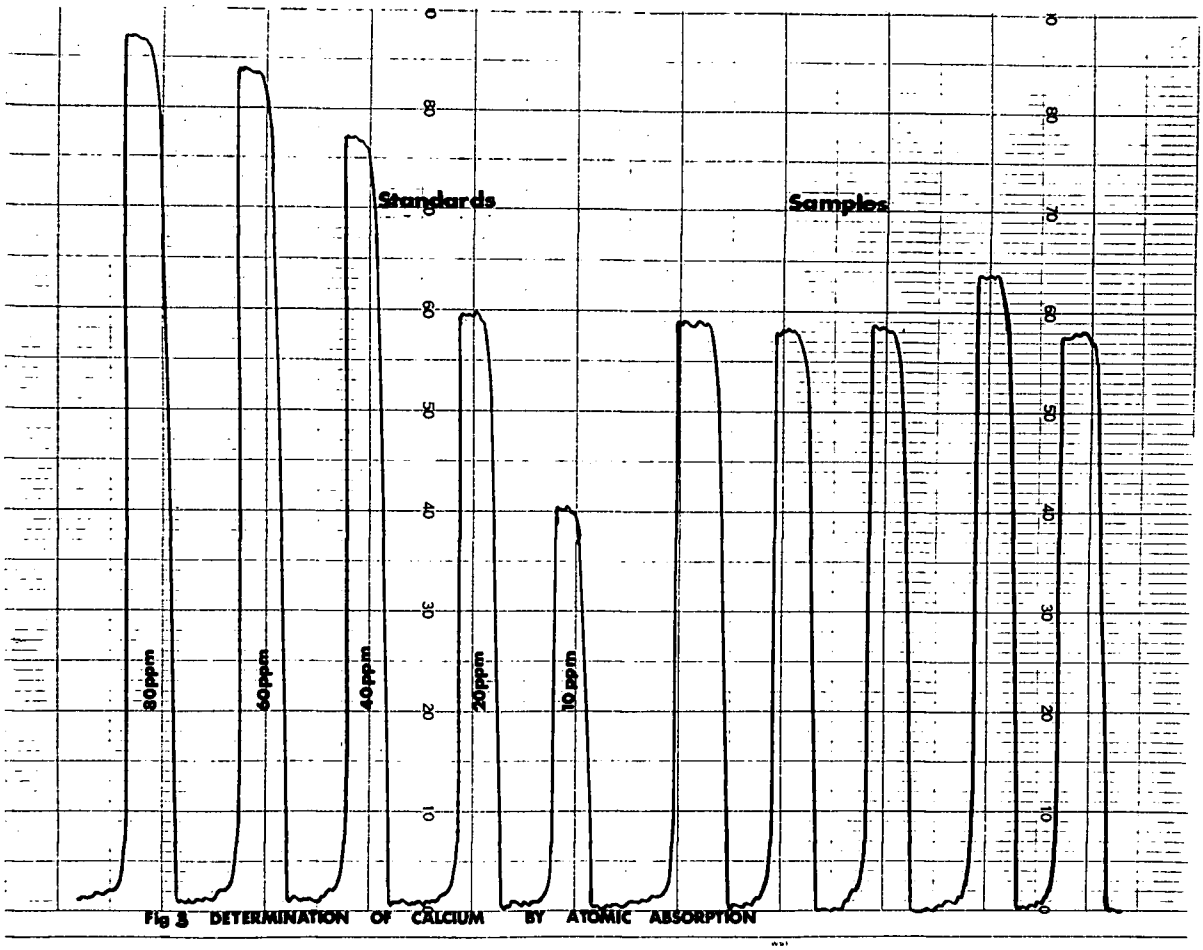

Fig 3 DETERMINATION OF CALCIUM BY ATOMIC ABSORPTION

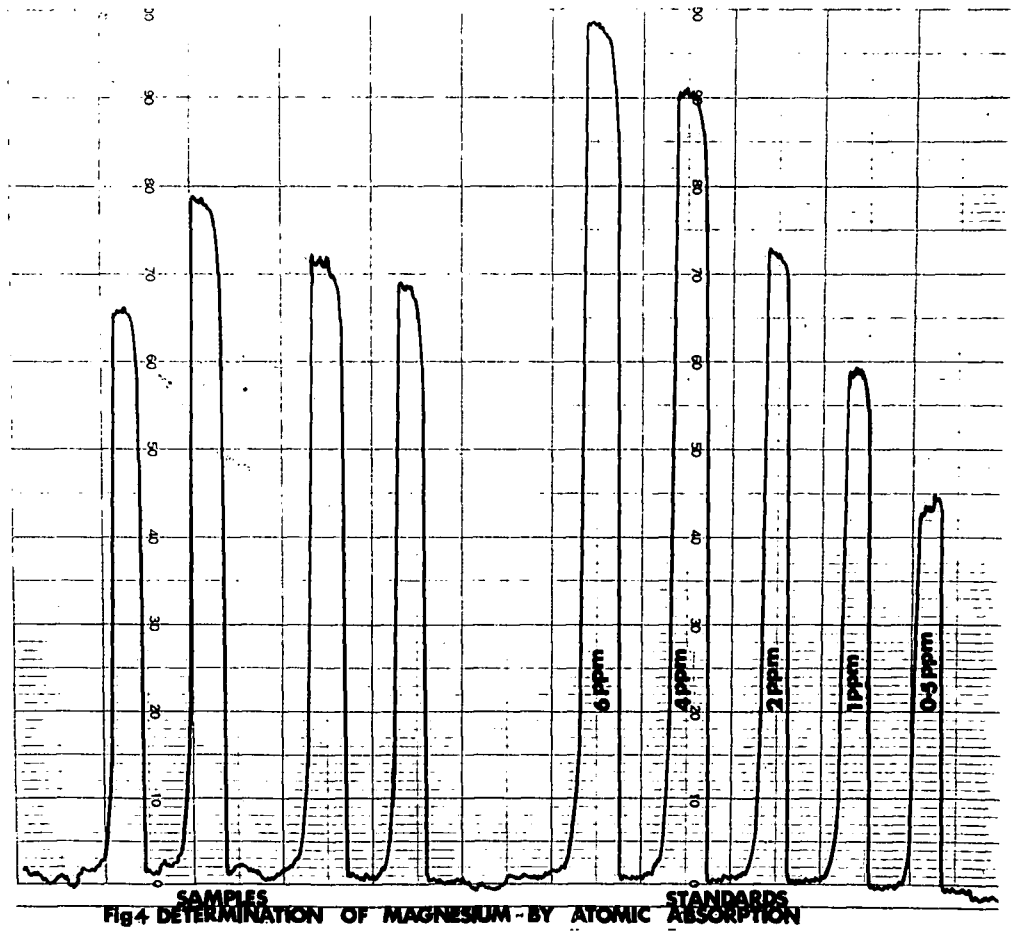

Fig 4 DETERMINATION OF MAGNESIUM - BY ATOMIC ABSORPTION

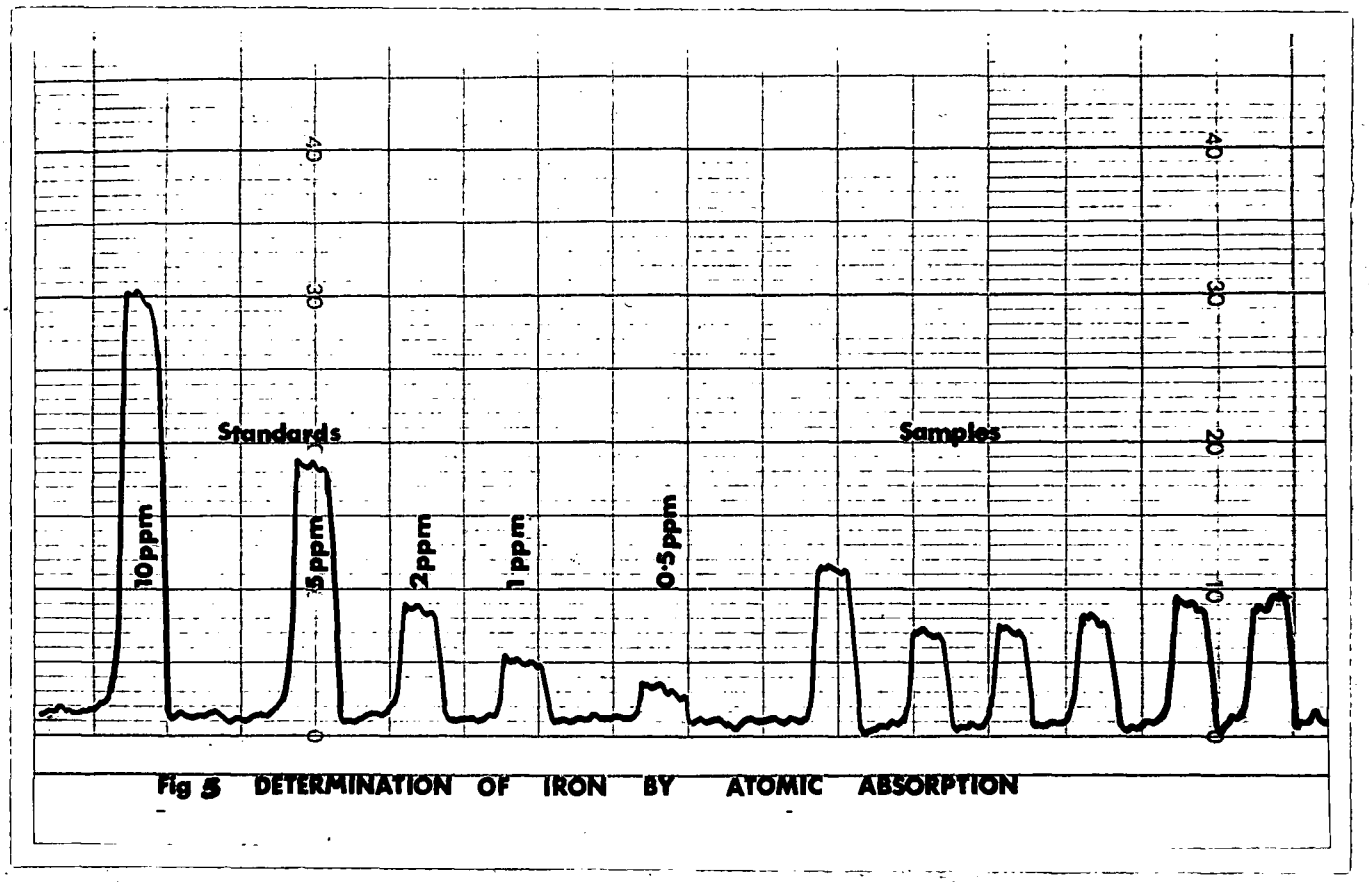

Fig 5 DETERMINATION OF IRON BY ATOMIC ABSORPTION

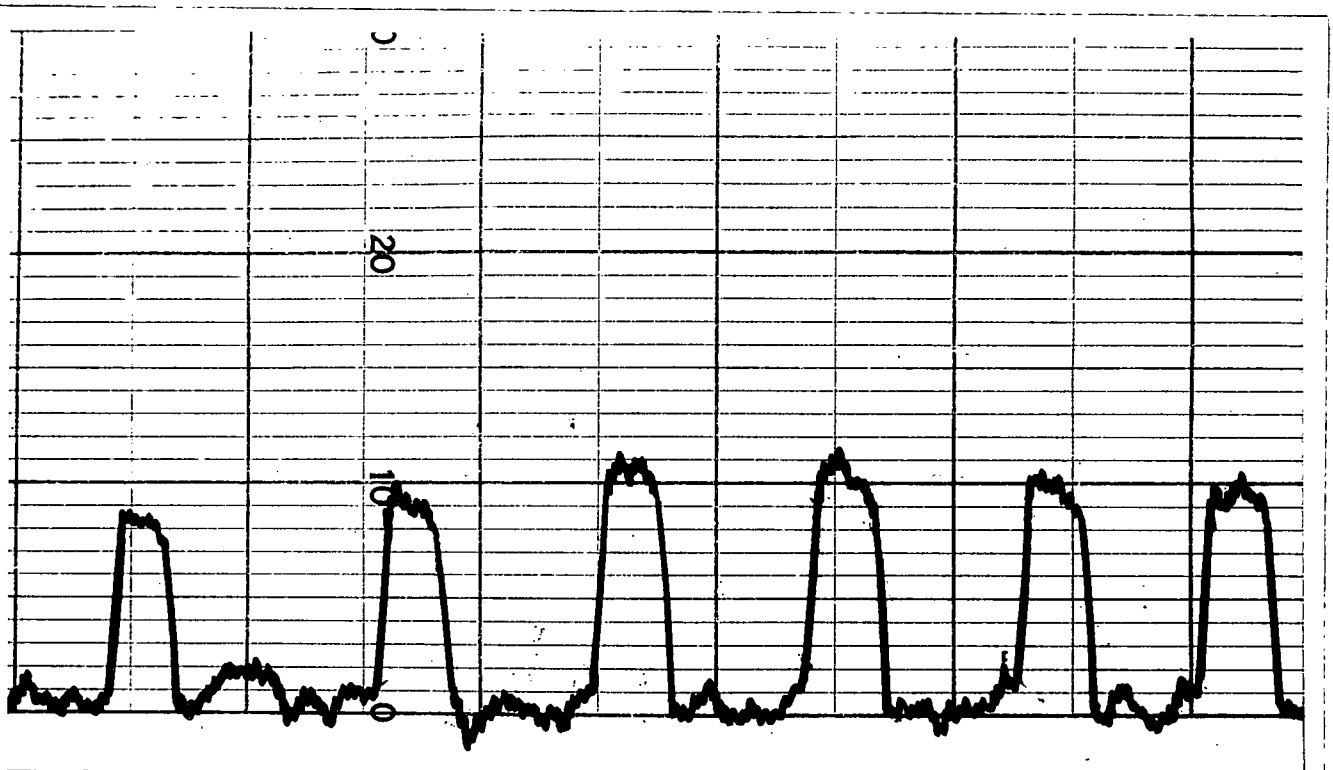

Fig 6 LINES SHOWING CONDITION OF A BLOCKED ASPIRATOR

A poorly functioning atomizer would give a lesser reading due to smaller amounts atomizing into the flame. In general about 10% of the spray from the atomizer passes through the expansion chamber in the form of minute droplets that finally vaporize into the flame. The larger droplets collect at the bottom of the expansion chamber and leave via the water trap outlet. The rate of atomization and the physical properties of the sample to be aspirated play a vital role in the production of maximum efficiency in absorption. From preliminary runs it was apparent that the diluted extract showed no P interference at the range in which Ca determinations were made. The same effect could be obtained by the use of an efficient atomizer. The size of droplets is dependent on the fineness of the spray given out by the atomizer. In the case of interference by compounds such as calcium phosphate, if there is a greater production of droplets that vaporize sufficient Ca atoms into the flame the effect of interference is considerably diminished. According to Elwell and Gidley (27) the exact mechanism of interference and suppression is not fully understood although the use of many organic solvents or the addition of chlorides of Sr, La, Fe, and Sc have been tried out with some degree of success. The fact remains however, that a simple adjustment and the proper care and use of a fine atomizer unit in the aspirator assembly would give ample signal strength for routine plant analysis work.

The reliability of the method of atomic absorption has been verified and the fact that results are reproducible when the same

instrumental parameters are employed lends support for its use in plant analysis work. Chart data for standards of the work done in 1966 and 1967 agreed very closely when the adjustment for each element was carried out in the same manner.

Finally, the causes of interference affecting both absorption and emission are summarized below as given by Elwell and Gidley (27).

1. The effect of different physical characteristics of solutions on atomizer efficiency.
2. Closely linked to the above condition the differential rates of vaporization due to variability of solutions used. Both these are influenced by the viscosity of the solution and its ability to form droplets easily.
3. The proportion of atomized solution that enters the flame to be separated into excited or ionized atoms and ground state atoms would largely depend on the flame characteristics.

The interferences mentioned above are practical aspects of atomic absorption spectrophotometry one has to consider when this method is employed for plant analysis work. If the same set of conditions are given when an element is analysed a number of times, the results thus obtained are comparable. During the course of the present investigations all instrument parameters were kept as uniform as it was practically possible.

Each peak on the chart as seen in the Figures 3-5 represents the concentration of the element being analysed for a particular sample. The height of this line is measured from the base to

the widest portion of the peak. Little specks of suspended particles in the samples temporarily blocking the atomizer would at times tend to increase and decrease signals momentarily, resulting in a jagged peak. Figure 7 demonstrates the way to measure the base and peak of any given absorption line. Since the variability in measurements from chart data can easily reduce the efficiency of an experiment, a uniform technique of reading chart data was found necessary. In the case of elements like Fe where the peaks are small and differences between samples are harder to detect, a slight error in reading may well exceed the magnitude of the residual standard deviation for that set of data.

Measurement of these lines were either taken in inches or by counting the number of lines that span across the chart paper. These values were utilized in two ways for statistical analysis. Originally the values for the standard curves were calculated manually for a least squares fit, and the standard curve thus obtained was used to interpolate the sample values after they were corrected for the blank readings. This method was later streamlined by punching the readings for the standards as well as for the samples directly on computer data cards. The concentration of each sample was then calculated on the computer using the preliminary data deck, and a modified fortran linear regression program.

C. Statistical Analysis

Analysis of variance was carried out on all the data collected. The subdivisions of degrees of freedom for the various

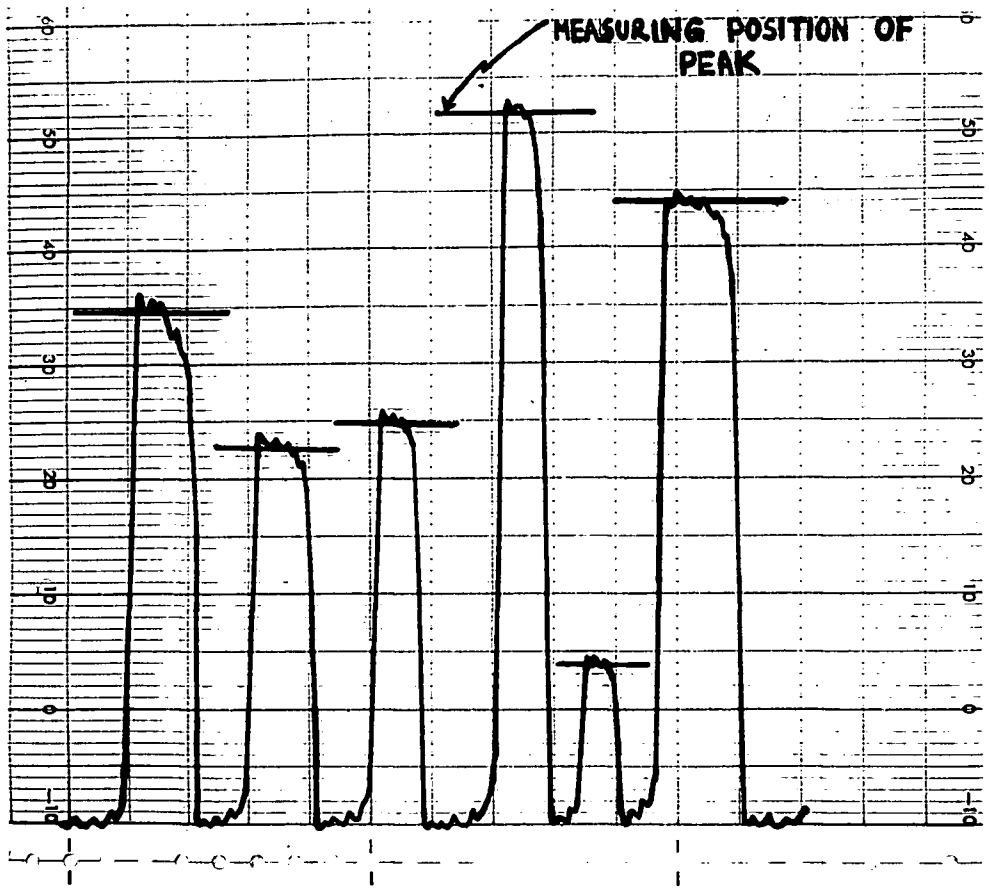

Fig.7 METHOD OF MEASURING SAMPLE CONCENTRATIONS

analyses are presented in Table 2. Significance of differences among means were tested by Duncan's New Multiple range test as described by Li (38). Significant results of single effects as well as interactions are presented in charts and tables with the incorporation of Duncan's Multiple range test values. Unless otherwise stated, all results reported were significant at the 5% level or lower.

IV. RESULTS

A. Main Effects of Water Table

1. General Observations

Of the variables studied in this investigation, a high water table had a profound effect on certain aspects of growth and nutrition. As the plants responded to the effect of the change in the root environment due to a high water table, distinct discoloration of leaves appeared. The original pale color developed pigmentation similar to multiple deficiency symptoms. These symptoms became more pronounced as the season advanced. Apart from these qualitative visual ratings between the two water table treatments no chlorophyll estimations were attempted due to lack of sufficient leaf tissue for analysis.

Growth retardation appeared to manifest itself in smaller, brittle and deformed leaves. This difference in leaf size was significant only at the 5% level, (Table 5). It is also apparent from the data presented in this table on other growth records that the two water regimes did not show significant differences. Visual observations however showed marked differences in the general appearance of the plants. Because the testing term used for water table was blocks/water table in the model used for the analysis of variance, and because the variation between blocks was large, any greater variance due to the water table alone could have easily been obscured. The large variation among plants within each treatment was mainly due to the difficulties confronted in maintaining a steady and continuously uniform water table as the rates of water loss from plant to plant differed widely. The

Table 4. Effect of water table on mineral composition of foliage of Bluecrop Blueberry[1]

Month	Water table	N	P	K	Ca	Mg	Fe
August	High	1.68 d	0.094 c	0.308 d	0.193 b	0.488 b	100 ab
	Low	1.99 b	0.129 b	0.355 c	0.213 b	0.520 ab	99 ab
September	High	1.68 d	0.121 b	0.356 c	0.163 c	0.326 d	85 bc
	Low	2.25 a	0.221 a	0.614 a	0.214 b	0.529 ab	106 a
October	High	1.76 c	0.132 b	0.378 b	0.204 b	0.403 c	81 c
	Low	2.23 a	0.199 a	0.615 a	0.242 a	0.588 a	90 b

Means in the same column followed by the same letter are not significantly different (Duncan's New Multiple Range Test - 5% level)

[1] Mean of 28 plants.

Table 5. Effect of water table on growth of Bluecrop Blueberry

Water table	Leaf number	Leaf area	Shoot number	Shoot length
	N.S	*	N.S	N.S
High	95.98	24.74	7.35	142.8
Low	112.23	32.82	8.71	178.9

* Significant difference between water tables at P = .05
N.S. - not significant

same problem arose in the free drained crocks. In certain cases even regular watering failed to prevent irreversible drying out of the peat during the height of the summer.

2. Effect of Water Table on Foliar Nutrient Composition

Highly significant differences appeared in the uptake of all elements studied. The data presented in Table 4 and in Figures 8-13 show that N, P, K, Ca and Mg were substantially decreased by a high water table in comparison with plants maintained under free drained conditions. The effect on foliar iron was not so profound at the beginning of the season, but showed a highly significant difference in October when leaves on plants maintained under waterlogged conditions exhibited symptoms of yellowing and premature aging.

Foliar N was decreased by the presence of a high water table. Highly significant reduction in leaf N content was obtained on all three dates of sampling (Table 4 and Figure 8). The yellowing effect brought about by the water saturated soil condition could be seen well during the middle of the season and it became more apparent as the leaves aged. Senescence and leaf abscission were hastened under these adverse conditions. Since the uptake of all the elements was affected, it would appear that the basic metabolic activities were slowed considerably. One effect of N fertilizer application was the significant increase in level of foliar N over that of the unfertilized control. The N level was highest for the second date in the low water table treatment; while N levels of the leaves decreased in the low water table treatments as the season advanced, they tended to increase slightly in the waterlogged medium. The date X water interaction

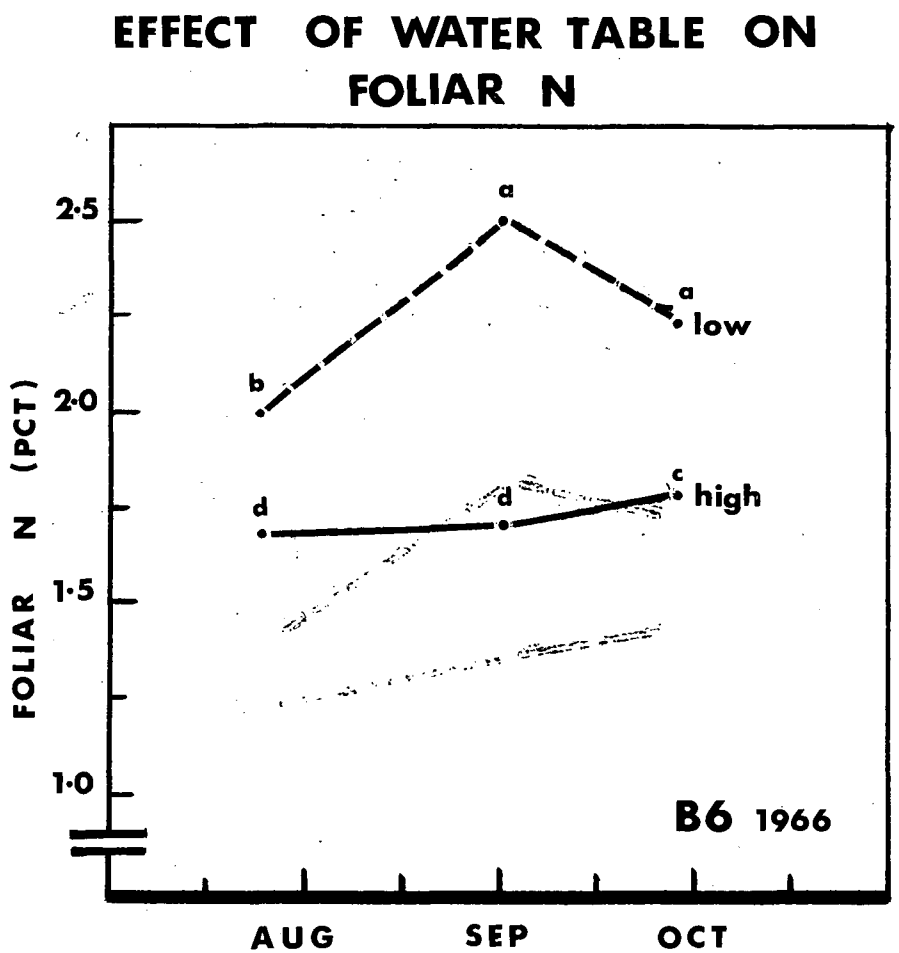

Fig. 8. SEASONAL CHANGE OF FOLIAR N LEVELS UNDER HIGH WATER TABLE AND FREE-DRAINED CONDITIONS.

Means sharing the same letter are not significantly different (D.N.M.R.T. 5%)

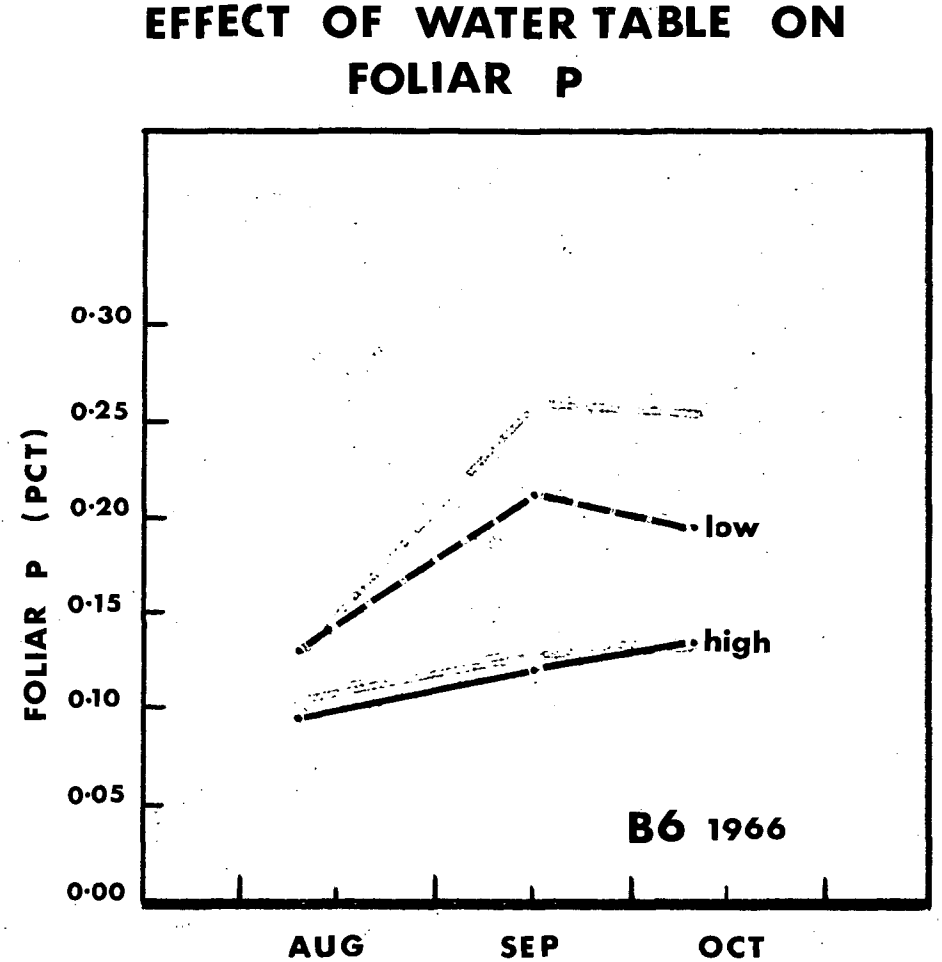

Fig. 9. SEASONAL CHANGE IN FOLIAR P AS INFLUENCED BY HIGH WATER TABLE AND FREE-DRAINED CONDITIONS

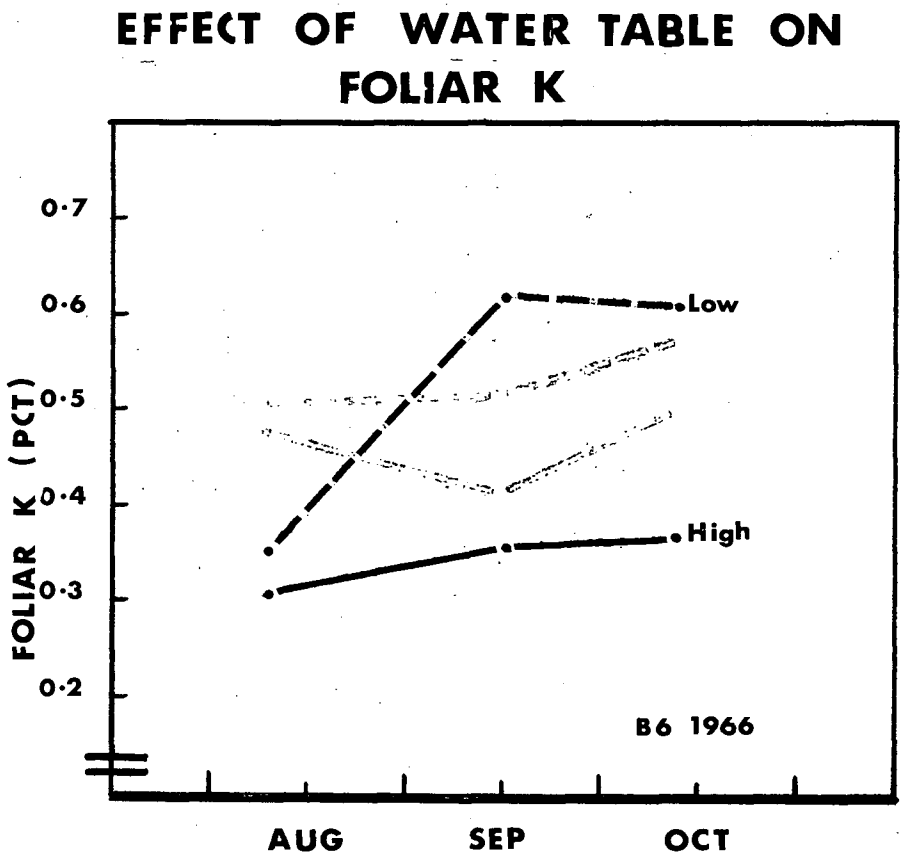

Fig. 10. SEASONAL CHANGE IN FOLIAR K AS INFLUENCED BY HIGH WATER TABLE AND FREE-DRAINED CONDITIONS.

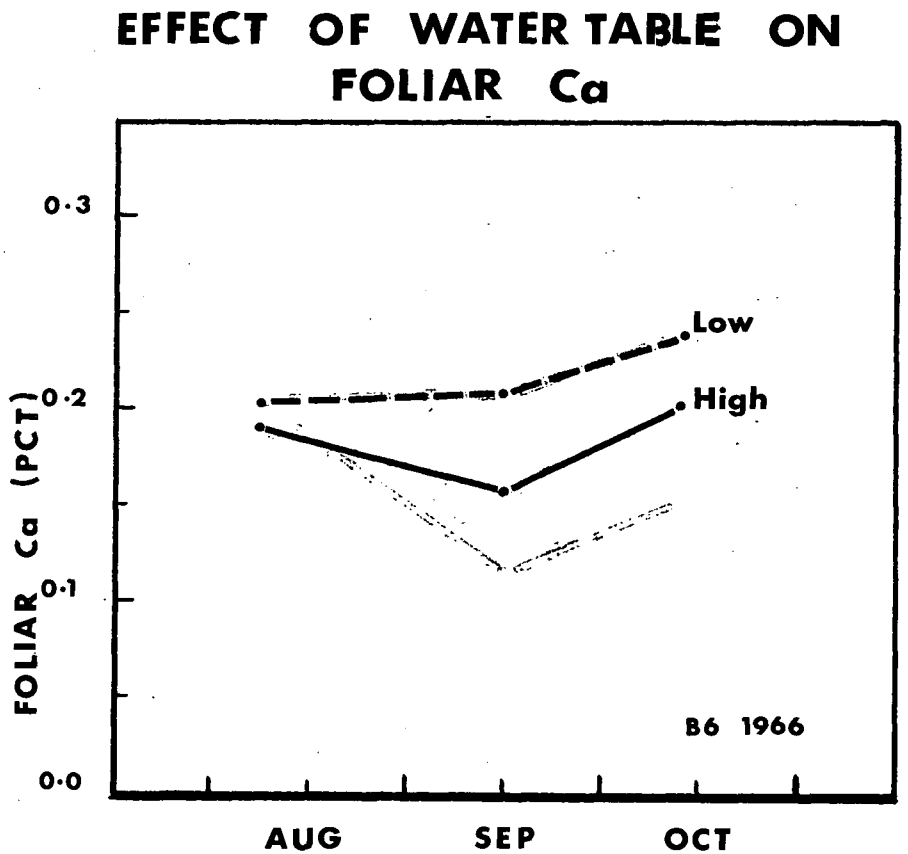

Fig. 11. SEASONAL CHANGE IN FOLIAR Ca AS INFLUENCED BY HIGH WATER TABLE AND FREE-DRAINED CONDITIONS.

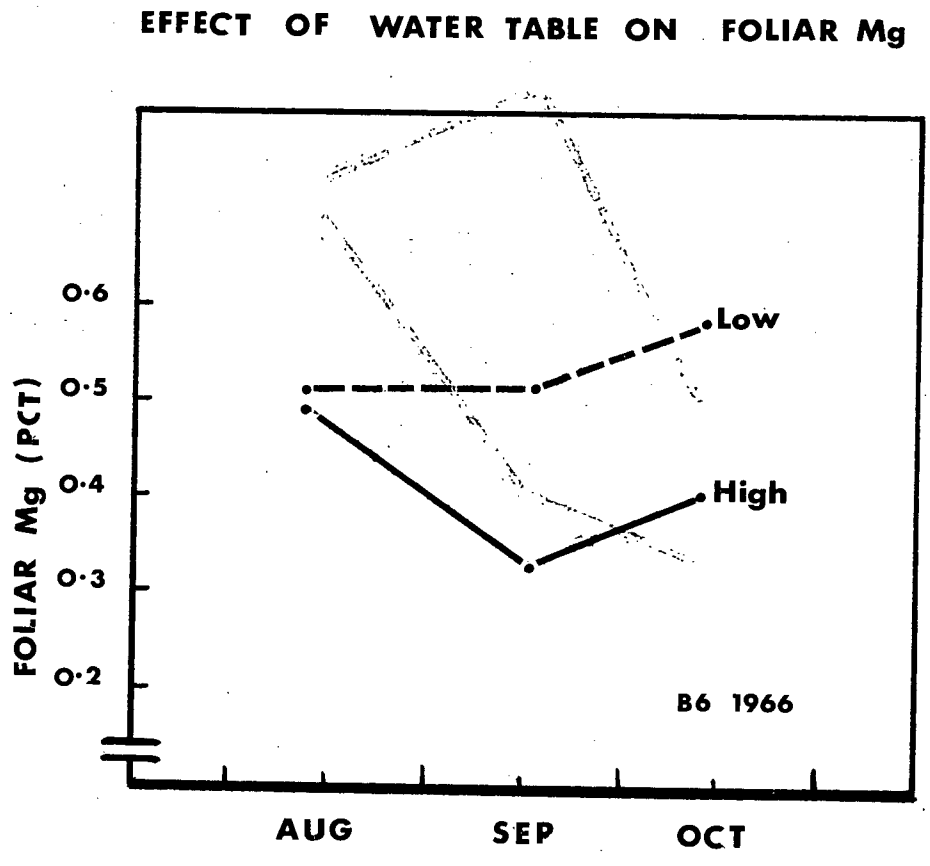

Fig. 12. SEASONAL CHANGE IN FOLIAR Mg AS INFLUENCED BY HIGH WATER TABLES AND FREE-DRAINED CONDITIONS.

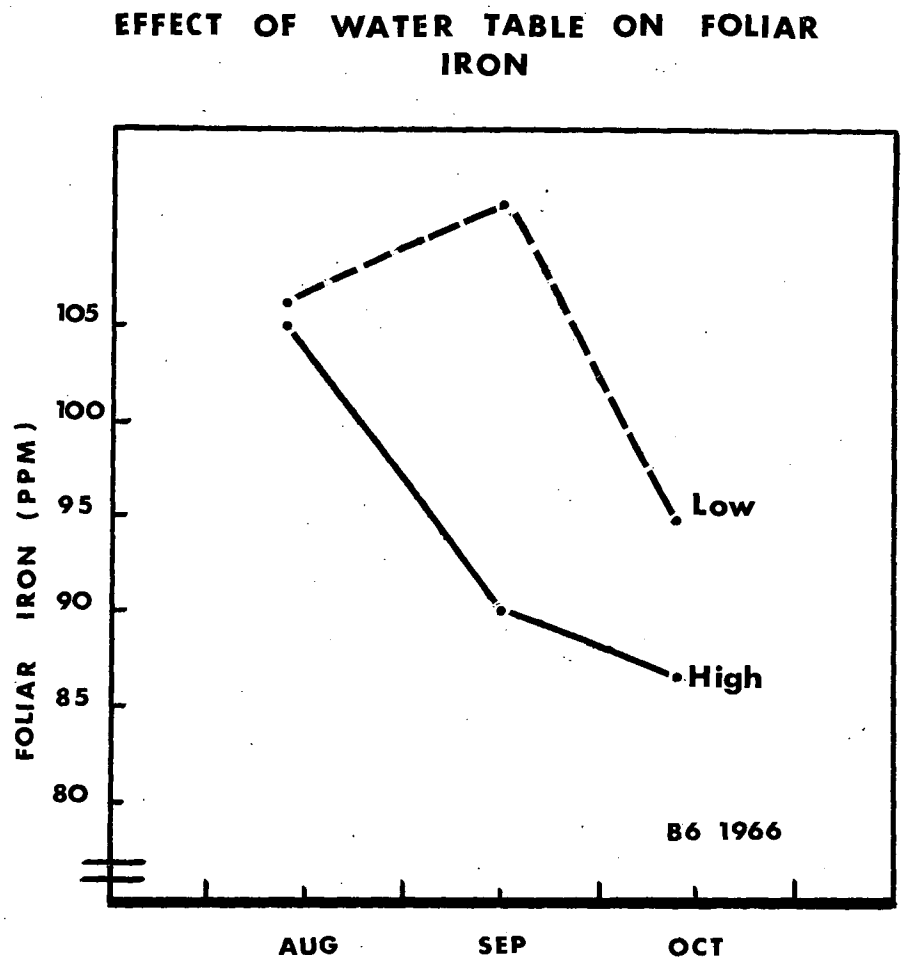

Fig. 13. SEASONAL CHANGE IN FOLIAR Fe LEVEL AS INFLUENCED BY HIGH WATER TABLE AND FREE-DRAINED CONDITIONS.

(Figure 8) was significant (P=0.05).

The seasonal trend for foliar P was similar to that of N. Differences between the two water regimes were highly significant for all three dates. The interaction of date X water table was highly significant. Plants receiving a regular supply of water without any waterlogging took up more P in midseason than when they were waterlogged. This trend is normally observed in crops that are well supplied with phosphate. No significant differences were obtained between dates when plants were maintained under high water table conditions.

There was a highly significant increase of leaf K under free-drained conditions, the level remaining high even at the end of the season. Under waterlogged conditions the level of foliar K remained low even in October. The differences between the two water regimes were more marked with progressive maturing of leaves as compared with the negligible increase in early summer. Uptake of K thus appears to have been impeded when the root system was subjected to oxygen stress.

The fluctuation of Ca levels was more pronounced under waterlogged conditions than when plants were maintained under free-drained conditions. A low water table gave higher Ca values in the foliage on all three dates of sampling, the difference being highly significant (P=0.01) in the months of September and October. In August, however, leaf Ca showed no significant difference between the two water treatments. In September, the leaf Ca level dropped considerably in the high water table treatment, and as growth slowed

down towards the end of season, the level increased.

There was a depression in foliar Mg when the water table was high, the decrease being very evident and highly significant in both September and October. The date X water table interaction was highly significant. There was no difference due to water regimes in August. Whilst leaf Mg gradually increased under well aerated conditions, there appeared to be hardly any change in Mg level of leaves in the poorly drained conditions since the initial depression brought about by poorly drained conditions. The behaviour of leaf Mg in the two water table treatments was very similar to that of Ca. Mg levels were, however, higher than Ca levels in all plants maintained under high as well as low water treatments.

Significant differences in foliar Fe levels showed up late in the season. Premature leaf aging due to the waterlogged condition seemed to be closely related to the low N level and resultant yellowing of leaves. In September the high water table treatments registered a drop in foliar Fe while an opposite trend was observed in plants under free-drained conditions.

3. Discussion of main effects of water table.

Results of this experiment indicate a distinctive sensitivity of the highbush blueberry to waterlogged conditions. Although growth indices studied did not show significant differences in all cases, there is ample evidence to conclude that waterlogged peats do not provide the ideal conditions for growth or for maintaining a proper balance of nutrients in the highbush blueberry. The primary cause may be the lack of

proper aeration and consequent interference with normal functioning of the root system. The lower levels of leaf N, P, K, Ca, Mg, and Fe observed in the waterlogged treatments do not necessarily indicate that the waterlogged peat was unable to supply these elements in sufficient quantity. Since both sets of crocks received similar fertilizer treatments, it is reasonable to suspect that poor aeration impeded normal physiological functions of the roots. Analogous conclusions have been reached by Buttery et al (10), Gore and Urquhart (28) and by Labanauskas et al (37). They concluded that growth reduction under waterlogged conditions could not be directly attributed to external limitations of the nutrient environment.

When citrus plants were grown under oxygen stress as a result of excess water treatments, Labanauskas et al (37) reported that total leaf N, Cl, Zn, Cu, and Fe decreased significantly. They also found that total P, K, Ca, Mg, Mn, and B were not affected. In the study made by Gore and Urquhart (28) on Eriophorum vaginatum and Molinia caerulea, it was found that waterlogging did not affect P levels but caused severe N deficiency. They also reported that waterlogging resulted in low redox potentials in the peat medium. In the present work on highbush blueberry, the results on foliar nutrient levels under waterlogged conditions do not seem to be in accord with the above findings, except in the case of N and Fe. As presented in the results, highly significant differences were also obtained for leaf P, K, Ca, and Mg. The severity of symptoms of the effect of a highbush blueberry may have been due to the prolonged wet condition affecting the root system which was confined to such a small volume

of peat in the crocks. An additional factor partly responsible for these striking differences may have been the prevention of any inward diffusion of air from the sides or the base of the crocks. By and large these conditions may prevail under field conditions, long enough to affect growth and performance of the blueberry. At this stage it is only possible to speculate as to the physiological nature and cause of these observed differences. In order to make a critical study of the damage to the root system, further investigations are necessary. Estimation of respiration rates, root regenerative capacity with constant and fluctuating water tables were not within the scope of this experiment.

Although the highbush blueberry is supposed to tolerate a high degree of water excess, it is obvious from these findings that better growth could be obtained by regulating the water supply. The shallow rooted nature of the crop clearly indicates that survival in such environments depend to a large measure on the fine network of roots the plants have closer to the surface. Profuse root growth on the surface and around the collar of the waterlogged plants in the experiment showed the so-called "hilling effect" as seen in the field. There were clear indications that the artificially created high water table induced a greater rooting propensity at the surface where it was beyond the reach of the water table, unlike in the well aerated peat where the root distribution was more uniform. Field grown blueberries when growing under prolonged submerged conditions in the root zone, appear to exhibit characters symptomatic of multiple nutrient deficiencies. This is often seen in poorly drained locations where plants

also show in addition to these deficiency symptoms, a typical "stag-horn" appearance, poorly colored leaves and severe stunting even though such fields have been supplied with fertilizers.

B. The Influence of Water Table in Relation to Ammonium and Nitrate Nutrition

1. Leaf Symptoms:

One week after fertilizer treatments were administered the foliage registered symptoms of marginal necrosis and leaf abscission which were assumed to be toxicity symptoms. The condition was more pronounced in the nitrate than in the ammonium treatments. At 20 lbs. N per acre, both forms of N showed no "toxic" effects. At 40 lbs. N per acre, only nitrate treatments were affected. At 60 lbs. N per acre, "toxicity" was observed on plants with both sources of N, the symptoms being more severe in the nitrate treatment.

"Toxicity" symptoms varied slightly under the two water regimes. Plants receiving a high water table showed less marginal necrosis, but leaf abscission occurred in the treatment receiving the equivalent of 60 lbs. N as nitrate. Under free-drained conditions toxicity was shown in the form of severe necrosis, appearing first on the tender shoot tips and progressing down to the mid-shoot region. Most plants recovered sufficiently after a few weeks and normal healthy growth was observed in the new foliage, except those plants receiving the 60 lbs. N per acre as nitrate, under both systems of water management. Leaf growth on these plants was very sparse and the plants never fully recovered.

2. Growth data:

Using total shoot length as an index of growth, significant interactions were obtained between N source and water table (Figure 14). In the high water table treatment a significant growth response was obtained over the check when ammonium N was applied at 40 and 60 lbs. per acre of N. No significant differences were obtained between the two forms of N at 20, 40, or 60 lbs. N when the water table was high.

Under free-drained conditions overall growth was greater at the low fertilizer levels, in contrast to the trend in the high water treatments. Depression of growth in the check was less severe than when the root zone was under oxygen stress. At 20 lbs. per acre of applied N both forms of fertilizer gave a better response than the nitrate treatment of 60 lbs. N application. Although the difference in shoot growth between the two forms of N at the applied level of 20 lbs. per acre were not significantly different, the ammonium treatment was also significantly different from the nitrate treatment of 40 lbs. N under similar free-drained conditions. The differences in shoot length between the check and the three fertilizer treatments or between source of N at each level were not significant in the low water treatments.

Comparing the two water table treatments, poor growth was obtained in the check and the 20 lbs. N per acre level when the water table was high, but far better growth occurred at 20 lbs. N level when plants were grown under free-drained conditions. No significant differences were obtained at 40 and 60 lbs. N per acre between the two water treatments. Neither leaf number, mean leaf area nor shoot number

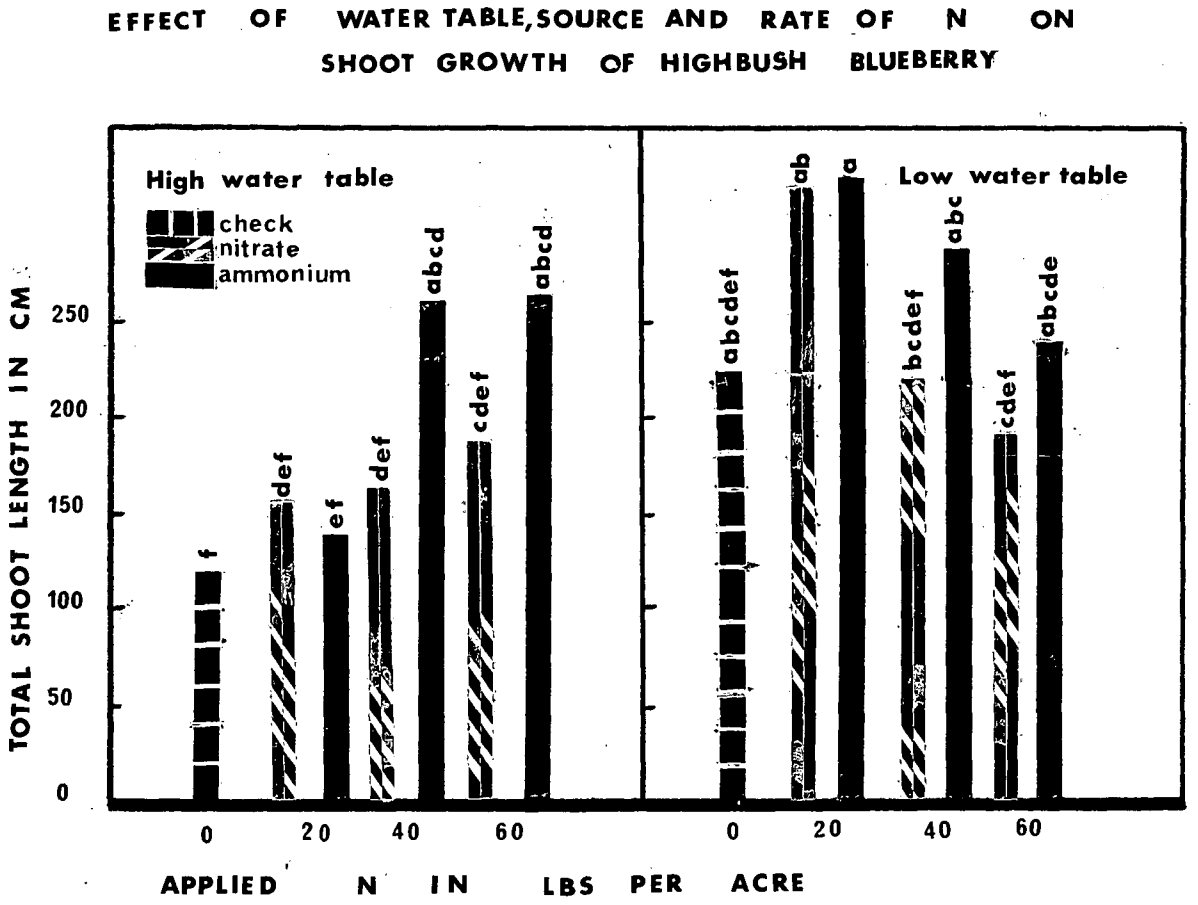

Fig. 14. A COMPARISON OF THE TWO FORMS OF NITROGEN NUTRITION ON SHOOT GROWTH OF THE 'BLUECROP' VARIETY OF HIGHBUSH BLUEBERRY GROWN UNDER WATERLOGGED AND FREE-DRAINED CONDITIONS. MEAN SHOOT LENGTHS SHARING THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT (D.N.M.R.T. 5%)

were affected by the forms of N. At the end of the growing season it was observed that high N treatments delayed leaf fall and in a few cases older leaves remained on the plants throughout the winter.

3. Flowering:

The fertilizer effects on flowering were highly significant. The number of flower clusters per plant and the number of flowers per cluster (mean of two clusters taken from the third position from the terminal bud) were determined and the flowering records analysed statistically. The check was significantly lower in flower cluster number than all other fertilizer treatments except the one receiving 60 lbs/ac N as nitrate (Table 6). The data on flower number per cluster showed similar trends. In the ammonium treatments, blooming was earlier than in the nitrate treatments by as much as four days.

C. Effect of Nitrate and Ammonium Fertilizer on Foliar Nutrient Composition:

N, P, K, Ca, and Mg levels of the foliage were affected by the form of N as well as by the different rates of application. In August, foliar N levels were not affected by the treatments. This was perhaps due to the plants not being fully established in the crocks. Significant differences did appear however, by the middle of September. The analysis of results on this date indicated a significant response in leaf N to both forms of applied N (Figure 15). There were no significant differences between the two sources at 20, 40, or 60 lbs. per acre of N application. Differences were, however, significant between levels of applied N. The check had significantly lower leaf N levels

Table 6. Effect of source and rate of N-fertilizer on flowering[1]

Treatment	lbs. N/acre	Clusters per plant[2]	Flowers per Cluster[3]
Check	0	3.69 c	2.69 c
NO_3	20	13.19 ab	5.69 ab
NH_4	20	18.50 a	6.91 a
NO_3	40	12.88 ab	5.10 ab
NH_4	40	18.50 a	5.87 ab
NO_3	60	6.44 bc	4.53 bc
NH_4	60	15.00 a	6.13 ab
		Standard error = 2.3114	Standard error = 0.7346

1. Means within a measurement followed by the same letter do not differ significantly (P=0.05)

2. Mean of 16 plants

3. Mean value of two clusters per plant was taken for statistical analysis and the mean of 16 such values represent each mean in the table.

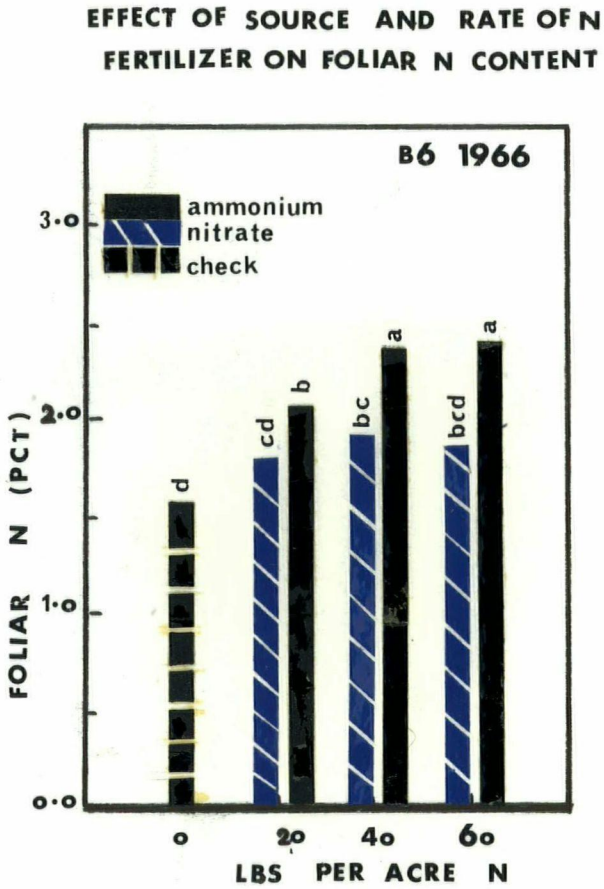

Fig. 15. THE RELATIONSHIP BETWEEN APPLIED N IN THE FORM OF NITRATE AND AMMONIUM NITROGEN ON FOLIAR N CONTENT OF 'BLUECROP' BLUEBERRIES.

than ammonium N treatments of 20, 40, and 60 lbs. applications. On the other hand, the check was only significantly lower than the nitrate treatment of 60 lbs. N per acre. Both forms of N at 60 lbs. N application gave significantly more leaf N than at other levels of applied N, (Table 7), in September. Since this sampling date was in mid-season, it was considered the most crucial phase of growth when foliar nutrients could occur in limiting concentrations. The correlation coefficients in matrix form presented in Table 8, show significant correlations obtained between leaf nutrients analysed, and the different growth indices measured. In September, leaf N was significantly correlated with shoot length, leaf number, flower cluster number and shoot number. Although leaf N levels at the end of season are not of immediate importance, substantial amounts present at this time may imply a steady supply for the spring flush. Therefore analysis of the October sampling was carried out. The check plants in October had significantly lower N than all other fertilizer applications. There was a progressive decrease of leaf N in the check from the beginning to the end of season. As in September, there was no significant difference between the two forms of N at each level of application. There was no significant correlation of October leaf N levels with any of the growth indices studied.

Leaf P levels followed trends similar to those of N. The overall leaf P values showed a highly significant positive correlation with leaf N in September (Table 9). Judging from the level of leaf P obtained at this time of year, there appeared to be a beneficial effect

Table 7. Effect of N source and rate on leaf nutrient element composition[1], [2] on three sampling dates

Month	Check	20 lbs. N/Acre		40 lbs. N/Acre		60 lbs. N/Acre		Standard Error	
		NO_3	NH_4	NO_3	NH_4	NO_3	NH_4		
Aug	1.69	2.01	1.83	1.84	1.79	1.79	1.86	0.08	N.S.
% Sept	1.57 d	1.75 cd	1.89 bc	1.82 bcd	2.05 b	2.34 a	2.35 a	0.08	
N Oct	1.43 c	2.05 ab	1.98 ab	1.87 b	2.14 ab	2.26 a	2.25 a	1.10	
Aug	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.005	N.S.
% Sept	0.09 b	0.19 a	0.19 a	0.16 ab	0.19 a	0.18 a	0.16 ab	0.02	
P Oct	0.07 c	0.15 b	0.19 a	0.15 b	0.20 a	0.20 a	0.19 a	0.01	
Aug	0.31	0.34	0.31	0.36	0.34	0.35	0.32	0.02	N.S.
% Sept	0.28 b	0.55 a	0.57 a	0.44 ab	0.43 ab	0.57 a	0.55 a	0.06	
K Oct	0.27 b	0.50 a	0.55 a	0.46 b	0.51 a	0.64 a	0.55 a	0.06	
Aug	0.21	0.22	0.19	0.18	0.20	0.21	0.20	0.02	N.S.
% Sept	0.19	0.21	0.17	0.15	0.19	0.21	0.20	0.02	N.S.
Ca Oct	0.22 ab	0.19 b	0.21 ab	0.20 ab	0.23 ab	0.23 ab	0.28 a	0.01	
Aug	0.50	0.48	0.50	0.52	0.54	0.47	0.51	0.04	N.S.
% Sept	0.37 cd	0.33 d	0.51 ab	0.33 d	0.51 abc	0.39 bcd	0.55 a	0.05	
Mg Oct	0.43 cd	0.37 d	0.52 bc	0.44 cd	0.67 a	0.48 cd	0.56 ab	0.04	
Aug	94	129	94	95	97	98	94	11	N.S.
ppm Sept	111	112	88	92	88	87	92	12	N.S.
Fe Oct	80	81	87	96	84	87	85	3	N.S.

[1] Means within a single date sharing the same letter are not significantly different (Duncan's New Multiple Range Test - 5%).

[2] Treatment means for one element on a single date without letters, were not significantly different on Analysis of variance (P=0.05), and were not tested with Duncan's New Multiple Range Test. The standard errors are given for means on all dates.

Table 8. Significant correlation coefficients for growth indices and nutrient elements of leaves[1]

	Foliar			
	N	P	K	Ca
Shoot length	0.53	0.48	0.53	0.34
Leaf area (L X W)	--	--	--	--
Leaf number	0.33	0.38	0.52	--
Flower clusters	0.28	--	0.27	--
Shoot number	0.44	0.32	0.43	--

[1] Only significant correlations with leaf analyses in September are presented.

Critical r at 5% = 0.26

Critical r at 1% = 0.34

Table 9. Correlation coefficients for matrix involving leaf nutrients[1]

Relationship between leaf nutrient elements in September

	N	P	K	Ca	Mg	Fe
N	--	0.36	0.50	--	-0.35	--
P	--	--	0.40	0.56	-0.34	0.37
K	--	--	--	0.37	-0.26	--
Ca	--	--	--	--	-0.35	0.77

[1] Only significant correlations are presented.

Critical r at 5% = 0.26

Critical r at 1% = 0.34

of N applications on foliar P, a clear demonstration of the existence of an N-P relationship at these leaf concentrations observed. The P level of check plants were not significantly different from the nitrate treatment of 40 lbs. N and the ammonium treatment of 60 lbs. N per acre. All other treatments were significantly higher than the check. Significant correlations were observed for P values in September with shoot length, leaf number and shoot number, (Table 8). In October, P levels were highly correlated with shoot number.

Leaf K levels in August did not show any significant differences. This trend was also observed in the case of N and P. The check plants in September were significantly lower in foliar K than when plants were given N fertilizer at the rate of 20 and 60 lbs. per acre. This difference was, however, not significant at the 40 lbs. N rate of application. Leaf K values were positively correlated with leaf area, shoot length and shoot number in August; with shoot length, leaf number, flower cluster number and shoot number in September and with the same indices of growth in October. When leaves were analysed in October, K level of check plants was significantly lower than all other applied N levels. In either September or October the differences between the two sources of N were not significant at any level of N application.

In spite of the liming treatments in this experiment, leaf Ca values were little affected. No significant effects were observed, except in October where the 60 lbs. N application in the ammonium form gave a significantly higher leaf Ca value than plants grown with 20 lbs. nitrate N.

As in the other major elements already discussed, leaf Mg did not show significant differences in August. The analysis of results for September gave significant differences in leaf Mg between the two sources at each level of application. All plants maintained at 20, 40 and 60 lbs. N per acre with ammonium as their source of N gave significantly higher leaf Mg than plants grown with equivalent levels of nitrate N. The leaf Mg values remained in much the same manner in October save for an overall increase at the higher levels of N application. In September foliar Mg was negatively correlated with leaf N, P, K and Ca (Table 9). This may well be the manifestation of ion antagonism at this crucial period in the nutrition of the blueberry.

In this experiment leaf Fe content did not seem to be affected by the source or the level of N used. This may have been due to the fact that the leaves were analysed for the total Fe fraction, which does not give a true indication of the active form of Fe in the leaves. Cain (11) found chlorotic plants to have high Fe levels. No significant correlations were obtained between Fe content and any of the factors of growth studied. Leaf Fe was, however, significantly correlated with leaf P and Ca in September.

1. Discussion of N nutrition and interactions

The observed increase in the levels of leaf N, when higher levels of ammonium fertilizers were given, lend support to the theory that the principal form of N preferred by the highbush blueberry is the ammonium ion. The results of Cain (11) also indicated

that this was the case as far as highbush blueberries were concerned. The absence of sufficient ammonium ions in calcareous soils could probably be the reason why blueberries fare poorly if adequate quantities of ammonium fertilizers are not supplied. Although no mention is made of the exact pH range, Cain and Eck (14) report that in New Jersey, Michigan and North Carolina, nitrate N fertilization in highbush blueberry plantings is widely practiced on acid soils with good results.

Fertilizer mixtures used by blueberry growers in the lower mainland of British Columbia commonly contain the three sources of N, namely Urea, ammonium sulphate, and ammonium nitrate in varying proportions in combination or singly. By resorting to this practice they feel that a steady supply is assured. A similar recommendation has been made by Doelhert (24) for very sandy soils. It is, however, a matter of conjecture, whether the soil conditions would ensure an adequate supply of N to meet the growing demands of a heavy bearing crop like the highbush blueberry.

The movement of ammonium ions has been studied by Townsend and cited by DeLong (21). Experiments on the movement of the ammonium ion when added in the form of a fertilizer to the soil in highbush blueberry fields in Eastern Canada, showed that penetration was slow due to its retention by the soil colloidal complex closer to the surface. The ammonium ion, however, is weakly held by the soil colloids and almost with the same intensity as the K ion. But both these ions are held with less tenacity than the H ion in an acid soil. Due

to its loose attachment with soil colloids, heavy rain or a constantly fluctuating water table, could easily leach the ammonium ion. These experiments also showed that leaching occurred as much as 3 inches with an application of one inch of water. The leaching of ammonium ions in a mineral soil could be due to the difficulty of replacement of Al ions when ammonium N is added to the soil. These conditions discussed here are perhaps too drastic to expect in a highly organic environment where the matric potential of the soil solution is not only governed by hydrostatic, gravitational and absorptive components but also by the more important entities of an organic soil like osmotic concentration at the low pH as obtaining in these peat bogs. Although the acid nature of the peats would promote a preponderance of free ammonium ions, other factors could limit the availability of ammonium N. Since denitrification is mainly brought about by the microflora, poor aeration as a result of a high water table would result in low microbial activity. The optimum pH range for activity of such organisms is not ideal in these peat soils.

Mycorrhizal associations of blueberry with certain basidiomycetes have been reported by Coville (19) who claimed that in acid soils the fungi involved in this association transform the organic N into available forms while Rayner (41) described a process which brought about the fixation of atmospheric N by the mycorrhiza. It has since been shown by Addoms and

Mounce (3) that this amount of N was insufficient to sustain the plant. There is little doubt that nitrogen nutrition of the blueberry is dependent on the soil pH under natural conditions. On the other hand, by supplying the plants with the desired source of N, successful cultivation of the blueberry could be done at any pH level provided a proper nutrient balance is maintained in respect of the other essential elements in the soil (44).

The increase of leaf P with the increase of N applications mentioned in the results of this greenhouse investigation was also observed in a contemporary field investigation on two year old "Bluecrop" blueberries. At certain concentrations of each element, it has been shown by the use of multiple curvilinear regression methods by Dumenil (26) that the critical N-P concentration is not a point nor a narrow range of values, but a wide range of concentrations. Within the limitations of this experiment and the results from the field, it can be speculated that at a critical point of one element or both, there appears to be a highly positive correlation when the elements are in a highly mobile state in mid-season. The cation antagonism of Mg has also been clearly demonstrated in this investigation.

The inability of plants to obtain sufficient N at low N levels when the plants were waterlogged and the lack of differential responses to water treatments at higher levels of N may be

due to two reasons. Under waterlogged conditions the uptake of N may be impeded by malfunction of the absorption mechanism of the roots purely due to lack of proper aeration. It may also have been due to dilution by excess water in the crock. No serious leaching was possible from the high water table treatments since it was a closed system as far as the movement of water was concerned.

D. Effect of pH on Growth

The four pH levels used in this experiment were arbitrarily selected to find out whether pH influenced growth and also to find out the effect of liming in relation to water table and form and level of N supply. Results indicated that shoot development was better above pH 4.3. There was no significant difference in total shoot length between pH 5.2 and pH 6.0. Plants maintained at pH 3.4 were significantly lower in shoot length than grown at pH 5.2 and pH 6.0 but they did not differ significantly from plants grown at pH 4.3 (Figure 16). Liming did not induce an accumulation of Ca in the foliage. The highbush blueberry appears to be frugal in its Ca requirements. The effect of liming on growth, evident from these results (Table 10), was apparently indirect. Liming also affected other growth indices, but not so markedly. More shoots were produced at pH 6.0 than at any other pH level.

Soil pH influenced flowering in the following season. Both flower cluster number per plant and the number of flowers per

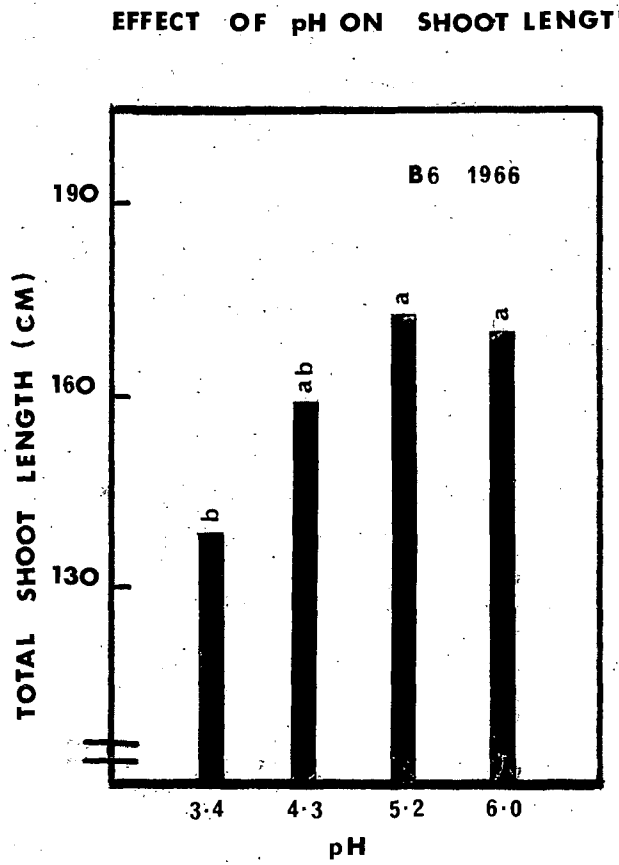

Fig. 16. THE INFLUENCE OF pH ON SHOOT GROWTH OF 'BLUECROP' BLUEBERRIES GROWN IN PEAT.

(Means sharing the same letter are not significantly different.
D.N.M.R.T. 5%)

Table 10. Effect of pH on Growth and Flowering[1]

pH	Shoot Length	Shoot Number	Leaf Number[2]	Leaf Area[2]	Flower Clusters	FL/CL
3.4	139.4 b	7.3 b	87.3	25.7	7.3 b	4.2 b
4.3	159.3 ab	7.7 b	117.9	29.5	14.8 a	6.5 a
5.2	173.3 a	8.2 ab	105.9	30.3	16.7 a	5.9 ab
6.0	171.6 a	9.0 a	105.2	2.96	11.5 ab	4.4 b
Standard Error	8.80	0.41			7.47	1.21

[1] Means within a measurement sharing the same letter are not significantly different. (P =0.05)

[2] No main effects were significant but interactions with pH shown in Figures 17 and 18 were significant.

cluster were affected. Maximum flowering appeared to be around pH 4.3 and pH 5.2. A lower pH suppressed flower bud development (Table 11). This effect on flowering is probably only a reflection of the effect upon shoot growth. Although leaf area and leaf number measurements showed no significant main effects, the pH X water table interactions were significant (Figures 17 and 18). Comparing the two water tables at each pH level, significantly higher leaf numbers were obtained in the low water table treatments only at pH 4.3. All other differences were not significant. A study of leaf area of treatments at the four pH levels showed that water table and pH affected leaf size (Figure 18). With a high water table pH 3.4 produced significantly smaller leaves than plants grown at pH 6.0. No significant effect of pH level was found when plants were grown under free-drained conditions.

1. Effect of pH on Foliar Nutrient Composition

Except for some significant differences of leaf N and K in October and leaf K in August, the pH levels studied did not significantly affect foliar nutrient levels (Table 12). Higher pH values in these instances tended to increase the uptake of N and K.

2. Discussion of effect of pH on growth and foliar nutrient Composition

Since the blueberry has low cation requirements as cited earlier (36), and since the plants used in this experiment were non-bearing, there was probably not much growth stress on the plants and little demand for nutrients from the peat. Furthermore, peat is

Table 11. Effect of pH (Liming) on flowering[1]

Soil pH	Clusters per Plant[2]	Flowers per Cluster[3]
3.4	7.32 b	4.21 b
4.3	14.82 a	6.50 a
5.2	16.71 a	5.88 ab
6.0	11.54 ab	4.45 b
	Standard error = 7.4714	Standard error = 1.2014

1 Means within a measurement followed by the same letter do not differ significantly (P=0.05)

2 Mean of 56 plants

3 Mean of 56 plants and two clusters per crock

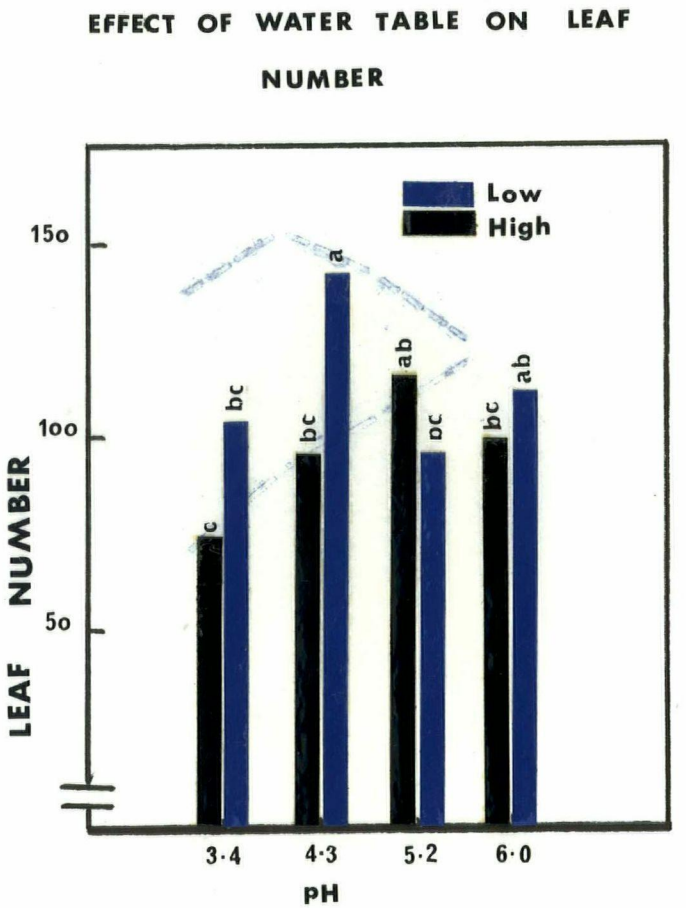

Fig. 17. LEAF NUMBER AS INFLUENCED BY THE INTERACTION OF WATER TABLE AND pH (LIMING).

(Means sharing the same letter are not significantly different)

(D.N.M.R.T. 5%)

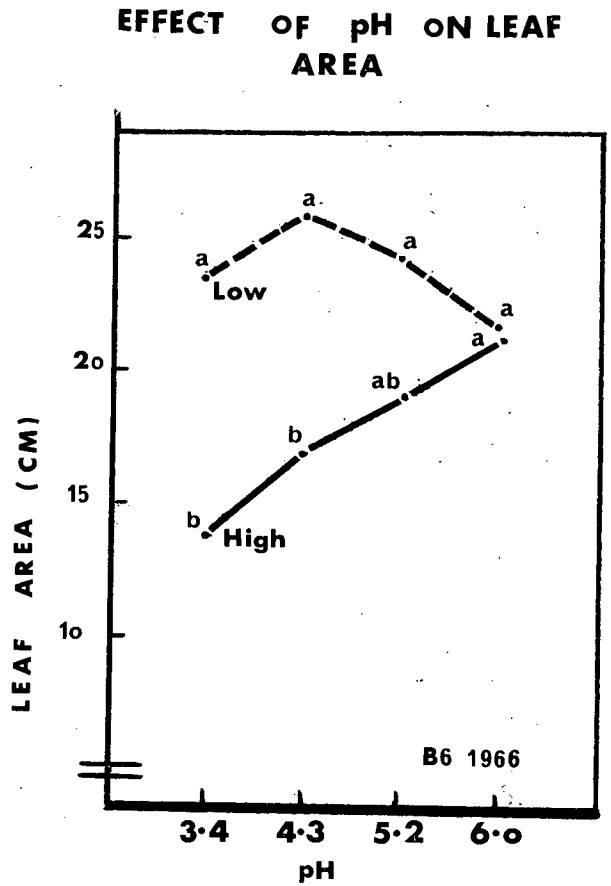

Fig. 18. LEAF AREA AS INFLUENCED BY THE INTERACTION OF WATER TABLE AND pH.

(Means sharing the same letter are not significantly different)

(D.N.M.R.T. 5%)

Table 12. The Effect of pH on Foliar Nutrient Composition[1]

Element	Month		Initial pH values 3.4	4.3	5.2	6.0	$S_{\bar{y}}$
%N	Aug		1.71	1.91	1.84	1.87	0.06
	Sept		1.80	1.97	2.12	1.97	0.08
	Oct	*	1.80 b	1.99 b	2.12 a	2.08 a	0.07
%P	Aug		0.10	0.12	0.11	0.11	0.00
	Sept		0.20	0.16	0.15	0.15	0.02
	Oct		0.16	0.18	0.16	0.16	0.01
%K	Aug	*	0.28 b	0.34 a	0.35 a	0.36 a	0.02
	Sept		0.47	0.46	0.46	0.55	0.05
	Oct	*	0.40 b	0.49 ab	0.46 b	0.64 a	0.05
%Ca	Aug		0.20	0.20	0.20	0.21	0.01
	Sept		0.21	0.18	0.19	0.18	0.02
	Oct		0.21	0.23	0.23	0.22	0.01
%Mg	Aug		0.52	0.50	0.49	0.51	0.03
	Sept		0.46	0.37	0.45	0.44	0.04
	Oct		0.54	0.52	0.45	0.48	0.03
ppm Fe	Aug		93	90	99	116	9.0
	Sept		113	86	93	92	9.3
	Oct		85	87	85	85	2.7

* Means showing significant differences among pH levels according to the analysis of variance (P=0.05) for each date were tested with Duncan's new multiple range test.

[1] Means sharing the same letter are not significant (P=0.05)

supposed to have a high buffering capacity and any release of additional nutrients for the plants may have been slow. Although growth in general was affected by pH, the distribution of minerals in the foliage was not significantly affected. Soil acidity does however, contribute indirectly in combination with other factors as seen from the results discussed earlier. The importance of soil acidity has been stressed by Coville (19). Johnston (34) specifically cites the examples of commercial plantings grown on mineral soils that are used for cultivation of this crop. However, in plantings in the lower Fraser valley which are mainly established on peat soils, the problem appears to be different in that the pH is often too low. In most of the areas of the lower mainland, a newly developed peat bog would have a pH of about 3.0 and in older plantings it may go up to pH 4.7. The rise in pH in these mature plantings would probably be due to the use of dolomitic limestone on the peat bogs as well as due to the increased microbial activity.

Although leaf mineral status was not much affected by the pH treatments given in this experiment, soil pH appear to play a vital role in the performance of the highbush blueberry. Merril (39) found that low pH levels were detrimental to blueberries. This may perhaps be due to the preponderance of free H ions competing for ion exchange sites or the solubility of a greater amount of heavy metal ions in the soil solution. Ammonium and H ions have a profound influence on the lower cation ab-

sorption due to high concentration of these ions on the root film. Clark (17) found that ammonium ions reduced the uptake of bases in strawberry resulting in lower organic acids in the leaf tissue. A similar condition was observed by Cain (13) in highbush blueberry. Colgrove and Roberts (18) suggested that the H ion was similar to the ammonium ion in its effects on absorption of other bases. Under conditions of high H concentration Hoagland and Broyer (30) found evidence of Ca loss from the plant. They found that the accumulation of anions and cations was substantially increased when the pH was raised. With increasing dosage of nitrate, leaf Ca of the blueberries increased. This was true for K and Mg too, thus supporting the work of Sideris and Young (43) on pineapple. Increased rates of ammonium, however, did not lower the absorption of any of the bases significantly.

Merril (39) found leaf scorch appearing at low pH values, which was symptomatic of toxicity and this condition was corrected by raising the pH above 4.0 by the addition of lime. In the present study symptoms of nitrate toxicity appeared very early and the severity of the symptoms in the fertilized treatments appeared to be high at higher pH levels (Figure 19). In most of the previous investigations, it has been attempted to specify an optimum pH range from pH 4.5 to pH 4.8. Bailey (5) even suggested that liming a soil at pH 4.6 was harmful. The results of the investigations carried out here are not in accord with the above findings. No harmful effects

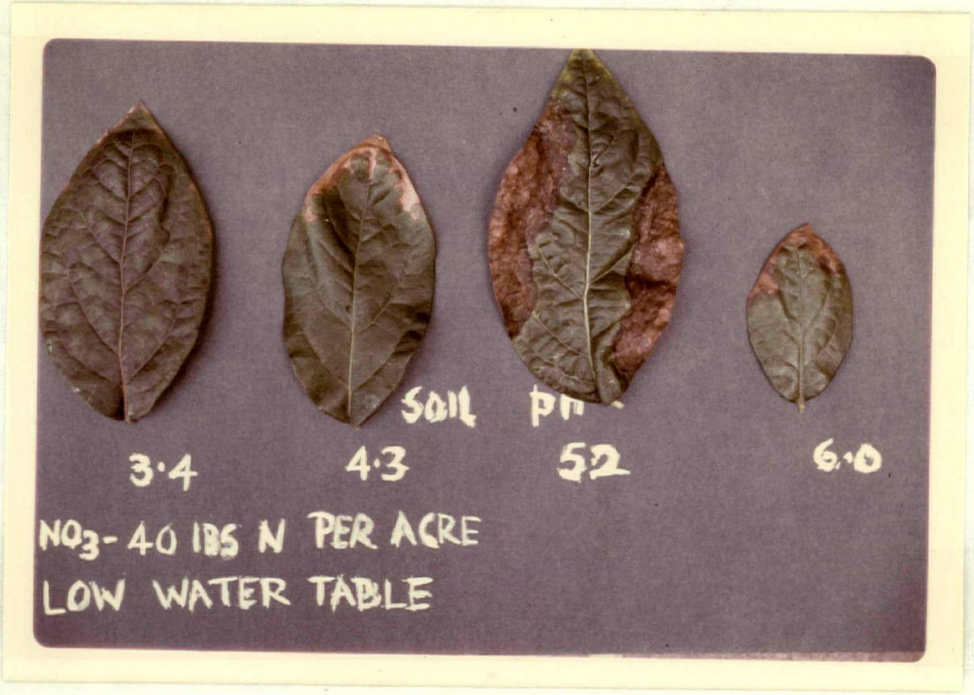

Figure 19A
Leaf symptoms of Nitrate toxicity on 'Bluecrop' Blueberry grown in pot-culture at 4 pH levels with a high water table. Note yellowing of leaves at low pH levels and leaf scorch at higher pH levels. Leaf size has no bearing on treatment effects, as leaves shown here are from different position on shoots.

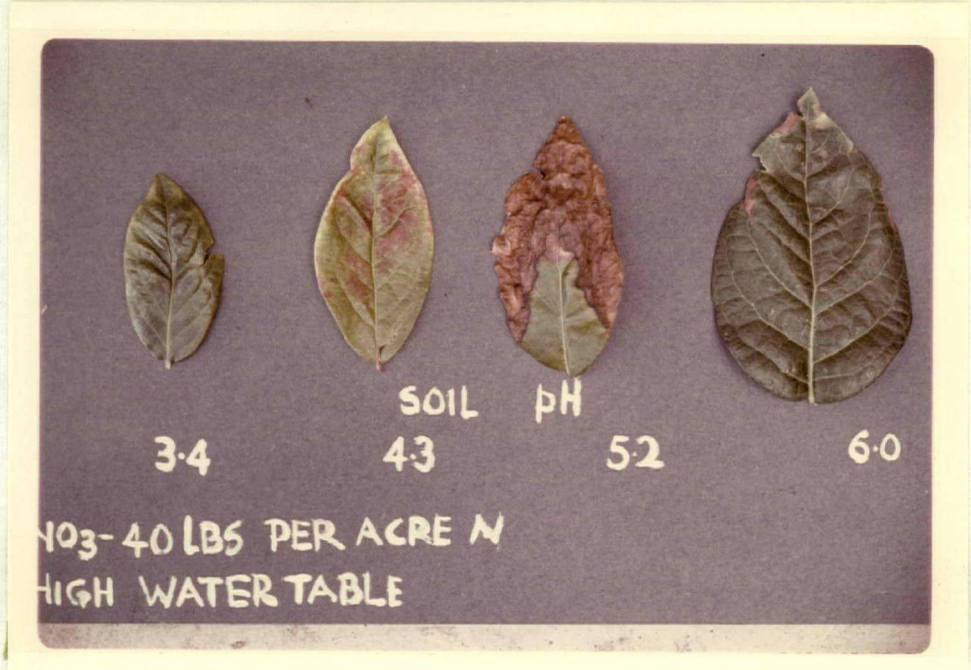

Figure 19B
Leaf symptoms of Nitrate toxicity on Bluecrop blueberry grown in pot-culture at 4 pH levels under free-drained conditions. Leaf scorch symptoms were more severe at higher pH levels. Leaf size has no bearing on treatment effects, as leaves shown here are from different positions on shoots.

NH_4-N NO_3-N

Figure 19C
A comparison of the effect of 60 lbs. N per acre applied as ammonium and nitrate N to 'Bluecrop' blueberry grown in peat at pH 5.2. Note severe leaf scorch symptoms in the nitrate treatment (right). Ammonium treated plant (left) shows only mild symptoms.

NH_4-N NO_3-N

Figure 19D
The comparison of the effect of 60 lbs. N per acre applied as ammonium and nitrate N to 'Bluecrop' blueberry grown in peat at pH 6.2. Toxicity symptoms were observed on nitrate treatment (right). Ammonium treated plants show no symptoms of toxicity at this stage of growth although symptoms were observed immediately after treatment.

due to pH alone were observed in the peat even when the pH was raised to 6.0. These observations seem to be in agreement with the results of Stene (44), Boller (8) and Cain (11), who all claimed that blueberries could be successfully grown even at pH 6.5 provided there was a proper nutrient balance. The ammonium form of N is believed to be essential at high pH levels, and the nitrate in acid soils is usually converted to the ammonium form by soil denitrifiers. Cain and Eck (14) have suggested that this conversion of nitrate to ammonium could be the reason for success of the blueberry in acid soils.

Soil pH and leaf tissue pH seem to be closely interrelated (13). High soil pH values tend to promote the uptake of substantially large amounts of basic cations resulting in a higher leaf pH. Cain (13) found that this condition resulted in chlorosis, which could be prevented by increasing soil acidity or creating better conditions in the nutrient environment. Although pH was adjusted in the present experiment no chlorosis symptoms were noted. The toxicity of higher levels of nitrate was, however, more prevalent at higher pH values in both high and low water table treatments.

V. SUMMARY

The effect of waterlogging on the growth and mineral composition of the highbush blueberry was investigated using one year old plants of the variety "Bluecrop" grown under greenhouse conditions. Under waterlogging, growth retardation was observed in all the parameters studied: namely shoot length, shoot number, leaf number and leaf area. Significant interactions were obtained between water table and pH on the growth factors studied. Shoot length was affected by the rate and source of N under the two water regimes. At lower concentrations of both nitrate and ammonium forms of N, the adverse effect of waterlogging manifested itself in the form of shorter and more compact plants. This was evident in the check as well as the treatment receiving 20 lbs. per acre of N. Severe yellowing and premature leaf aging was also characteristic of the waterlogged treatments. More obvious than any other factor was the effect of a high water table on leaf nutrient composition. Leaf N, P, K, Ca, Mg, and Fe levels in the leaves were all significantly lower than in plants maintained under free-drained conditions. A greater disparity was seen between the two systems of water management in October. The overall reduction of foliar nutrients with the presence of a high water table in the highbush blueberry, suggests the need for aeration. The deficiency values suggested in Table 1 and the obtained levels (Table 4), show that the high water

table treatments were deficient in leaf N, K, and Ca. Of these, the most pronounced deficiency was that of N, which hardly increased until October when plants were waterlogged.

Many workers have stressed the importance of soil pH for blueberries. The critical range was presumed to be between pH 4.2 and pH 4.8. Four pH levels were manipulated by the addition of lime giving pH levels of 3.4, 4.3, 5.2, and 6.0. Some effects of pH on growth were significant. With increase in pH from 3.4 the amount of shoot growth appeared to increase. A higher leaf number was also obtained at pH 4.3. Leaf number and leaf area were, however, influenced both by pH and water table as cited earlier. Except for small differences in leaf N in October and leaf K in August and October, levels of no element appeared to be affected by pH.

Of the two forms of nitrogen used in the experiment, it was clearly demonstrated that the ammonium form of N was taken up in larger amounts, giving significantly higher leaf N values. Although leaf N levels increased with increasing doses of N, shoot growth and general performance of the highbush blueberry seemed better with lower doses (20 and 40 lbs.) of N fertilizer, especially with the ammonium form of N. In the nitrate form, soil pH and rate of application are vital. If the level exceeds 20 lbs. N per acre, nitrate toxicity may result in severe leaf-burn and perhaps ultimate death of the plant. These symptoms were more severe at the higher pH levels than when the soil was maintained at pH 3.4. The unfertilized plants exhibited more multiple deficiency symptoms when the peat was

not limed, indicating the need for supplementing plant nutrient needs when highbush blueberries are grown in raw peat.

The success of blueberry cultivation depends to a large extent on specific climatic and edaphic factors. From these studies and from previous investigations made elsewhere, it is apparent that the plant is peculiar in its nutrient requirements. As a member of the Heath family, Ericaceae, the highbush blueberry is distinctive as a group, showing preference for elements that are in preponderance in nutrient environments essentially acid in nature.

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Dr. C.A. Hornby, Division of Plant Science
Dr. D.P. Ormrod, Division of Plant Science

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