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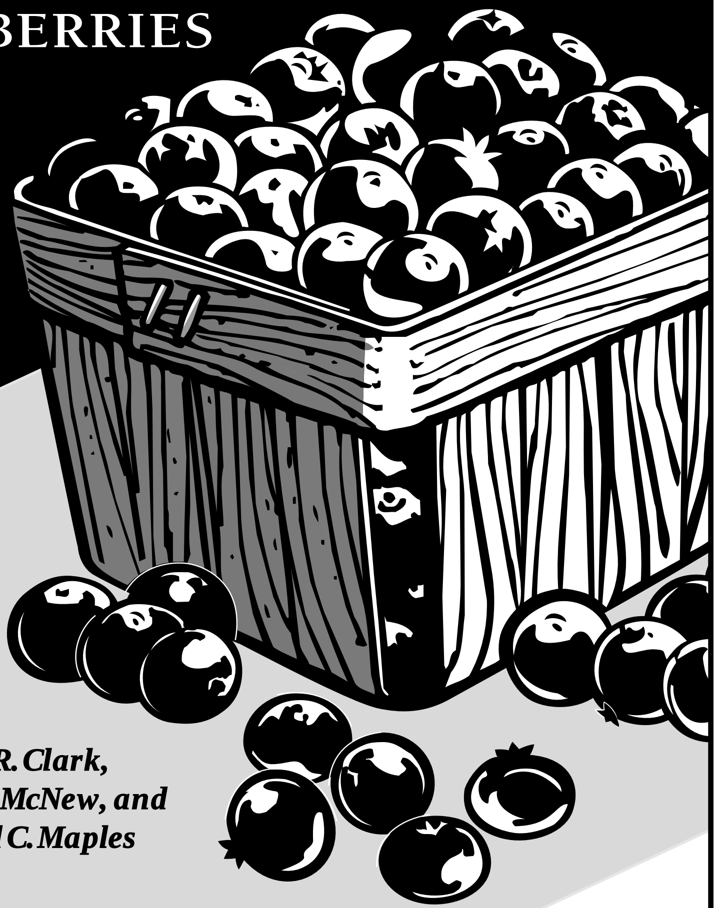

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ARKANSAS AGRICULTURAL EXPERIMENT STATION

Division of Agriculture | University of Arkansas

June 1999 | Research Bulletin 961

Editing and cover design by Karen Eskew

Arkansas Agricultural Experiment Station, University of Arkansas Division of Agriculture, Fayetteville. Milo J. Shult, Vice President for Agriculture and Director; Charles J. Scifres, Associate Vice President for Agriculture. PS1.2699PM65. The Arkansas Agricultural Experiment Station follows a nondiscriminatory policy in programs and employment.

ISSN:0097-3491 CODEN:AKABA7

INFLUENCE OF NITROGEN RATE AND SAMPLING DATE ON SOIL ANALYSIS VALUES OF HIGHBUSH BLUEBERRIES

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SUMMARY

Three studies were conducted on nitrogen (N) fertilization effects on soil of highbush blueberries in Arkansas. Objectives included: 1) determination of varying N rate effects on the standard soil analysis variables, 2) determination of date of soil sampling effects on soil analyses, 3) evaluation of the interactions of N rate and time of sampling, and 4) determination of changes in soil content over years. This research was done in two of the more important highbush blueberry production areas in Arkansas: the Arkansas River Valley where blueberries are grown on sandy loam soils, and northwest Arkansas where production is more common on silt loam soils. This information provides greater insight into the soil dynamics of highbush blueberry plantings in Arkansas and can be used to increase precision of fertility and other soil property recommendations provided to growers.

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ACKNOWLEDGMENTS

The authors wish to thank Mr. James Cox of Cox Berry Farm, Clarksville, Arkansas, for providing areas of his blueberry fields for a portion of the studies reported in this publication. Thanks also to Dr. James N. Moore for allowing the use of the 'Collins' blueberry plots in his research program at the Arkansas Agricultural Research and Extension Center, Fayetteville. Appreciation is expressed to Gina Fernandez, Kelly Irvin, and Bruce Bordelon for assistance in collecting and handling soil samples in the studies reported herein.

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INTRODUCTION

Blueberry fertilization is largely based on the annual application of nitrogen (N) fertilizers. Two major factors affecting N fertilization include form and rate of the fertilizer material applied. Cain (1952) reported that the ammonium form of N was preferable to nitrate for blueberries and was also essential for normal growth. Townsend (1967) agreed that for sand culture, ammonium forms of N or ammonium N plus nitrate N were preferable to nitrate N alone for highbush blueberries. A major consideration of blueberry growers is which form of the common N fertilizers should be used. Pritts and Hancock (1992) recommended that urea be used if the soil pH is less than 5.0, while ammonium sulfate be applied if the pH is above 5.0. Clark (1994) and Patterson (1993) recommended to Arkansas growers that ammonium sulfate be used if pH is 5.3 or above, while urea be applied if pH is 5.2 or below.

Numerous studies determined the response of highbush blueberries to varying levels of soil-applied N. Bailey *et al.* (1966) in Massachusetts found that increasing ammonium sulfate level from 0.5 lb / plant (equivalent N of 114 lb / acre or 128 kg / ha) to 2.0 lb / plant (N equivalent of 456 lb / acre or 512 kg / ha) increased the N level in the leaves in two of four years of the study. The average leaf N levels were 1.71, 1.83 and 1.86 % dry weight for the 0.5, 1.0 and 2.0 lb / plant rates, respectively. Bishop *et al.* (1971) in Nova Scotia reported no effect from N source (ammonium sulfate, urea, or ammonium nitrate) on leaf levels of highbush blueberries growing on a sandy loam soil with a pH of 4.0, although increasing N rate enhanced leaf N levels. Townsend (1973) found that 'Bluecrop' plants fertilized with ammonium sulfate with increasing rates over a seven-year period had lower yields than non-fertilized plants. He suggested that highbush blueberries have a lower fertilizer demand and that applications of fertilizers in the amounts common to other crops may be excessive for blueberries. He also reported on the effect of ammonium sulfate on soil analysis values, and found that soil pH, calcium (Ca) and magnesium (Mg) were reduced while phosphorus (P) increased and potassium (K) levels were unaffected by ammonium sulfate applications. In an eight-year study, Cummings (1978) and Cummings *et al.* (1971) reported that the application of ammonium nitrate (full rates applied to fruiting plants in years three to eight of 30, 75, and 150 lb/acre N or 34, 84, and 168 kg/ha N) increased soil pH and decreased K level on a fine sandy soil in North Carolina. They suggested that the increase in pH with increasing levels of N fertilizer was due to soil organic matter breakdown that resulted from N application. Foliar N, K, and iron (Fe) levels were increased with greater levels of N application, although there was some variation among years. The application of N reduced foliar Ca and Mg. Fruit yields were similar for the two lower N rates while the highest N rate reduced yields and berry weight.

Eck (1977) found that the application of more than 30 lb/acre (34 kg/ha) of N (using ammonium sulfate as the N source) to an Atsion sand did not result in increased blueberry yields. He also found that the application of more than 57 lb/acre N (64 kg/ha) may have reduced fruit production. Eck evidenced this when increasing N rates resulted in reduced foliar K in two of five years and reduced Ca in four of five years of his study. Magnesium levels were reduced by increased N rate in two of five years. Fruit load on the plants affected foliar N. During heavy fruit production years, N levels were reduced. In years with lighter crops, foliar levels were increased. Martin and Pelofske (1983) conducted a study in Oregon which focused on N rate response on highbush blueberries grown on a mineral soil with sawdust mulch applied to the plants. In their study, ammonium sulfate was applied at rates of 25, 75, 125, 175, and 225 lb of actual N/acre (28, 84, 140,196, and 252 kg/ha) in split applications (three applications/season) over a four-year period. Their results indicated increased rates of ammonium sulfate decreased soil pH. The pH of soil in the area of the 25 lb N/acre (28 kg/ha) application had a pH of 5.1 after two seasons and the 225 lb/acre N (252 kg/ha) had a pH of 4.2. Their data showed little to no reduction of soil pH for the following two years regardless of the N application levels. This indicated that the reduction of soil pH did not continue during the entire experiment. Soil Ca and Mg levels decreased with increased ammonium sulfate applications. Foliar N and manganese (Mn) increased while foliar Mg decreased with increasing ammonium sulfate rates. Fruit yields were highest for the 125 lb N/acre in 1976 and 1977, but the 75 and 125 lb N/acre treatments had similar yields in 1978 and 1979, suggesting an early N deficiency for highbush blueberry. They concluded that a fertilization rate of about 89 lb N/acre (100 kg/ha) was sufficient to maintain high fruit yields for mulched highbush blueberries grown on mineral soils.

These studies lay the foundation for recommendations for commercial growers in most highbush blueberry production regions. The standard N rate recommended for mature highbush plantings is 60 to 65 lb/acre N (67-73 kg/ha) on unmulched soils (Eck, 1988; Mainland, 1985; Pritts and Hancock, 1992). Most of these recommendations also suggest that the N rate be increased 50 to 100% if the plants are mulched with organic materials such as sawdust. In the Pacific Northwest, higher N rates of 100 to 150 lb/acre N (112 to 168 kg/ha) are recommended with sawdust-mulched plantings needing 50 to 100% more N depending on the degree of sawdust decomposition (Strik and Hart, 1991).

Our studies provide information on N fertilization effects on soils of highbush blueberries in Arkansas. Objectives included: 1) determining varying N rate effects on the standard soil analysis variables, 2) determining date of soil sampling effects on soil analyses, 3) evaluating the interactions of N rate and time of sampling, and 4) determining changes in soil content over years. This research was done in two of the more important highbush blueberry production areas in Arkansas: the Arkansas River Valley where blueberries are grown on sandy loam soils, and northwest Arkansas where production is more common on silt loam soils. A major focus of our studies was to produce information to enhance the precision of fertility recommendations from analyses for sandy loam and silt loam soils.

MATERIALS AND METHODS

This report includes data from three studies on highbush blueberries; one conducted at the Arkansas Agricultural Research and Extension Center, Fayetteville, and two in a commercial blueberry planting in Johnson County, northeast of Clarksville. The specific treatments and other components of each study are outlined below.

Study 1: **Bluecrop mulched (BCMU) and Study 2: Bluejay non-mulched (BJNM)**. These studies consisted of 'Bluecrop' and 'Bluejay' plants established in 1981 near Clarksville on a Linker fine sandy loam soil (fine-loamy, silicious, thermic Typic hapludults). The plants were mulched at planting but the mulch on the 'Bluejay' plants had decomposed by the time of the initiation of this study in 1988, and the 'Bluejay' site was considered non-mulched since no mulch residue was present.The 'Bluecrop' plants had a bark / sawdust mulch maintained during the entire study to a depth of 6 inches (15 cm). All plants were spaced 4 ft. apart with 10 ft. between rows (1.2 m x 3 m). Similar cultural practices were carried out on these plots including annual preemergence herbicide applications, trickle irrigation, and annual dormant pruning. The planting was maintained with sod middles with no tillage. N rates for these studies were 20, 60, and 120 lb actual N / acre (22, 67, and 134 kg / ha) and treatments began in 1988 and continued through 1991. Urea (46% N) was used as the N source in these studies. For a treatment, a replicate consisted of six plants, with the area under the four inner plants systematically sampled, leaving a two-plant border between plots. Both studies were arranged as a randomized complete block design.

Study 3: Collins mulched (COMU). This study, located in Fayetteville, consisted of 'Collins' planted in 1981. All plants in the study were mulched with hardwood sawdust mulch maintained at a depth of 6 inches (15 cm). Plants received annual preemergence herbicide applications, trickle irrigation and annual dormant pruning, and sod middles were maintained between the rows. The soil type in this study was a Captina silt loam (mixed, mesic, Typic Fragidult), and the plants were spaced 4 ft. x 10 ft. (1.2 m x 3 m). N rates in this study were 0, 60, 120, and 180 lb N / acre (0, 67,134, and 201 kg / ha) with the 60 and 120 lb / acre rates applied from 1988 through 1991, the 0 lb / acre rate from 1989 through 1991, and the 180 lb / acre rate applied only in 1991. Ammonium sulfate (21% N) was the N source in this study. There were four replications of each treatment arranged in a randomized complete block design with a 6 ft. open-space border between plots.

In all studies, the annual total N applied was divided into three applications, with the first application at budbreak, followed by a second and third application applied at 6 and 12 weeks. All N materials were surface-applied and rainfall or trickle irrigation was used to incorporate the N into the soil.

Soil samples were collected in March (prior to fertilization) and early August (at the standard time for foliar sampling) each year from all plots. The initial sampling was done in March 1988 and the final sampling in March 1992 which completed the soil sampling cycle for four years. Samples were taken from the topsoil only to a depth of 8 in. (20.3 cm) under the dripline of the plants which was in the area of N application and where roots were present. A total of 10 random soil probe cores per replicate were collected. Samples were analyzed by the University of Arkansas Soil Testing and Research Laboratory in Marianna, and procedures included pH measurement using a 1:1 ratio of soil to water, nitrate using specific ion electrode (Gaines and Mitchell, 1979), electrical conductivity (EC) by 2:1 dilution with deionized water and measuring with a fixed-cell probe, and elemental analysis using Mehlich 3 extraction (Mehlich, 1984) followed by measurement by inductively coupled plasma spectrophotometry.

Data on soil properties were analyzed separately by study. Statistical computing was done by the GLM procedure of SAS (SAS Institute Inc., 1989). The analysis of variance for an experiment was conducted as a split plot in time (Steel and Torrie, 1980), in which the treatment factor was N rate and the time factor was sample date. Means were separated by multiple *t* tests. Spring-sampled data were analyzed by polynomial regression to investigate trends across years; spring, rather than fall data were expected to reflect long-term trends that may exist for soil attributes. Statistical significance was declared at the 5% level of significance, unless otherwise indicated.

RESULTS AND DISCUSSION

Electrical conductivity, pH, and nitrate had significant main effects and interaction of N rate and date of sampling in all three studies. For most soil elements (except sulfur [S] and Mn), N rate had no effect on soil content, although date of sampling was significant. The following discussion explains the findings for each variable measured for the three studies.

EC. Electrical Conductivity is a measure of salt level in the soil usually resulting from fertilizer application. For Study 1 (BCMU), the 20 and 60 lb / acre N rates for most years had no differences in EC level when the current-year spring (prior to fertilizing) and summer (in August at the time of foliar sampling) samples were compared (Fig. 1). Likewise, in most years there were no differences in the mean EC level for the summer vs. the following spring sample for the 20 lb / acre N rate. There was a difference for the 60 lb / acre N rate for three of the four years. For the 120 lb / acre N rate, the summer EC level was significantly higher than the spring level in three of the four years of the study. In all years the EC level was significantly lower in the spring compared to the previous summer. For Study 2 (BJNM), the lowest N rate (20 lb / acre) had similar EC levels among most within-year sample dates (Fig. 2). For the 60 and 120 lb /

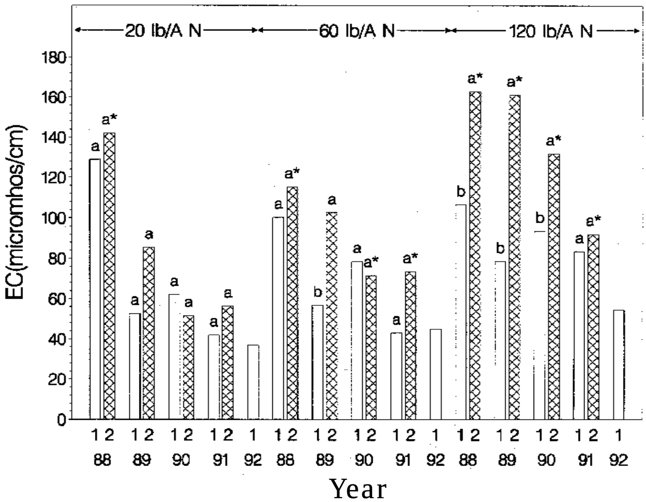

Fig. 1. Soil electrical conductivity (EC) for 'Bluecrop' mulched (BCMU) samples collected in the spring (1) at budbreak or summer (2) in early August from 1988 to 1992 for three N rates. The same letters by adjacent columns (representing mean EC values within N rate and year) indicates no significant difference between the two EC values. Letters followed by an asterisk indicate that there was a significant difference between that value and the value for the following spring.

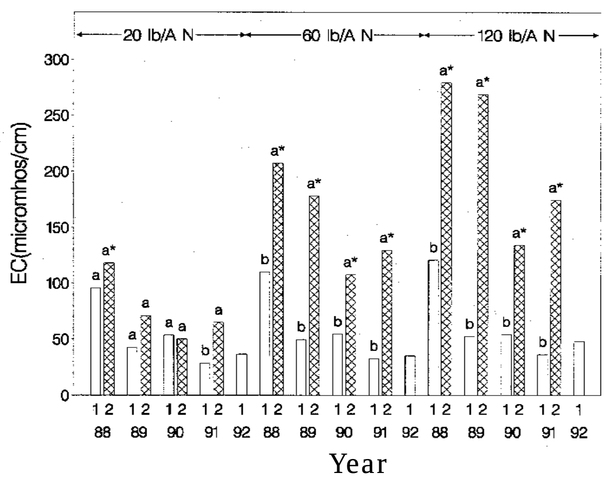

Fig. 2. Soil electrical conductivity (EC) for 'Bluejay' non-mulched (BJNM) samples collected in the spring (1) at budbreak or summer (2) in early August from 1988 to 1992 for three N rates. The same letter by adjacent columns (representing mean EC values within N rate and year) indicates no significant difference between the two EC values. Letters followed by an asterisk indicate that there was a significant difference between that value and the value for the following spring.

acre N rates, the summer EC levels were always significantly higher than those of either the previous or following spring indicating a seasonal effect of N rate on EC levels. For Study 3 (COMU), the 0 lb / acre N rate values for EC were similar within years for sample date with the exception of the summer 1990 EC level, which was higher than the previous spring (Fig. 3). Also for the 0 rate, the summer values for 1989 and 1990 were higher than the following spring levels. This indicates that some variation existed in EC levels in this study even where no fertilizer had been applied, especially in comparing summer with the following spring. For the other N rates, most of the spring vs. summer comparisons were significant, with the summer EC levels highest except for 1991 when the values for spring and summer were statistically similar for 60 and 120 lb / acre N rates. The greatest difference in EC levels occurred in 1990 when the EC was over 320 micromhos / cm greater for the 120 lb / acre N rate for the summer compared to the previous spring value. For all three studies, regression analysis for EC indicated some significant trends but these were all of higher order (quadratic or cubic). No studies indicated any practical trends for use in interpreting EC findings.

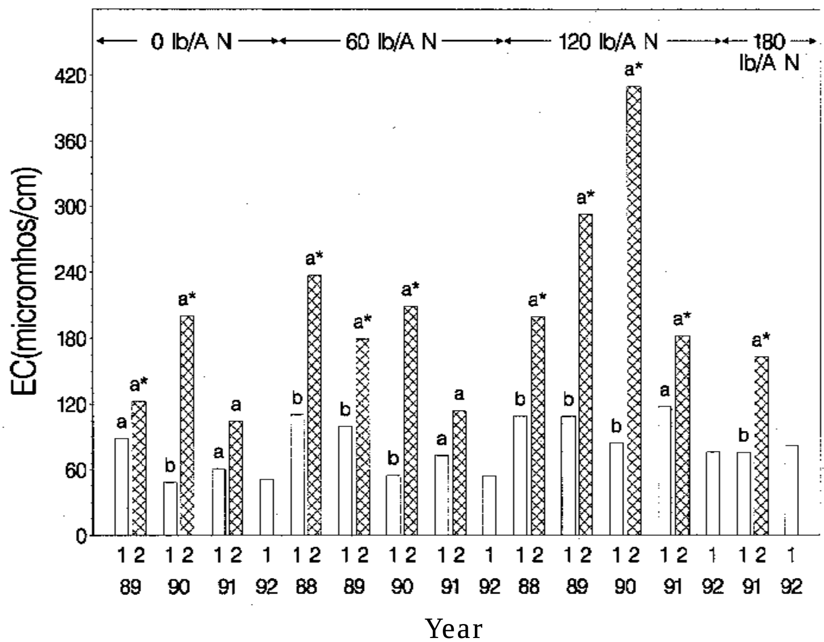

Fig. 3. Soil electrical conductivity (EC) for 'Collins' mulched (COMU) samples collected in the spring (1) at budbreak or summer (2) in early August from 1988 to 1992 for three N rates and a control. The same letter by adjacent columns (representing mean EC values within N rate and year) indicate no significant difference between the two EC values. Letters followed by an asterisk indicate that there was a significant difference between that value and the value for the following spring.

Several practical comments can be made from the EC data. The most obvious finding is the consistently higher summer vs. spring EC levels where higher N rates were used. Additionally, BCMU had similar summer vs. spring values for the 20 and 60 lb / acre N rate, while the BJNM plots had differences in EC levels among all sample dates at the 60 lb / acre N rate. Although the levels among studies cannot be statistically compared, it appeared that the presence of mulch in BCMU may have lowered the EC level at the 60 lb / acre rate compared to the non-mulched 'Bluejay' (the average summer EC value for four years for the 60 lb / acre N rate was 93 for BCMU and 154 for BJNM). The overall EC levels for all rates were lower for BCMU compared to BJNM even though all plots were a Linker fine sandy loam soil. These findings should be considered when evaluating plantings if management decisions are being made based on the presence or absence of mulch. Following University of Arkansas Cooperative Extension Service guidelines, fertilizer reductions for the current or following year are suggested if EC levels are above 200 micromhos / cm on sandy and silt loam soils (Chapman, 1998). In our data, many of the summer EC levels exceeded 200 micromhos, and for each sample location, the average EC value in the following spring was below 200 micromhos / cm. Therefore, if growers have excessive EC levels in their soils at the time of foliar sampling, then soil sampling should be repeated before spring fertilizing, ensuring that appropriate N rates are chosen.

Nitrate. Sample analysis for nitrate is done for the same reason as EC, to determine excess salt levels in the soil. The findings for nitrate closely reflect those for EC. For BCMU and BJNM, the 20 lb / acre N rate had statistically similar nitrate levels both within year or when comparing the summer with the following spring for most dates. Higher rates of N resulted in differences in nitrate levels for almost all date comparisons (Figs. 4 and 5). For COMU, results were similar with the exception of a significantly higher nitrate level where no N had been applied in 1990 (Fig. 6). As with EC, regression analyses for all locations did not indicate any practical trends for nitrate.

Our findings emphasize the influence of date of sampling on background salt levels in the soil. The Extension Service guidelines indicate that recommended fertilizer amounts be reduced if nitrate levels exceed 20 lb nitrate N / acre (Chapman, 1998). Based on these guidelines, fertilizer reductions are suggested where high salt concentrations predominate. Samples taken from these same areas in the spring prior to fertilizing are considered to have acceptable nitrate levels.

pH. pH is most important to blueberry health because blueberries are acid-loving plants that grow in soils with a very narrow optimum pH range (5.0 to 5.2) in Arkansas. In our studies, the effects of N rate and time of sampling were distinct among the plantings. The data from BCMU revealed that time of sampling and rate of N had no significant effect on pH (Fig. 7). The pH did decline yearly for samples taken in the spring (Fig. 8). The pH values diminished faster for the largest N application. The low pH is of concern since in 1992 values were below the recommended level of 5.0 to 5.2 for blueberries in Arkansas, indicating that at least at BCMU pH might require attention, especially if excess levels of Mn are found in foliar samples.

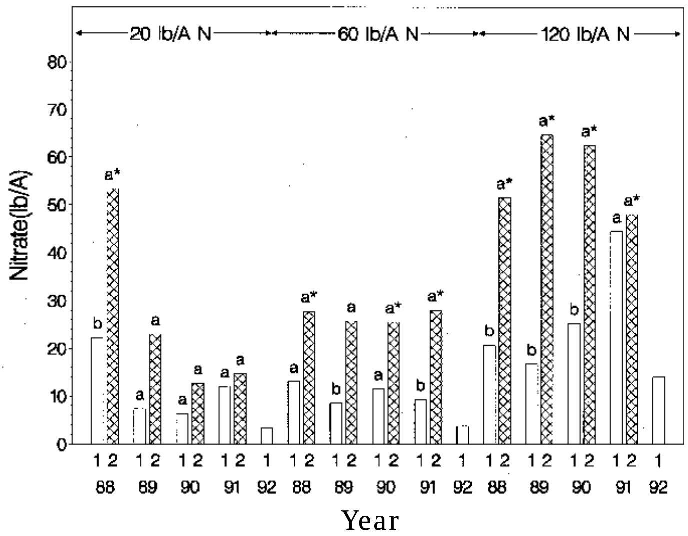

Fig. 4. Soil nitrate for 'Bluecrop' mulched (BCMU) samples collected in the spring (1) at budbreak or summer (2) in early August from 1988 to 1992 for three N rates. The same letter by adjacent columns (representing mean nitrate values within N rate and year) indicates no significant difference between the two nitrate values. Letters followed by an asterisk indicate that there was a significant difference between that value and the value for the following spring.

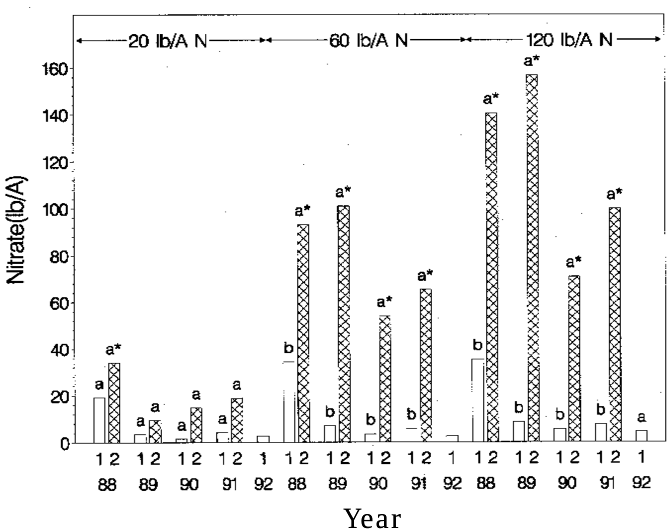

Fig. 5. Soil nitrate for 'Bluejay' non-mulched (BJNM) samples collected in the spring (1) at budbreak or summer (2) in early August from 1988 to 1992 for three N rates. The same letter by adjacent columns (representing mean nitrate values within N rate and year) indicates no significant difference between the two nitrate values. Letters followed by an asterisk indicate that there was a significant difference between that value and the value for the following spring.

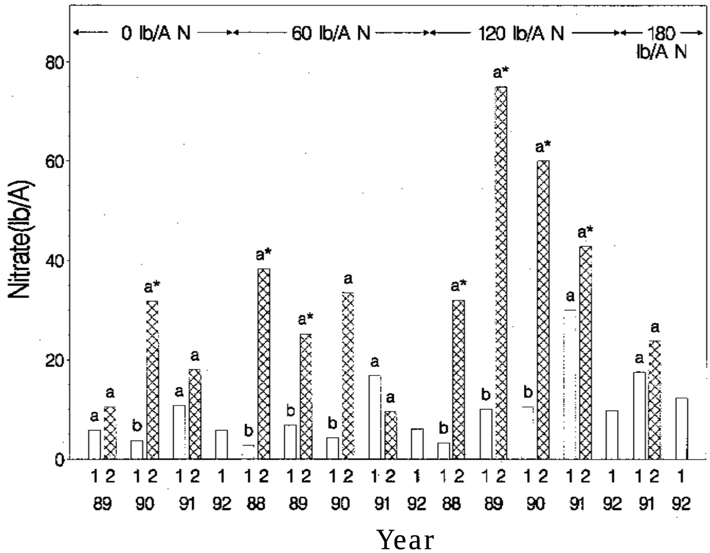

Fig. 6. Soil nitrate for 'Collins' mulched (COMU) samples collected in the spring (1) at budbreak or summer (2) in early August from 1988 to 1992 for three N rates and a control. The same letter by adjacent columns (representing mean nitrate values within N rate and year) indicates no significant difference between the two nitrate values. Letters followed by an asterisk indicate that there was a significant difference between that value and the value for the following spring.

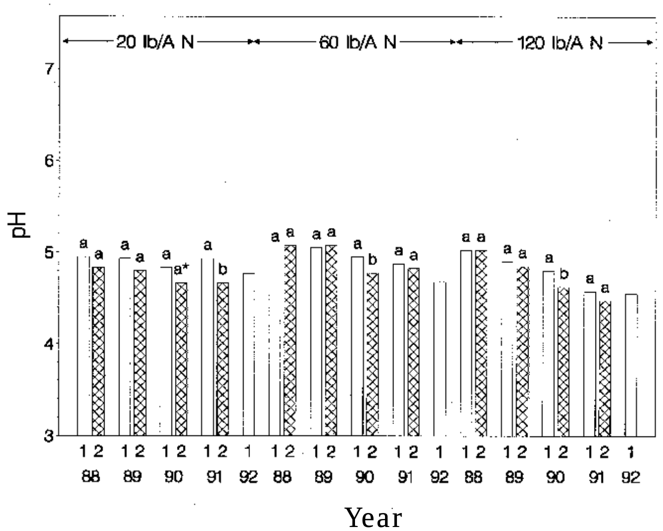

Fig. 7. Soil pH for 'Bluecrop' mulched (BCMU) samples collected in the spring (1) at budbreak or summer (2) in early August from 1988 to 1992 for three N rates. The same letter by adjacent columns (representing mean pH values within N rate and year) indicates no significant difference between the two pH values. Letters followed by an asterisk indicate that there was a significant difference between that value and the value for the following spring.

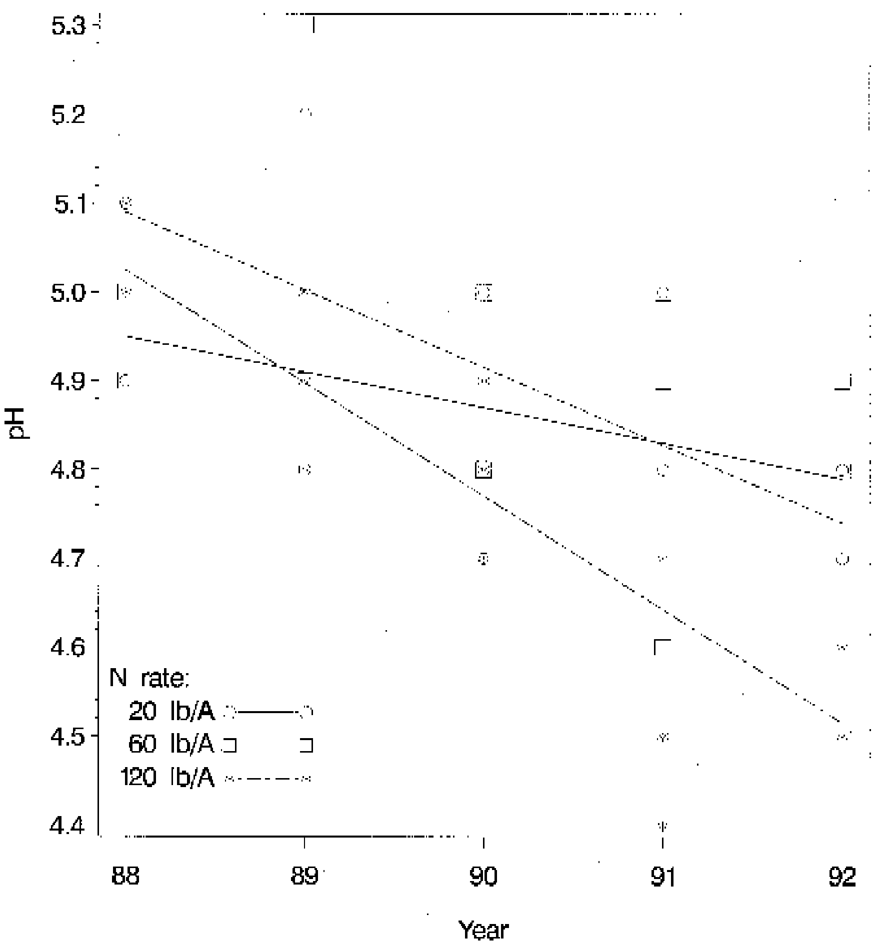

Fig. 8. Linear regression of pH on year by N rate for 'Bluecrop' mulched (BCMU) for spring samples from 1988-1992.

For BJNM, pH decreased yearly for the fertilizer treatments (Figs. 9 and 10), and was lower for the summer samples. However, for the 20 lb / acre rate, significant annual reduction was not found. Annual reduction for pH of 0.14 and 0.18 units was predicted for 60 and 120 lb / acre, respectively. Noteworthy is the greater annual reduction in pH for BJNM compared to BCMU. In both locations, initial pH in 1988 was around 5.0. In 1992, pH fell to 4.2 for the highest N rate for BJNM and 4.6 for BCMU. For COMU, the 0 lb / acre N rate was associated with summer pH values 0.5 pH units lower than the previous spring (Fig. 11), indicating a natural, seasonal reduction in pH. For 60 lb / acre N, there were few significant differences for summer vs. the following spring comparisons. The regression analysis indicated a significant linear response (regression did not include the 180 lb / acre rate due to limited data for this rate) (Fig. 12). Little to no change in pH was found for the 0 and 60 lb / acre rates over time, while the 120 lb / acre rate had an annual predicted reduction in pH of 0.27 units. Of note is the substantial reduction over time of the high pH (approximately 6.0) at the beginning of the study to 5.1 by the spring of 1992 for the 120 lb / acre rate. Thus, using ammonium sulfate successfully reduced pH over time.

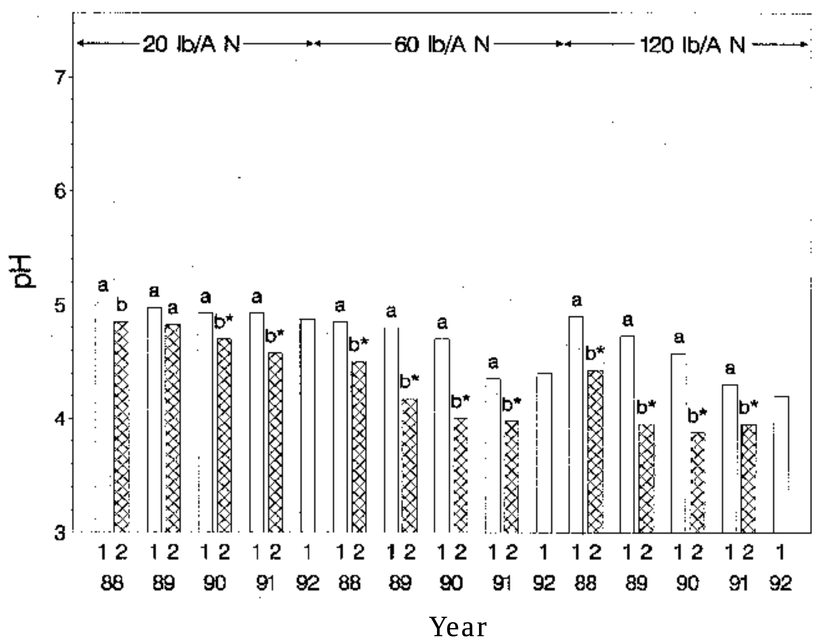

Fig. 9. Soil pH for 'Bluejay' non-mulched (BJNM) samples collected in the spring (1) at budbreak or summer (2) in early August from 1988 to 1992 for three N rates. The same letter by adjacent columns (representing mean pH values within N rate and year) indicates no significant difference between the two pH values. Letters followed by an asterisk indicate that there was a significant difference between that value and the value for the following spring.

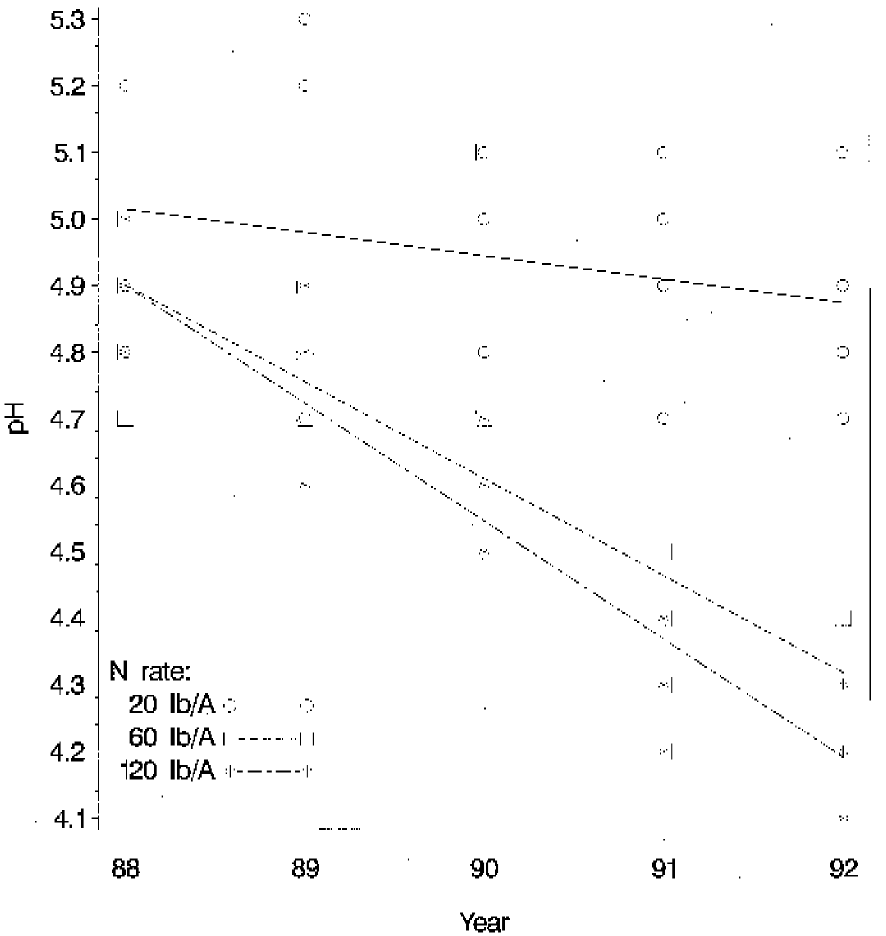

Fig. 10. Linear regression of pH on year by N rate for 'Bluejay' non-mulched (BJNM) for spring samples from 1988-1992.

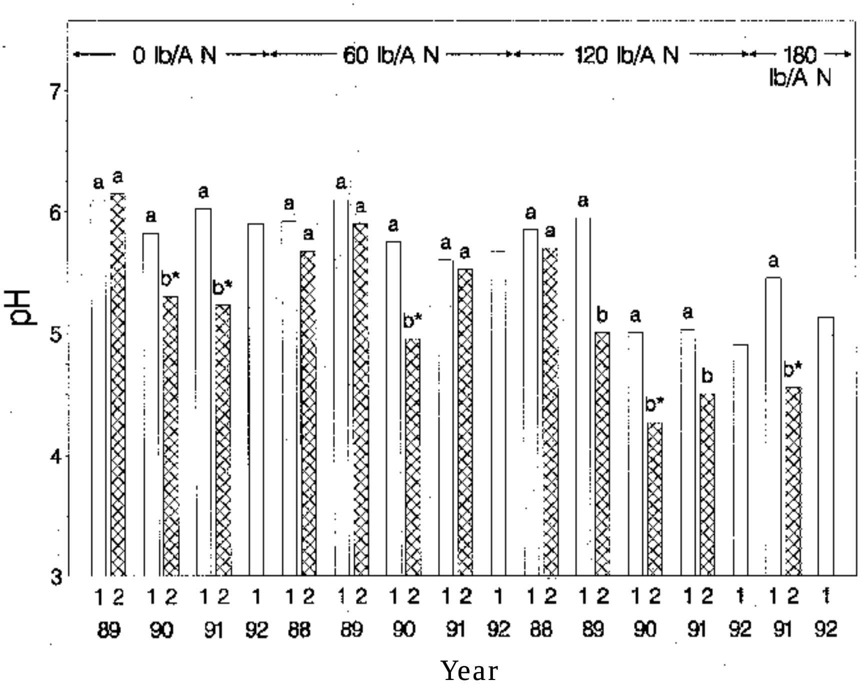

Fig. 11. Soil pH for 'Collins' mulched (COMU) samples collected in the spring (1) at budbreak or summer (2) in early August from 1988 to 1992 for three N rates and a control. The same letter by adjacent columns (representing mean pH values within N rate and year) indicates no significant difference between the two pH values. Letters followed by an asterisk indicate that there was a significant difference between that value and the value for the following spring.

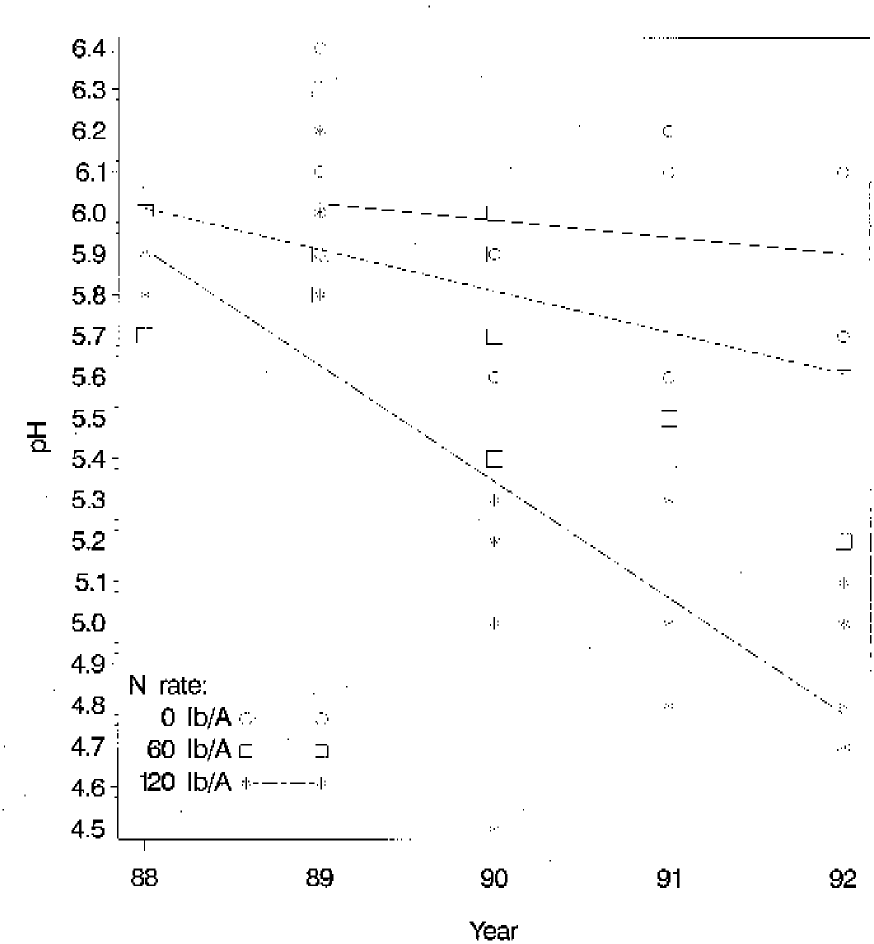

Fig. 12. Linear regression of pH on year by N rate for 'Collins' mulched (COMU) for spring samples from 1988-1992.

Our results corresponded with Townsend (1973) and Martin and Pelofske (1983) who found that ammonium sulfate reduced pH in blueberry plantings. Cummings (1971, 1978) reported an increase in soil pH with increased N applications, and he suggested that this pH increase was due to increased organic matter breakdown at the higher N rates. Although an increase in pH with increased N rates was not seen in our studies, it is noteworthy that overall there was usually less long-term pH reduction where mulch was present.

These studies provide several conclusions for blueberry growers to consider. First, the differences between spring and summer pH levels, especially at higher N rates, are important in that mistakes in management related to pH could be made if the pH of summer samples is used for decision-making purposes. For instance, the choice of N fertilizer should be based on soil pH prior to the growing season, or time of spring fertilization since this pH value best reflects the true pH for the site. Soil pH values, which are not the best reflection of this planting, can lead to the wrong fertilizer being used. Growers in Arkansas usually use either ammonium sulfate or urea when N alone is applied, and the choice of materials is based on soil pH. Ammonium sulfate is recommended when soil pH is 5.3 or above and urea for pH of 5.2 or below, independent of when the sample is collected. Therefore, a true pH reading is necessary to avoid inappropriate fertilizer application, which can lead to either too high or too low pH both within that growing season or in subsequent seasons when additive pH effects lower the overall pH over time. Secondly, if adjustments to pH using elemental sulfur or lime are considered, it is imperative that the correct pH of the planting be determined before these decisions are made. The impact of N application on BJNM at higher N rates was very distinct and led to a substantial decline in pH over the time of the study, while N applications on the mulched plants on the same soil type had less impact both within year and in the continuing years of the study. Additionally, the COMU planting had reductions in pH due to ammonium sulfate application, but the impact was mostly confined to the 120 and 180 lb / acre N rates. Therefore, growers should be aware of the buffering effects of mulch and soil type on soil pH when making management decisions.

Potassium. Soil levels of K were not affected by N rate in any of our studies, although K differences were reflected in date of sampling (Table 1). Differences for within-year samples were found although no consistent trend for date of sample was revealed. In the regression analysis of spring-only K values for BCMU and BJNM, the linear and quadratic effects were significant and the mean spring values in Table 1 showed the trend of reductions in K levels for several years followed by a leveling off of these reductions in 1991 and 1992 (regression not shown). For COMU, the linear, quadratic and cubic effects were significant, showing a slightly different trend of K level decline, but overall the K level was lower at the end of the study than at the beginning. Our results agreed with Townsend (1973), who reported no effect of ammonium sulfate application rates on soil K, but did not correspond with Cummings (1971, 1978), who reported decreased soil K with increased N rate.

Table 1. Soil analysis potassium (K) values (lb/acre)for 'Bluecrop' mulched (BCMU), 'Bluejay' non-mulched (BJNM) and 'Collins' mulched (COMU) for samples from spring and summer of 1988-92.

	BCMU		BJNM		COMU	
Year	Spring	Summer	Spring	Summer	Spring	Summer
1988	127 b[z]	148 a*	200 a	193 a*	239 a	216 b*
1989	95 a	80 b	128 a	112 a	182 a	184 a*
1990	74 a	70 a	103 a	95 a	170 a	162 a
1991	58 a	52 a	85 b	130 a*	158 a	108 b*
1992	55	-	89	-	122	-

[z] Mean separation within year among sample dates within location by *t* test ($P<0.05$).
*Significant difference ($P<0.05$) between summer and subsequent spring by *t* test.

These reductions of K in our studies are probably due to removal of K in fruit at harvest and from losses due to leaching from the soil. The reductions in K levels ranged from 32 to 72 lb/acre between spring 1988 and 1989 for BCMU and BJNM, respectively, but annual reductions for other years for all locations were less. Our data showed that K levels are reduced over time, a decline in K values should be anticipated by blueberry growers, and K levels could become limiting over time. Rate of N should not be a concern in the management of K levels in soils of blueberry plantings, however.

Phosphorus. Values for P were not affected by N rate, but P levels differed with sample date. For BCMU and BJNM, there were few significant differences for within-year comparisons (Table 2). For summer compared to the following spring, three differences were found (Table 2), however, neither spring nor summer values were consistently higher. For COMU, summer P levels were higher for summer samples either within- or among-years for three of four years, but the differences were not of a magnitude to affect management decisions for P applications. The regression analysis on spring values indicated no clear trend in P levels for any of the studies. The data in Table 2 shows the fluctuations in P levels over the years of investigation. Our data disagreed with Townsend (1973), who reported P levels increased with increasing am-

Table 2. Soil analysis phosphorus (P) values (lb/acre) for 'Bluecrop' mulched (BCMU), 'Bluejay' non-mulched (BJNM) and 'Collins' mulched (COMU) for samples from spring and summer of 1988-92.

	BCMU		BJNM		COMU	
Year	Spring	Summer	Spring	Summer	Spring	Summer
1988	171 a[z]	156 a*	254 b	275 a	77 b	101 a
1989	238 a	208 b	258 a	273 a*	99 a	110 a*
1990	213 a	230 a	297 a	280 a	74 b	98 a*
1991	223 a	212 a	260 a	253 a*	66 a	62 a
1992	195	-	227	-	57	-

[z] Mean separation within year among sample dates within location by *t* test ($P<0.05$).
* Significant difference ($P<0.05$) between summer and subsequent spring by *t* test.

monium sulfate applications. From a management standpoint, our data do not reflect any clear effects of N rate or sample date on P levels for blueberry growers to consider.

Calcium. As with other elements, Ca levels were not influenced by N rate but were affected by sample date. Again, no consistent seasonal high or low trend was evident in the data (Table 3). The regression analysis on spring Ca levels for BCMU showed significant linear and cubic responses, and the data in Table 3 reveal that overall the Ca levels decreased over time with the exception of a higher level for 1990. The BJNM regression showed significant linear response only, and the decline in Ca in this planting is clearly seen in the spring values. For COMU, the regression did not show any interpretable or consistent trends, and the spring values showed fluctuation among years. Our data did not agree with Townsend (1973) or Martin and Pelofske (1983), who found Ca levels reduced by increased N application; our Ca levels changed only due to sample time.

Arkansas blueberry growers have more concerns with high or excess Ca, and applications are rare unless soil pH is too low. Our data indicate that, on a sandy loam soil with low Ca level, Ca decreased over time. A soil higher in Ca did not consistently change in the same time period. Growers who are concerned with Ca level should monitor this with routine soil samples to determine changes over time in soil Ca.

Table 3. Soil analysis calcium (Ca) values (lb/acre) for 'Bluecrop' mulched (BCMU), 'Bluejay' non-mulched (BJNM) and 'Collins' mulched (COMU) for samples from spring and summer of 1988-92.

	BCMU		BJNM		COMU	
Year	Spring	Summer	Spring	Summer	Spring	Summer
1988	1122 bz	1723 a**	846 a	917 a**	2420 b	3075 a**
1989	838 b	1058 a	676 a	637 a	2350 b	2962 a**
1990	1025 a	818 a	623 a	479 b	1964 b	2398 a
1991	638 a	814 a	445 a	415 a	2315 a	1974 b
1992	642	-	333	-	1810	-

[z] Mean separation within year among sample dates within location by *t* test ($P<0.05$).
**Significant difference ($P<0.01$) between summer and subsequent spring by *t* test.

Magnesium. No N rate effects were seen on soil Mg, although sample date influenced Mg. Only scattered differences among Mg levels for sample date were found, and no seasonal trends were evidenced (Table 4). Regression analysis on spring Mg levels indicated a significant linear trend for COMU, linear and quadratic trends for BJNM, and linear and cubic trends for BCMU. In all studies, the Mg level declined over time (Table 4). The greatest decline occurred in BCMU and BJNM, and levels at the end of the studies were less than half those at the beginning. Our findings disagreed with Townsend (1973) and Martin and Pelofske (1983), who found reduced soil Mg levels with increasing N fertilization.

Magnesium is not routinely applied to blueberry plantings in Arkansas, and foliar deficiencies are uncommon. Soil Mg standards have not been established for blueberries in Arkansas. In other highbush blueberry production areas, however, Mg deficiencies are seen and diagnosed by the presence of chlorosis on older leaves and by low foliar levels. Our data indicated that Mg levels can decline over time and that, as the levels are reduced, greater chances of Mg deficiency may occur. Further work is needed to determine critical soil Mg levels.

Table 4. Soil analysis magnesium (Mg) values (lb/acre) for 'Bluecrop' mulched (BCMU), 'Bluejay' non-mulched (BJNM) and 'Collins' mulched (COMU) for samples from spring and summer of 1988-92.

	BCMU		BJNM		COMU	
Year	Spring	Summer	Spring	Summer	Spring	Summer
1988	108 b[z]	150 a**	103 a	97 a**	115 a	123 a**
1989	79 b	97 a	71 a	72 a	99 a	106 a*
1990	90 a	70 b	62 a	49 b	91 a	93 a
1991	71 a	70 a*	43 a	47 a	89 a	79 b
1992	49	-	40	-	76 a	-

[z] Mean separation within year among sample dates within location by *t* test ($P<0.05$).
* Significant difference ($P<0.05$); **significant difference ($P<0.01$) between summer and subsequent spring by *t* test.

Sulfur. Unlike other soil elements, S levels were influenced by N rate and date of sampling for BCMU and COMU and the interaction of N rate x date of sampling was significant for these studies. For BCMU, the differences in values for sample dates were rather small (Fig. 13). The regression for this location showed a cubic response which is of no value for further interpretation. For COMU, where ammonium sulfate was the N fertilizer used, soil S levels were much higher than the other locations. Within-season comparisons often had significantly higher S levels in the summer (Fig. 14). For the 120 lb/acre rate, spring levels were lower than the previous summer in three of four years which coincides with the greater pH values during this same period for COMU. The regression for COMU indicated a quadratic response. A plot of the regression showed that very little increase was seen in S over time at the lower N rates (0 and 60 lb/acre). With 120 lb/acre, soil S increased 15 lb/acre over the four years (data not shown). Therefore, an accumulation of S occurred with the application of ammonium sulfate at the higher rate. BJNM had the only significant date of sample effects. Soil levels of S for BJNM were similar for within- and among-year comparisons (Table 5). Little is known of S soil levels in blueberries, but our data indicate that, if S is limiting, then soil S can be increased substantially by higher rates of ammonium sulfate.

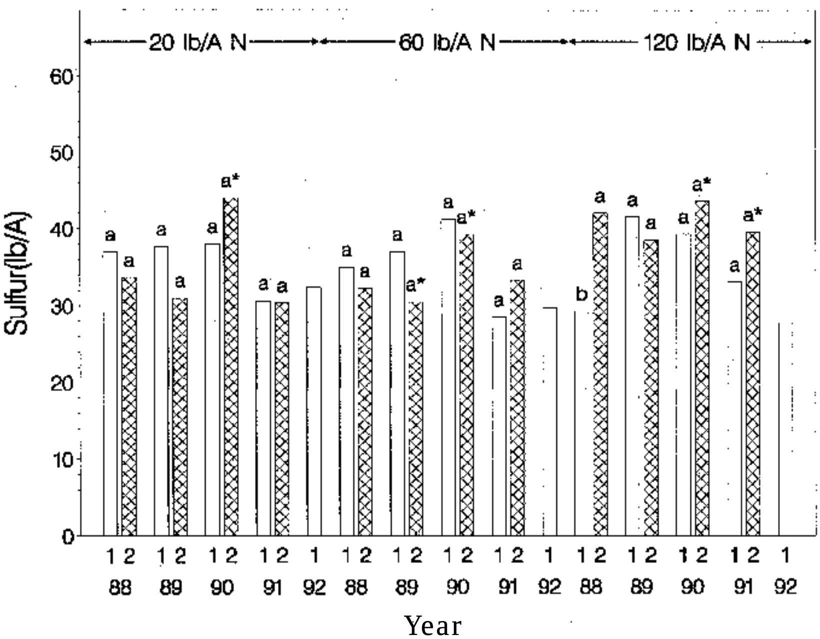

Fig. 13. Soil S for 'Bluecrop' mulched (BCMU) samples collected in the spring (1) at budbreak or summer (2) in early August from 1988 to 1992 for three N rates. The same letter by adjacent columns (representing mean pH values within N rate and year) indicates no significant difference between the two pH values. Letters followed by an asterisk indicate that there was a significant difference between that value and the value for the following spring.

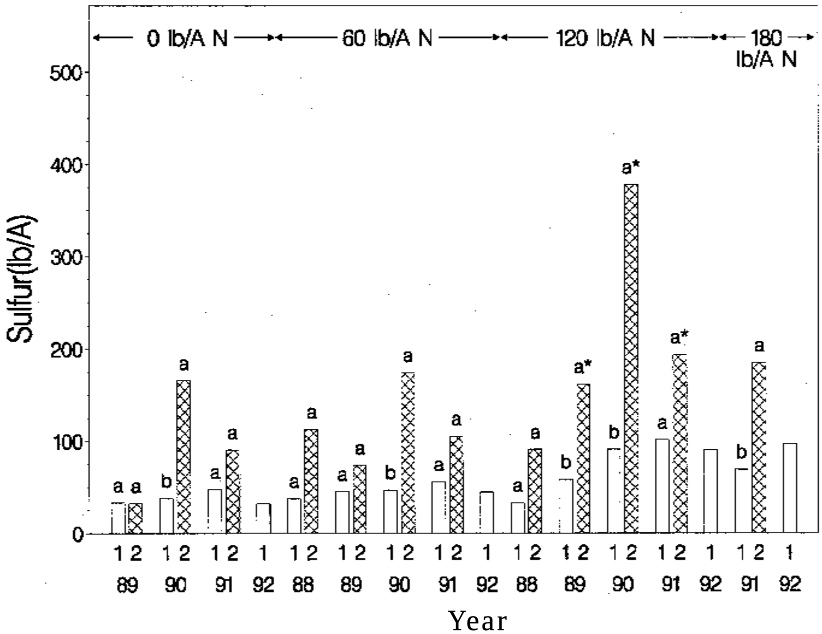

Fig. 14. Soil S for 'Collins' mulched (COMU) samples collected in the spring (1) at budbreak or summer (2) in early August from 1988 to 1992 for three N rates. The same letter by adjacent columns (representing mean pH values within N rate and year) indicates no significant difference between the two pH values. Letters followed by an asterisk indicate that there was a significant difference between that value and the value for the following spring.

Table 5. Soil analysis sulfur (S) values (lb/acre) for 'Bluejay' non-mulched (BJNM) for samples from spring and summer of 1988-92.

Year	Spring	Summer
1988	35 a[z]	37 a
1989	39 a	32 b**
1990	40 a	42 a
1991	42 a	44 a
1992	39	-

[z] Mean separation within year among sample dates by *t* test ($P<0.05$).
**Significant difference ($P<0.01$) between summer and subsequent spring by *t* test.

Iron. Levels of Fe were not affected by N rate, although sample date influenced Fe levels in all studies. In all significant within-year comparisons, the summer Fe level was higher than the corresponding spring sample (Table 6). This may be a result of pH influence in that pH was lowered in many of the summer samples, especially those from higher N plots, which are included in the mean Fe levels. Regression analysis for each study revealed no clear trends in the data, and the means for the spring values indicated mostly a fluctuation in Fe levels among years. Levels of Fe did not decline or increase appreciably over the years in any of the studies.

Manganese. Excessive Mn levels are the more common concern for blueberry growers. For BCMN and COMU, N rate had no effect on soil Mn levels, although sample date effect was significant for these studies. Only one difference for within-year comparisons was significant for BCMU with the summer Mn level higher than spring in 1988. In comparisons of summer vs. the following spring, the summer value was significantly higher in three of four years (Table 7). The Mn levels for BCMU, however, were low, and the numerical differences among samples were small. Regression of the BCMU data showed no usable trends for interpretation due to fluctuating Mn levels over time. For COMU, within-year comparisons indicated spring Mn levels were higher three of four years; and in all summer and following spring comparisons, the spring levels were higher. Regression indicated only higher order trends, and no practical applications were seen from the analysis. Of note in the data is the fact that summer pH was often lower among the COMU samples, especially at higher N rates. Under these conditions, Mn levels might be higher since Mn is more available at lower pH, although the results did not support this. Data for BJNM indicated a significant N rate x sample date interaction. At this location across all N rates, summer Mn was occasionally higher than the current-year spring level. At 120 lb / acre N, the following spring level was often significantly reduced from that of the previous summer (Fig. 15). This may be due to the influence of the higher N rate on pH, which resulted in higher Mn. The regression of BJNM indicated linear and quadratic responses (data not shown). For both the 60 and 120 lb / acre N rates, there was a reduction in spring Mn levels over time, although the reduction was not simply linear. This reduction was about 50% of the soil Mn from 1988 to 1992. This indicated, at least in this specific soil and site, Mn level reduction occurred over time. In COMU, where Mn levels were much greater, reduction did not occur.

Copper. Soil Cu levels are not considered important in the management of high-bush blueberries in Arkansas, and there was little variation in Cu levels in our studies. Rate of N did not influence Cu levels; the actual differences in sample dates were very small for all studies (Table 8). Differences between significant date comparisons were usually 1.0 to 1.5 lb / acre Cu and were of no practical value for further interpretation. Regression analysis did not reveal any practical findings for interpretation.

Table 6. Soil analysis iron (Fe) values (lb/acre) for 'Bluecrop' mulched (BCMU), 'Bluejay' non-mulched (BJNM) and 'Collins' mulched (COMU) for samples from spring and summer of 1988-92.

	BCMU		BJNM		COMU	
Year	Spring	Summer	Spring	Summer	Spring	Summer
1988	164 a[z]	159 a	238 a	236 a*	151 b	169 a
1989	166 b	189 a	220 b	258 a**	180 a	192 a**
1990	193 b	208 a*	287 a	283 a	174 b	206 a
1991	206 a	204 a	291 a	280 a**	189 a	188 a**
1992	187	-	256	-	171	-

[z] Mean separation within year among sample dates within location by *t* test ($P<0.05$).
* Significant difference ($P<0.05$) ; **significant difference ($P<0.01$) between summer and subsequent spring *t* test.

Table 7. Soil analysis manganese (Mn) values (lb/acre) for 'Bluecrop' mulched (BCMU) and 'Collins' mulched (COMU) for samples from spring and summer of 1988-92.

	BCMU		COMU	
Year	Spring	Summer	Spring	Summer
1988	36 b[z]	42 a**	216 a	192 b**
1989	23 a	28 a**	218 a	163 b**
1990	19 a	20 a**	236 a	182 b**
1991	27 a	25 a	182 a	194 a**
1992	23	-	242	-

[z] Mean separation within year among sample dates within location by *t* test ($P<0.05$).
**Significant difference ($P<0.01$) between summer and subsequent spring by *t* test.

Table 8. Soil analysis coppe (Cu) values (lb/are) for 'Bluecrop' mulched (BCMU), 'Bluejay' non-mulched (BJNM) and 'Collins' mulched (COMU) for samples from spring and summer of 1988-92.

	BCMU		BJNM		COMU	
Year	Spring	Summer	Spring	Summer	Spring	Summer
1988	4.2 a[z]	4.4 a*	5.0 a	4.8 a	4.5 a	5.0 a
1989	5.0 b	6.0 a**	5.6 a	5.3 a	5.1 a	5.0 a
1990	5.0 b	5.8 a**	4.8 a	5.1 a**	5.4 a	4.6 b**
1991	4.3 b	5.7 a**	3.6 b	4.8 a	3.8 b	5.3 a**
1992	4.4	-	4.4	-	4.0	-

[z] Mean separation within year among sample dates within location by *t* test ($P<0.05$).
* Significant difference ($P<0.05$);**($P<0.01$) between summer and subsequent spring by *t* test.

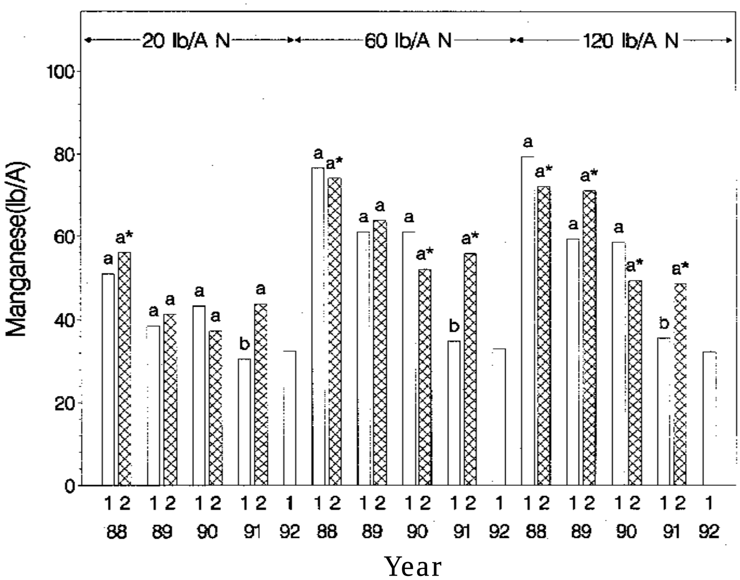

Fig. 15. Soil Mn for for 'Bluejay' non- mulched (BJNM) samples collected in the spring (1) at budbreak or summer (2) in early August from 1988 to 1992 for three N rates. The same letter by adjacent columns (representing mean pH values within N rate and year) indicates no significant difference between the two pH values. Letters followed by an asterisk indicate that there was a significant difference between that value and the value for the following spring.

Zn. Levels of Zn were not influenced by N rate or date of sampling for BCMU. Date of sample was the only factor influencing Zn levels for BJNM and COMU. The only differences in the data for these two studies were in the three significant comparisons of summer and the following spring values. In BJNM and COMU, both higher spring values and for one the summer value was higher (Table 9). Also, the numerical differences were small and of little, if any, value for practical interpretation and use. Spring Zn level fluctuated for all studies, and regression analysis showed no useful results. As with Cu, Zn soil levels have not been considered important in blueberry planting management.

Table 9. Soil analysis zinc (Zn) values (lb/acre) for 'Bluecrop' mulched (BCMU), 'Bluejay' non-mulched (BJNM) and 'Collins' mulched (COMU) for samples from spring and summer of 1988-92.

	BCMU		BJNM		COMU	
Year	Spring	Summer	Spring	Summer	Spring	Summer
1988	16.5 a[z]	18.0 a	12.0 a	12.6 a	4.6 a	5.9 a
1989	12.5 a	17.1 a	9.3 a	12.3 a*	2.9 a	3.5 a**
1990	17.6 a	21.5 a	17.2 a	13.1 a**	8.6 a	7.0 a
1991	16.2 a	19.3 a	6.4 a	7.7 a	6.3 a	6.8 a
1992	16.1	-	5.3	-	5.3	-

[z] Mean separation within year among sample dates within location by *t* test ($P<0.05$).
* Significant difference ($P<0.05$); **($P<0.01$) between summer and subsequent spring by *t* test.

CONCLUSIONS

The major findings from these investigations are:

1) Nitrogen rate and time of soil sampling interacted to have major effects on pH, EC and nitrate values. Recommendations for N rates and sources can be greatly affected by the time of sampling. Soils sampled in summer and found to be low in pH, and high in EC and nitrate, should be re-sampled in late winter prior to application of fertilizers to determine if fertilizer rate and N source modifications are needed.

2) Yearly soil pH changes over time depended on location, N rate, mulch, and N material used. This finding showed the need for routine monitoring of soil pH for correct fertility and pH management.

3) Most soil elements were not affected by N rate, but time of sampling often affected elemental concentration. Usually, the time of sampling during the year did not affect soil values enough to be a concern in fertility recommendations of elements other than N.

4) Changes in spring-sampled soil elemental levels independent of N rate over the four years of the study were noteworthy, with K and Mg consistently reduced over the years. Of particular importance was the reduction in K over time. This varied from 3 to 72 lb / acre for single years. In addition, depending on location, Ca and Mn levels declined over time. Sulfur was largely unaffected over time except when high ammonium sulfate rates were applied. Levels of P, Fe, Cu, and Zn were also largely unaffected over time.

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