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Assessing Phosphorus Fertilization in Blueberry Production

Abstract

Blueberry plants are calcifuge plants adapted to soil pH from 4.5 to 5.5. Low pH soils have low cation exchange capacity (CEC) and low available phosphorus (P) to the plants. Constant fertilization reduces soil pH and compromises plant nutrient availability causing nutrient deficiencies or toxicity. Customizing fertilizer applications to plant physiological demands will allow growers to effectively manage crop nutrition while avoiding overfertilization. In this research project, leaf tissue and soil samples were collected to quantify phosphorus content in the leaf and soil and to determine the relationship between leaf P content and P available in the soil. Experimental plots were established in three commercial farms and samples were collected throughout the 2020 season. Based on the lab results obtained, there was no correlation between soil P and leaf P concentration. The farm with the highest fruit yield had the lowest soil P concentration and the highest leaf P level. Furthermore, leaf Al, Fe, Ca, and Mg had a negative correlation with leaf P, whereas soil Ca levels positively impacted leaf P. These findings imply that lowering soil recommendation levels for blueberries may be possible without compromising yield and leaf P levels.

Keywords: Blueberry, rabbiteye (RE), southern highbush (SHB), phosphorus fertilization, nutrient management, nutrient sufficiency.

Introduction

A substantial understanding of how plants acquire, use, and transport essential nutrients and their relation to crop yield contribute significantly to the success of crop production. After nitrogen and potassium, phosphorus is plants' third most abundant macronutrient. Thus, an adequate P concentration in the plant tissue is essential in promoting crop growth, development, and yield. Phosphorus is a major component of nucleic acids, membrane phospholipids, and adenosine. Phosphorus is integral to plant energy metabolism, respiration, and photosynthesis (Taiz and Zeiger, 1998).

In acidic soils in which blueberries are grown, P is less available to the plant; thus, P fertilizer must be incorporated to allow for adequate yield. However, researchers have challenged the widespread idea that P is less soluble at low pH and less available to plants (Barrow, 2017; Penn and Camberato, 2019). In addition, the practice of measuring only the pH of the soil to quantify nutrient availability leaves aside the biological, chemical, and environmental influences that any type of soil suffers (Hartemink and Barrow, 2023). The soil is a complex, alive, and dynamic system, and diverse plant species respond differently to soil nutrient availability. Phosphorus has low mobility in the soil, and continuous fertilization with P causes phosphorus accumulation. High phosphorus rates can lower pH, reduce beneficial mycorrhizae, and cause deficiencies of other nutrients (Bingham, 1963; Pantigoso et al., 2018).

Blueberries have low nutritional requirements, and recent studies have implied that blueberries require less P than is usually recommended (Leon-Chang et al., 2023; Munoz et al., 2023; Strik and Davis, 2023). The University of Georgia recommends 240 lb. of phosphate fertilizer to increase the P level in soil by 30 lb. The University of Georgia Extension service considers that a medium soil P level ranges between 31 to 60 pounds per acre — 15.5 to 30 mg P/kg (Krewer and NeSmith, 1999). However, this recommendation dates back to 1999, and no recent research on P fertilization has been performed in the southeast, let alone in Georgia. Blueberry plants are considered deficient if P levels in leaves are below 0.12% (1200 mg/kg) for southern highbush (SHB) and 0.08% (800 mg/kg) for rabbiteye (Krewer and NeSmith, 1999). By matching

P fertilization to the plant's physiological needs, growers effectively manage plant nutrition and avoid overfertilization. Growers use soil and leaf tissue sampling to create and modify fertilization programs that maintain adequate plant nutrition status (Bryla and Strik, 2015). Georgia's fertilizer management practices were revised in 1999 and were primarily based on soil nutrient status (Krewer and NeSmith, 1999). When fertilization guidelines were developed, the quantity of nutrients accumulated in plant parts that were removed by pruning or fruit picking was not considered. Constant chemical fertilization tends to make the soil more acidic, which affects the availability of nutrients to plants and causes nutrient deficiencies (Hart et al., 2006). According to Prange and DeEll (1997), inadequate or excessive fertilization impacts plant growth, reduces productivity, makes plants more susceptible to pests and diseases, and decreases the postharvest quality of berry crops.

As the agricultural industry moves to reduce its carbon footprint, the use of phosphorus fertilizer must be optimized not only to reduce production cost but also for stewardship of the environment. The objectives of this study were to determine the effect of different nutrient management practices on the phosphorus content of blueberry plant tissue and soil P; and to assess the relationship between soil nutrients and plant P content.

Materials and Methods

Location and experimental design

During the 2022 growing season, blueberry farms in Pierce, Bacon, and Brantley County, Georgia with different nutrient management practices were evaluated. Experimental plots were established on four commercial farms in Georgia. Each experimental plot was composed of three blocks, and each block was composed of ten plants. Only the five most vigorous and representative blueberry plants were sampled from each block. Table 1 shows the variable within the experimental design.

Table 1. Experimental design variables

Experimental Sites	**Farm 1: Nahunta – RE – P**	**Farm 2: Alma – SHB – F**	**Farm 3: Alma – RE – V**	**Farm 4: Hoboken – SHB – F**
Location	Nahunta	Alma	Alma	Hoboken
Species	Rabbiteye (*Vaccinium virgatum*)	Southern highbush (*Vaccinium corymbosum* interspecific hybrid)	Rabbiteye (*Vaccinium virgatum*)	Southern highbush (*Vaccinium corymbosum* interspecific hybrid)
Cultivar	Premier	Farthing	Vernon	Farthing
Year of establishment	2009	2018	2013	2014
Pruning	Mechanical pruning. After harvest, every other year.	Mechanical pruning. After harvest, every year.	Mechanical pruning. After harvest, every other year.	Mechanical pruning. After harvest, every year.
Blooming	February - March 2022.	Full blooming until March 10th.	Full blooming until March 25th	The end of March
Harvesting	Third week of June - second week of July.	May 5th to May 10th	Last week of May - 2nd week of June.	May 25th – second week of June.
Irrigation	Drip irrigated; irrigation occurred at 40-50% moisture status.	Drip irrigated every 30 min, four times per day.	Drip irrigated every 30 min, four times per day.	Drip irrigation.
Plant Density	Twelve by 3-foot row spacing: 1210 plants per acre.	Eleven by 2.5-foot row spacing: 1584 plants per acre.	Eleven by 4-foot row spacing: 990 plants per acre.	Twelve by 3-foot row spacing: 1210 plants per acre.
Fertilization- Year 1	Granular, 10N-10P-10K toasting by hand. Three times per year, 30 lb./acre per application.	Granular, 13N-6P-6K slow release. 1 tablespoon per plant on March, April, May, June and July. 50 lb./acre per application.	Granular, 13N-6P-6K slow release. 1 tablespoon per plant on March, April, May, June and July. 37 lb./acre per application.	Fertigation, 10N-5P-5K. 30 lb./acre per week from March until mid-June.
P fertilization during Year 1	3.4 g P per plant per year.	4.3 g P per plant per year.	4.3 g P per plant per year.	7.9 g P per plant per year.
Fertilization during production (current)	Granular, 10N-10P-10K toasting by hand. 300 lb./acre, three times per year: spring (during blooming), fall: after harvesting and in the mid-August.	Granular 13N-6P-6K twice per year in March and June, applied on a three-foot band across the bed. 450 lb./acre per application.	Granular 13N-6P-6K twice per year in March and June, applied on a three-foot band across the bed. 300 lb./acre per application.	Granular, 150 lb./acre 10N-10P-10K twice per year on the 1st of March and on mid-June after harvest. Fertigation, 50 lb./acre of 6N-6P-12K once per week from the March until the mid of June.
P fertilization during production (current)	33.8 g P per plant per year.	15.5 g P per plant per year.	16.5 g P per plant per year.	Granular 11.3 g P per plant per year. Fertigation 15.8 g P per plant per year. Total 27.1 g P per plant per year.
Reported Yield	3500 lb./acre	8500 lb./acre	8000 lb./acre	12000 lb./acre

Plant tissue and soil collection

Plant leaf samples were collected from fully expanded mature leaves. Leaf samples were collected from May to July, in two-week intervals; and after that, once per month until November. Soil samples were also collected from each commercial farm divided into two depths, 0–4 inches and 4–8 inches. Samples were sent to the University of Georgia (UGA), Athens Soil and Water Lab for analysis.

Soil testing

Routine soil analysis performed in this study (Mehlich,1953) first involved oven drying (40°C) of the collected soil samples followed by grinding and sieving through a 2-mm screen. Afterwards, the soil was weighed (~5.0 g), then 20 mL Mehlich I (0.025N H_2SO_4 + 0.05N HCl) extracting solution was added. Samples were immediately placed on a shaker at high speed (250 oscillations per minute) within a period of 5 min. Samples were then filtered using Whatman #1 paper followed by the analysis of soil extracts for phosphorus by ICP-OES (Spectro Arcos FHS16).

Plant tissue analysis

Blueberry leaf tissue samples were oven dried for about 24 hours at 65°C. Dried tissue samples were then ground in a Wiley mill and sieved through a 20-mesh screen. Following the methodologies of EPA Method 3052 (USEPA, 1996), tissue samples were digested to form a solution. For digestion, 0.5 g of sample was weighed and placed in a fluorocarbon polymer microwave vessel followed by the addition of 10 mL of concentrated HNO_3. Vessels were sealed and placed in a microwave digester (CEM Mars 6 Microwave, Matthews, NC, USA) at 200°C for 30 minutes. The digests were transferred quantitatively into volumetric flasks and brought to 100 mL volume with deionized water. Finally, the solutions were analyzed for various elements following the EPA Method 200.8 (Long and Martin, 1989) by Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES) (Spectro Arcos FHS16, Germany). All results were reported in mg/kg. Procedures for calibration standards were ensured, and independent laboratory performance checks were also run with acceptable deviations for recoveries set at 100 ± 5%.

Statistical analysis

Data of nutrient content from soil and leaf samples gathered from different blueberry cultivars across three commercial farms in Georgia was analyzed using JMP (JMP®, Version 16. SAS Institute Inc., Cary, NC, USA, 1989–2023). Partition predicting modeling and multivariate correlation tools from JMP were used to establish correlations between the variables. Comparisons between multiple means were determined by non-parametric comparisons for each pair using the Wilcoxon method ($p < 0.05$). All statistical analyses were performed using the JMP software package.

Yield and profit

Cost-benefit ratio was calculated for every fertilization treatment, following Formula 1. Fertilizer costs were provided by Graco Fertilizer Company, and the benefit was calculated based on the yield reported by the farmers and the fresh fruit priced reported by USDA (USDA, 2023).

$$\text{Cost} - \text{benefit ratio} = \frac{\text{Reported yield x Price fresh fruit}}{\text{Cost of fertilizer per year}}, \qquad \text{(Formula 1).}$$

Results and Discussion

Soil P content

Soil phosphorus content (mg/kg) was obtained at different soil depths. The level of phosphorus in soil varied depending on soil depth, farm location, and blueberry type. For instance, in Nahunta, ‘Premier’ had a higher average concentration of soil phosphorus in the 0 to 4” depth compared to the 4" to 8” depth. This difference makes sense since P is an immobile nutrient in soil and this farm applies 33.8 g P annually of granular fertilizer by hand. Additionally, the phosphorus levels at both depths — 80 mg/kg for 0 to 4”and 40 mg/kg for the 4 to 8” depth — were above the recommended soil concentration of 15.5 to 30 mg per kilogram. This difference in phosphorus content was statistically significant ($p = 0.0009$) (Figure 1A). In Alma, there was no significant difference in phosphorus levels between the two soil depths for both rabbiteye 'Vernon' and SHB 'Farthing'. Despite this, SHB ‘Farthing’ had a higher soil P compared to rabbiteye 'Vernon,' which had a soil phosphorus concentration that was close to the minimum recommended limit (Figures 1B and 1C). It is worth noting that both cultivars are receiving similar doses of P — around 16 g P per plant annually — but the SHB field located in Alma was established five years after the rabbiteye in the same location. It appears that soil P levels may decrease over time, and the current fertilization doses used on the farm resulted in lower P levels in the soil than what is recommended. Among the farms, SHB ‘Farthing’ in Hoboken exhibited the lowest soil P concentrations despite the high fertilization rates applied annually (27.1 g P per plant) (Figure 1D).

Leaf P content

There were no significant differences in the P levels (mg/kg) found in the young or old leaves of blueberry plants, except for SHB ‘Farthing’ in Hoboken (Figure 2). At the Nahunta farm and at the Alma farm, rabbiteye 'Premier' and 'Vernon' had similar P levels of 960 mg/kg and 1,000 mg/kg respectively, which exceeded the UGA recommended minimum of 800 mg/kg (Figures 2A and 2C) (Krewer and NeSmith, 1999). On the contrary, SHB 'Farthing' had a P leaf concentration of 1,050 mg/kg, which is less than UGA foliar sufficient levels of 1,200 mg/kg (Figure 2B) (Krewer and NeSmith, 1999). At the Hoboken farm, SHB ‘Farthing’ had P foliar concentration of 1,180 mg/kg, which was closer to the recommended sufficient foliar concentration (Figure 2D).

Regardless of the high amount of P in the soil at the Alma farm, SHB ‘Farthing’ had low leaf P concentration, but no nutrient deficiency symptoms were present. (Figure 1B). On the contrary, ‘Farthing’ in Hoboken had the highest concentration of leaf P, while the level of P in the soil was the lowest (Figures 1D and 2D). The Hoboken farm was the only one applying fertigation.

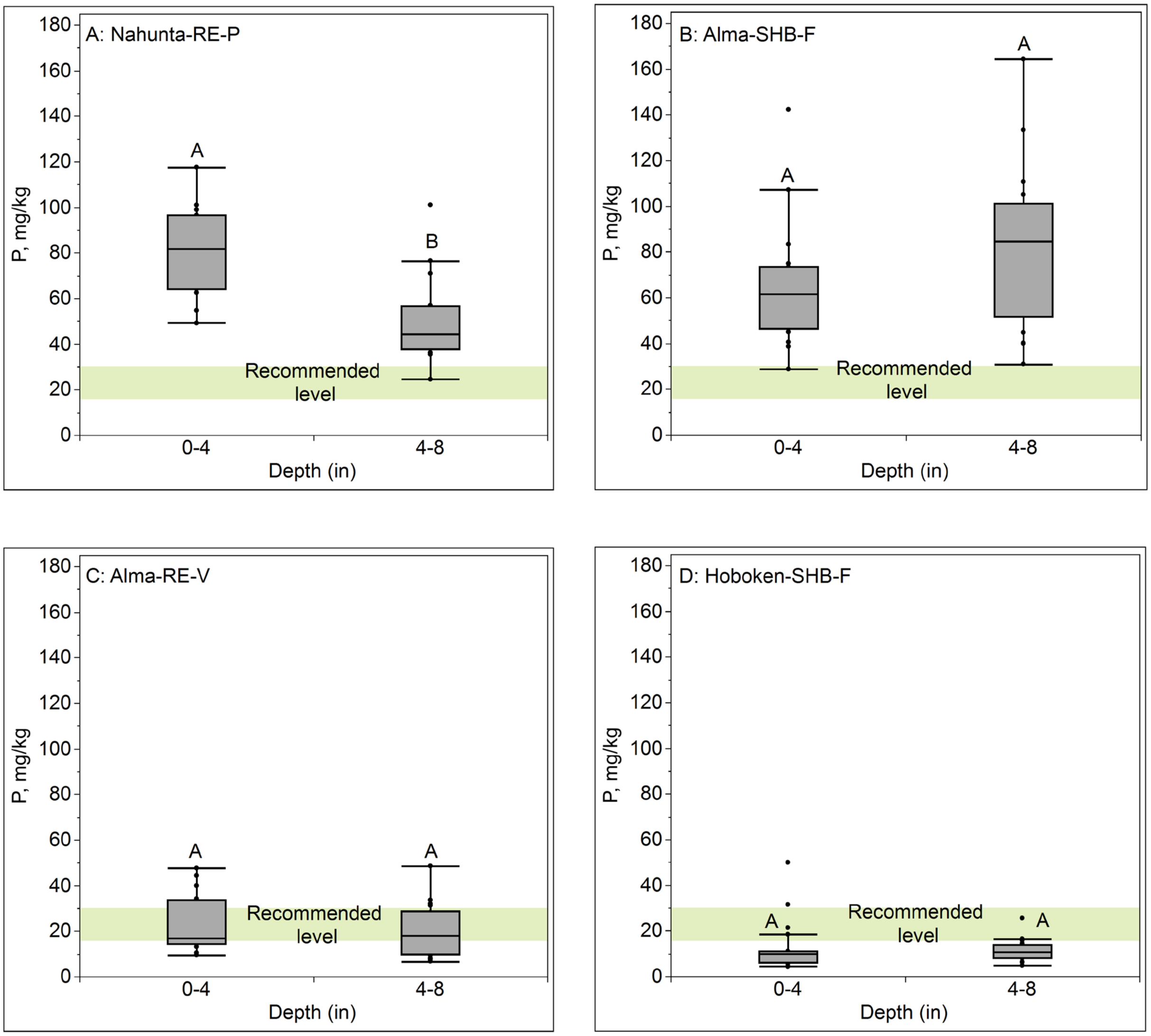

Figure 1. Phosphorus levels (mg/kg) in the soil at different depths (0–4 and 4–8 inches) collected from May to November of 2022 from different locations and blueberry cultivars: A) Rabbiteye ‘Premier’ located in a commercial farm in Nahunta (Nahunta-RE-P); B); SHB ‘Farthing’ (Alma-SHB-F); and C) Rabbiteye ‘Vernon’ (Alma-RE-V) located in a commercial farm in Alma, and D) SHB ‘Farthing’ located in a commercial farm in Hoboken (Hobokem-SHB-F). Light green bar represents the current recommended soil P level by UGA (15.5 to 30.0 mg/kg). Different letters a significant difference ($p < 0.05$).

Thus, the presence of water as a vehicle might help P root uptake and made P accessible to the plant, instead of accumulating it in the soil (Sathya et al., 2008). Similarly, rabbiteye 'Vernon' grown in the Alma commercial farm had a leaf P level within the recommended range, even though the soil phosphorus level was close to the lower limit (Figures 1B and 2B).

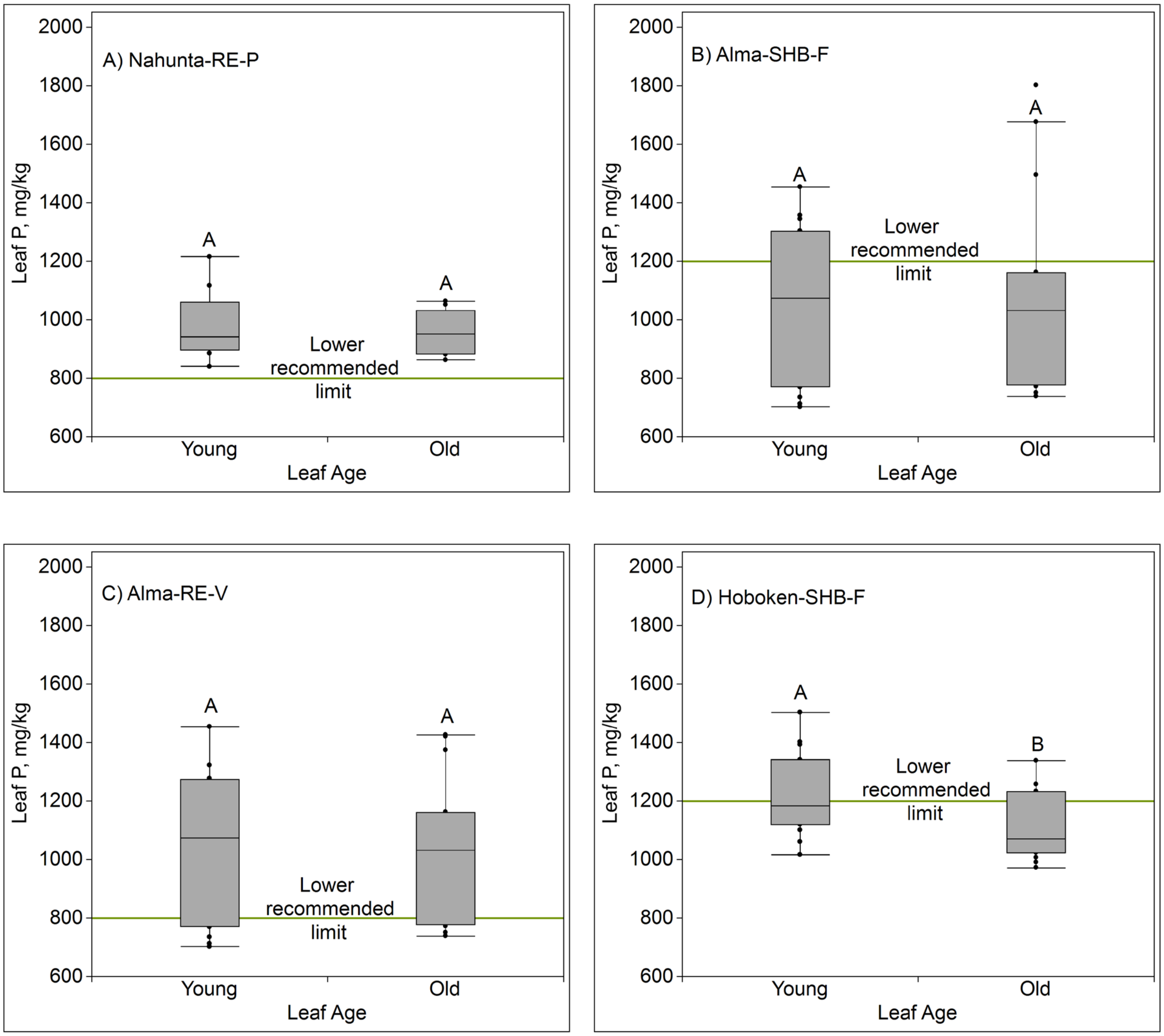

Figure 2. Phosphorus content (mg/kg) of old and young blueberry leaves sampled from different location and blueberry cultivars: A) Rabbiteye 'Premier' located in a commercial farm in Nahunta (Nahunta-RE-P); B) SHB 'Farthing' (Alma-SHB-F) and C) Rabbiteye 'Vernon' (Alma-RE-V) located in a commercial farm in Alma; D) SHB 'Farthing' located in a commercial farm in Hoboken (Hoboken-SHB-F). Green line represents the current UGA recommended leaf P concentration (800 mg/kg for rabbiteye and 1200 mg/kg for SHB). Different letters indicate statistically significant differences ($p \leq 0.05$).

These results display a disparity between the availability of soil phosphorus and the plant's ability to uptake it; similar results were found by Leon-Chang et al. (2023) for northern highbush cultivars in Oregon. It appears feasible to reduce P fertilization rates for blueberry production while still preserving an appropriate P concentration in the leaves. Fertigation appears to increase P plant availability. Therefore, future research is essential to comprehend the mechanisms by which blueberry plants store P during the first years of growth, and how P levels can affect fruit quality and yield.

Leaf P interaction with other nutrients

To address the discrepancy in P levels between soil and leaves, a multivariate tool from JMP software was used. The purpose was to investigate further the relationship between soil and leaf nutrients and their potential influence on P content in blueberry leaves. Table 2 displays the correlation between leaf P and various leaf nutrients.

There is a strong negative correlation between the levels of Mg, Ca, Al, and Fe in leaves and P. Thus, when these nutrients are present in higher quantities in the leaves, the leaf P decreases or vice versa. The interference of Al on the P metabolism was previously documented in barley, in which high Al in soil restricted P translocation from roots to other plant tissues (Wright, 1937, 1943). Aluminum starts accumulating in the leaves after it is accumulated in the roots, and there are no more Al sites in the roots to be occupied (Adams, 1980). Aluminum excess in soil prevents P uptake by highbush blueberry plants, but only if the plants were not colonized by mycorrhiza (Yang and Goulart, 1997).

The relationship between plant Fe concentration and soil P levels has been studied in mycorrhizal colonized lettuce and rice, in which high soil P levels were found to reduce Fe uptake by the plants (Azcon et al., 2003; Hoseinzade et al., 2016). In acid soils, P can be linked to Fe and become unavailable to the plants (Bingham, 1963). Soybean plants showing chlorosis caused by Fe deficiency had normal leaf Fe concentration but excessively higher ratio of P to Fe (Wallace et al., 1973).

The negative relation between leaf Mg and P is unusual since Mg is a known P carrier (Adams, 1980). There is currently no documentation of negative interaction between leaf Mg and Ca with P in blueberries. However, Strik et al. (2019) reported a negative correlation with K; and the former is positively correlated with leaf P in our results (Table 2) (Strik et al., 2019). Plants use Ca to control the allocation of P in the cells, preventing the formation and buildup of calcium phosphates in leaf or other tissue. Calcium cannot be transferred out of leaves to other plant organs, but P is able to move around freely. Thus, leaves with high soluble calcium content typically do not have high concentrations of phosphorus (Conn and Gilliham, 2010). There is a need to further understand the interaction between Ca and P in blueberry tissue and at the cellular level.

Leaf K had the highest positive correlation factor with P, possibly because they both participate in the cation/anion equilibrium in plant tissue. Moreover, both nutrients were consistently applied in equal amount across all the farms (Adams, 1980). It is noteworthy that Leaf S and Na displayed a positive correlation for the cultivars in the Alma farm but no significant effect elsewhere.

Table 2. Correlation factors between leaf nutrient concentration and leaf P concentration of different blueberry cultivars in four blueberry commercial farms. Positive correlations are represented by blue boxes, while negative ones are indicated by red boxes. Bolded numbers represented significant correlations (p-value < 0.05).

Nutrient	**Nahunta-RE-P**	**Alma-SHB-F**	**Alma-RE-V**	**Hoboken-SHB-F**	**Average correlation***
	Correlation with Leaf P				
Leaf Al	**-0.53**	**-0.70**	**-0.70**	-0.39	**-0.64**
Leaf B	**-0.73**	**-0.47**	**-0.47**	**-0.51**	**-0.55**
Leaf Ca	0.33	**-0.70**	**-0.70**	-0.30	**-0.70**
Leaf Cu	**-0.57**	-0.20	-0.20	-0.23	**-0.57**
Leaf Fe	-0.09	**-0.75**	**-0.75**	**-0.46**	**-0.65**
Leaf K	**0.63**	**0.71**	**0.71**	0.02	**0.68**
Leaf Mg	0.43	**-0.71**	**-0.71**	-0.27	**-0.71**
Leaf Mn	-0.29	-0.10	-0.10	**-0.44**	**-0.44**
Leaf Mo	-0.28	-0.28	-0.28	-0.19	
Leaf Na	0.40	**0.56**	**0.56**	-0.19	**0.56**
Leaf Ni	**-0.70**	**-0.57**	**-0.57**	0.10	**-0.61**
Leaf S	-0.26	**0.55**	**0.55**	-0.13	**0.55**
Leaf Total N	0.21	0.04	0.04	0.04	
Leaf Zn	**-0.52**	**-0.52**	**-0.52**	-0.09	**-0.52**

*Average correlation was made from the values that had a significant correlation only.

Table 3 shows the correlation between leaf P and various soil nutrients. None of the soil nutrients analyzed had a strong correlation with leaf P. The highest correlation was found for the Alma farm for both rabbiteye and SHB cultivars, in which Ca in the soil had a positive influence in leaf P concentration. Devau et al. (2010) reported that increasing Ca uptake in wheat plants can enhance P availability in soils with low-P concentrations. This occurs by reducing the effect of Ca adsorption on P adsorption. Furthermore, since plants absorb Ca, there is less Ca in the soil to promote P adsorption onto soil particles, therefore there are more free P molecules for uptake by the plant. Nevertheless, the concentration of P and Ca in the soil was different between the two cultivars in the Alma farm that showed positive correlation with leaf P (Figure 1A, 1B, 3B). In fact, ‘Farthing’ exhibited significantly higher concentrations of soil Ca and P compared to ‘Vernon’ and all the other cultivars in the other farms. These levels were even found to surpass the recommended threshold. To better understand the relationship between these nutrients, it will be important to analyze the Ca concentration in the plant root.

Table 3. Correlation factors between soil nutrient concentration and leaf P concentration of different blueberry cultivars in four blueberry commercial farms. Positive correlations are represented by blue boxes, while negative ones are indicated by red boxes. Bolded numbers represented significant correlations (p-value < 0.05).

Nutrient	**Nahunta-RE-P**	**Alma-SHB-F**	**Alma-RE-V**	**Hoboken-SHB-F**	**Average correlation***
	Correlation with Leaf P				
pH	-0.32	0.09	0.37	0.20	
Soil Ca	-0.27	**0.39**	**0.49**	-0.18	**0.44**
Soil K	0.02	-0.27	**-0.37**	-0.13	**-0.37**
Soil Mg	-0.06	0.21	0.06	0.08	
Soil Mn	0.12	-0.26	-0.09	0.08	
Soil P	-0.08	0.18	0.00	-0.20	
Soil Zn	0.16	0.10	0.18	-0.09	

*Average correlation was made from the values that had a significant correlation only.

The concentrations of Mg, Ca, Al, and Fe in the leaves were compared among the different fertilization regimes. The non-parametric comparisons for each nutrient pair using the Wilcoxon method revealed that the blueberry leaves of ‘Farthing’ SHB

(Hoboken) had significantly lower content of the three nutrients as shown in Figure 3. Soil pH was also compared between the three commercial farms.

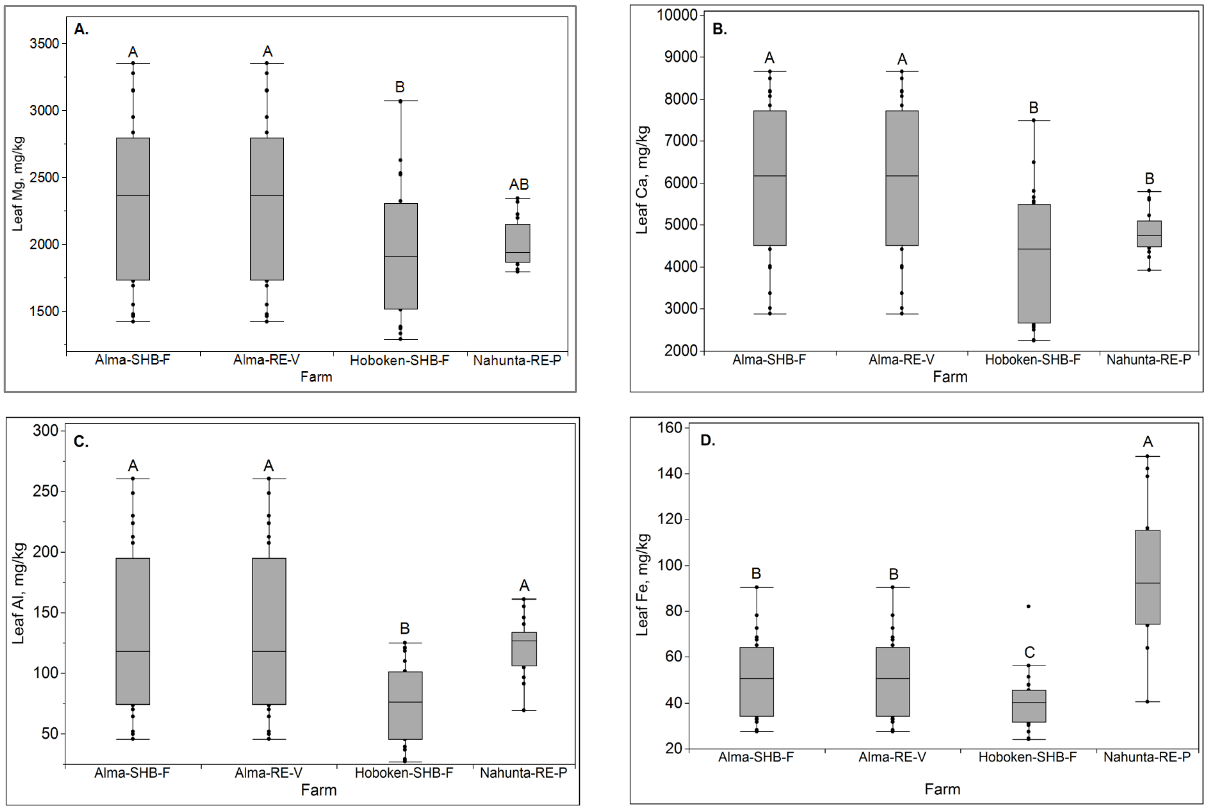

Figure 3. A) Leaf magnesium, B) Leaf calcium, C) Leaf aluminum, and D) Leaf iron concentration (mg/kg) of SHB and rabbiteye cultivars located in three different commercial farms. SHB ‘Farthing’ (Alma-SHB-F) and rabbiteye ‘Vernon’ (Alma-RE-V) located in a commercial farm in Alma, GA, SHB ‘Farthing’ (Hoboken-SHB-F) located in a commercial farm in Hoboken, GA, and rabbiteye ‘Premier’ (Nahunta-RE-P) located in a commercial farm in Nahunta, GA. Different letters indicate statistically significant differences ($p \leq 0.05$).

The Hoboken farm had the lowest pH value, pH<4.0 (Figure 4). A soil pH below 4.5 is typically linked to high concentration of Fe and Al in the soil, which can even be toxic to blueberries (Haynes and Swift, 1986; Matsuoka et al., 2018). However, the Hoboken farm had a soil pH lower than 4 and Al and Fe leaf content was the lowest (Figure 3C and 3D).

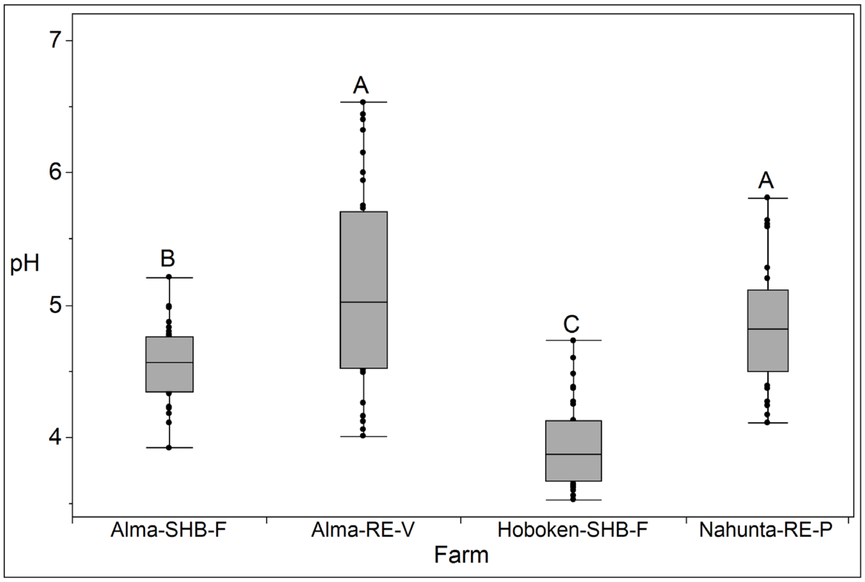

Figure 4. Soil pH from different blueberry farms and cultivars: SHB ‘Farthing’ (Alma-SHB-F) and rabbiteye ‘Vernon’ (Alma-RE-V) located in a commercial farm in Alma, GA, SHB ‘Farthing’ (Hoboken-SHB-F) located in a commercial farm in Hoboken, GA, and rabbiteye ‘Premier’ (Nahunta-RE-P) located in a commercial farm in Nahunta, GA. Different letters indicate statistically significant differences ($p \leq 0.05$).

Matsuoka (2018) reported that the soil texture influences Al, Mg and Fe in blueberry plants. When comparing the effects of fertilization treatment on blueberry bushes, it was found that Kasumigaura, a sandy loamy soil, exhibited the highest concentration of Al and Fe. This contrasted with the clay loamy soils, which did not show the same level of nutrient uptake. Our analysis did not include soil texture; but the Web Soil Survey indicates that the Alma farm has a loamy sand soil, the Nahunta farm has loamy fine sand soil, and the Hoboken farm has fine sand soil (NRCS, 2023). According to research by Matsuoka et al. (2018), blueberry plants cultivated in sandy loam soils are prone to have high Al and Fe concentration in the roots (95%) and only a smaller percentage of Al and Fe were present in leaves compared to other types of soil. This might explain why the leaf tissue collected from the Hoboken farm had low Al and Fe concentrations despite the low pH. Further analyses are needed in other plant tissues to understand how the Hoboken plants managed to thrive on low soil pH, have low Al and Fe concentrations and to have high P levels in leaves.

Cost and profit

An economic analysis was conducted to estimate the monetary cost-benefit ratio of various fertilization treatments (Table 4). According to the analysis, Hoboken-SHB-F farm showed the highest cost-benefit ratio, followed by Alma-RE-V. However, the analysis did not include labor costs used for granular fertilization, or irrigation maintenance costs for any of the farms. Even though the Alma-SHB-F farm was the second most productive, the cost-benefit ratio was 25 points lower than Alma-RE-V. Alma-SHB-F a was also the farm with the highest chemical fertilizer input per plant.

Table 4. Cost benefit ratio of four farms under different fertilizer management regimes.

Farm	**Fertilizer treatment during production year**	**Fertilizer cost (50 lb. bag) ***	**Fertilizer cost per production year**	**Yield (lb./year)**	**Approx. yield value****	**Cost-Benefit Ratio**
Alma-SHB-F	13N-6P-6K: 900 lb./acre	$ 32.13	$ 578.34	8500	$ 35,445.00	61.3
Alma-RE-V	13N-6P-6K: 600 lb./acre	$ 32.13	$ 385.56	8000	$ 33,360.00	86.5
Nahunta-RE-P	10N-10P-10K: 900 lb./acre	$ 16.24	$ 292.32	3500	$ 14,595.00	49.9
Hoboken-SHB-F	Granular 10N-10P-10K: 300 lb./acre	$ 16.24	$ 97.44	12000	$ 50,040.00	115.1
	Fertigation 6N-6P-12K: 700 lb./acre	$ 24.09	$ 337.29			

* Costs were obtained from Graco Fertilizer Company

** Based on the average retail price of $4.17 dollars per fresh fruit reported by USDA, 2020.

Conclusion

Soil P content did not match the leaf P content, not even when P was low in the soil. Phosphorus content derived from soil routine analysis alone is a poor indicator if it is not coupled with leaf tissue analysis. Indeed, the soil P sufficiency level for blueberry in Georgia needs further investigation.

The correlation analysis between soil and leaf nutrients in blueberry plants revealed that leaf Mg, Ca, Al, and Fe had a significant negative correlation with leaf P, while leaf K showed a strong positive correlation. Soil nutrients had limited correlation with leaf P, except for a positive influence of soil Ca in Alma farm. Further research is needed to understand the interaction between Ca and P in blueberry tissue.

Applying the highest dose of fertilizer does not guarantee the highest yield nor does it result in the best cost-benefit ratio.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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