Influence of organic fertilizers on container-grown highbush blueberries in high tunnels

Ève-Marie Boudreau-Forgues[1], Linda Gaudreau[1], Thi Thuy An Nguyen[1], André Gosselin[2], Laura Thériault[3], Annie Brégard[1], Martine Dorais[1]
[1]Centre de recherche et d'innovation sur les végétaux, Université Laval, Québec, QC, Canada. [2] Les Fraises de l'Île D'Orléans inc., St-Laurent-Île-d'Orléans, QC, Canada. [3] Berger, Saint-Modeste, QC Canada

Abstract

Canada ranks as the world's second-largest blueberry producer, with an increasing demand for organic blueberries largely driven by greater awareness of their health benefits, such as high antioxidants concentration. To enhance growth, yield, and fruit quality while promoting sustainability and effective nitrogen management, alternative production systems should be considered. Consequently, a split-plot design was established over two growing seasons at a commercial berry farm to compare four different fertilizer treatments: 1) poultry pellets + feather meal, 2) soy protein hydrolysate + rock phosphate, 3) bone meal + feather meal + crustaceous meal + alfalfa meal + seaweed extract, and 4) an inorganic nutritive solution control. Northern highbush blueberries (*Vaccinium corymbosum L.* Cv. 'Reka', 'Liberty', 'Bluecrop') were potted in 25-L containers filled with an organic peat-based growing medium supplied by Berger (Berger, Saint-Modeste, QC), irrigated through a drip system, and grown under high tunnels. The study observed a trend of higher soil microbial activity under organic management, although not significantly different from the inorganic control. Productivity varied across cultivars and fertilizer sources. The 'Bluecrop' and 'Liberty' cultivars produced similar yield under both organic and conventional fertilizers, except for 'Liberty' when using animal-based fertilizers. For the 'Reka' cultivar, yields were higher with conventional fertilizers than with organic alternatives. In 2021, fruit qualities, such as polyphenol concentration, were higher in blueberries fertilized with animal-based, plant-based or mixed organic fertilizers compared to conventional fertilizers.

Keywords: *Vaccinium corymbosum*, organic production, production systems, controlled environment, anthocyanins, polyphenols

INTRODUCTION

Organic blueberries are among Canada's most important fruit crops (Agriculture and Agrifood Canada, 2020). Historically, highbush blueberries were grown directly on in-ground, but they have strict soil requirements, such as well-drained, acidic, and organic-rich soils (Bryla and Strik, 2014). Highbush blueberries also have low nitrogen (N), phosphorus (P), and potassium (K) requirements, and improper fertilization can lead to nitrogen leaching. The shift to using organic fertilizers in blueberry production is driven by concerns that nutrient leaching losses may impact groundwater and freshwater quality globally (Messiga et al., 2020). These specific requirements have led to the development of container-based highbush blueberry cultivation to improve fruit yield and quality by enhancing control over irrigation, nutrient management, and growing media components (Voogt et al., 2014).

Additionally, producers are observing an increasing demand for high-quality highbush blueberries throughout the summer season and even year-round. To extend the berry harvest season, high tunnel cultivation has become an attractive solution, enabling

[a]E-mail: embof2@ulaval.ca

the production of berries with consistent size and minimal physical defects (Lamont, 2005). This system extends the season by raising air temperatures in the spring to accelerate fruit development and by protecting berries from frost damage and weather stresses (Smrke et al., 2021; Ogden and Van Iersel, 2009). However, despite its potential, the lack of a well-defined organic fertilization plan for container-grown highbush blueberries in high tunnels has impeded the progress of this production method. This limitation not only affects organic berry production but also restricts producers' ability to exploration alternative crops. These challenges become even more pressing with climate change, which adds further stress to traditional production methods.

In our study, three organic fertilizers and one conventional control were evaluated to develop a sustainable fertilizer plan for highbush blueberries with a low environmental impact: animal-based, plant-based, a mix of animal- and plant-based fertilizers, and an inorganic nutritive solution inspired by Voogt at al. (2014). Feather meal (animal-based) has been shown to improve cumulative yield while significantly raising the soil pH. It also provides a rapid and high rate of nitrogen mineralization (Stirk et al., 2019; Sullivan et al., 2010). Alfalfa meal (plant-based) and poultry pellets (animal-based) are known as a slow-release nitrogen fertilizer (Sullivan et al., 2010). Studies have found that organic fertilizers can produce yields comparable to inorganic nutrient sources (Caspersen et al., 2016). However, cultivar-specific responses to organic fertilizer have been reported, indicating that certain cultivars may be more compatible with organic management (Larco et al., 2013).

Over a two-year trial, we investigated the effects of organic fertilizers on microbial activity, soil nutrient content, productivity, plant growth, and fruit qualities in highbush blueberries. We hypothesized that using organic fertilizers for container-grown highbush blueberries under high tunnels could result in similar or superior yield, growth, and fruit qualities compared to inorganic nutritive solution. Additionally, we proposed that organic fertilizer could perform comparably to inorganic fertilizer options by maintaining optimal soil pH and microbial soil activity, while supplying adequate nutrients to meet plant requirements. Finally, we hypothesized that certain cultivars would be more compatible with organic management practices.

MATERIALS AND METHODS

Study site

The experimental field was located at the specialized commercial berry farm, Les Fraises de l'île d'Orléans Inc. in Saint-Laurent de l'île d'Orléans, QC, Canada (lat. 46 °86′ 32″ N, long 71 °02′63″W). To minimize weed growth, a black polyethylene plastic tarp was placed on the ground, and a multi-span high tunnels complex was built, covered with a high-transmittance silver film (Plastika Kristis S.A, Iraklion, Greece). The experiment ran from May 2021 to September 2022. Average daily temperature was 23.75 °C ± 2.56, and the average solar radiation was 479.84 ± 33.25 (averaged from June to September 2021 and 2022).

Plant material

The plants (Cv. 'Reka'. 'Liberty', and 'Bluecrop') were obtained as two-year-old plants from a local nursery in Saint-Césaire, QC, Canada, and initially grown in 10 L containers at the farm nursery. On May 15, 2021, 288 two-year-old highbush blueberry plants were transplanted in 25 L containers filled with a custom organic peat-based growing media provided by Berger (Berger, Saint-Modeste, QC). The three cultivars had different harvest periods with 'Reka' being the earliest and 'Liberty' being a late harvest cultivar. Plants were pruned in May using sanitized pruners and were spaced 0.75m center-to-center with 2 m between rows.

[a]E-mail: embof2@ulaval.ca

Experimental design

Four fertilizer treatments were assigned in a split-plot design, with cultivars serving as the main plot and fertilizer sources as subplots. Each treatment plot consisted of six plants, resulting in 48 experimental unit divided into four repetitions. The treatments are detailed in Table 1. Organic fertilizers were applied monthly to each container and mixed thoroughly. The inorganic nutritive solution was prepared as a concentrated nutrient solution of 150 L, diluted to 1% using a dosing pump, and supplied daily to the plants through three drippers. Organic plants received daily irrigation through three drippers, utilizing pH-adjusted water with sulfuric acid and 30 ppm of K_2SO_4. The irrigation pH of both solutions was maintained between 4.5 and 5.0, with electrical conductivity (EC) set at 0.7 mS cm^{-1} for the standard solution and at 0.3 mS cm^{-1} for the organic solution. Plants were irrigated for 20 minutes each day, totaling 2.0 L.

Soil chemical analysis and leaf mineral analysis

Soil samples were taken before the initial fertilizer's application and every month for microbial activity analysis (FDA analysis; Adam and Duncan, 2001) and nutrient analysis (Saturated media extract) for soil pH, electrical conductivity (EC), and macro- and microelement contents. A combined soil sample of 6 plants from each experimental unit was gathered by sampling within the root regions at a depth of 20 cm. Soil was conserved at 4 °C. During harvest, we took 15 mature leaves per plant: 5 from the top, 5 from the middle and 5 from the bottom. These leaves were dried at 60 °C for the analysis of the macro- and micro-elements.

Photosynthesis and plants growth measurements

Leaf chlorophyll content was measured using a SPAD 502 Plus Chlorophyl Meter (Konica Minolta Co. Ltd., Tokyo, Japan). SPAD indices were recorded on a leaf at the base of the plant and another at the top. Chlorophyll fluorescence (Fv/Fm) values were obtained from the same leaves using a Handy PEA (Hansatech Instruments Ltd., King's Lynn, UK) after 20-minute dark adaptation (Hansatech Instruments Ltd, 2006). The number of stems, height, and diameter of each stem were measured using a tape measure and digital caliper. Measurements were taken from three plants per experimental unit.

Yield and fruit qualities

Blueberries were harvested and weighed weekly during the harvest period. Unsellable fruits, defined as unripe, moldy, or physical damaged, were removed and weighed, constituting the non-sellable fruits. The sellable fruits from each experimental unit were also weighed, and the average size per fruit was measured. Soluble sugars in the blueberries were assessed on the same day of harvest using a BRIX PAL-1 3810 portable refractometer (Atago, Tokyo, Japan). For the determination of polyphenol content of blueberries, 50 halved fruits were freeze-dried using a Hull S30 Ultra Lyophilizer (SP Scientific, Warminster, PA, USA). The total phenolic compounds in the freeze-dried blueberries were quantified using the Folin-Ciocalteu method (Singleton et al., 1999). Evaluation of anthocyanin content was conducted on the freeze-dried blueberries using differential pH methodology (Durst and Wrolstad, 2005).

Statistical analysis

Analyzes of variance were performed using the MIXED procedure of SAS (SAS® OnDemand for Academics, SAS Institute Inc., Cary, NC, USA) with a significance level of $P \leq 0.05$. Data normality was assessed with a Shapiro-Wilk test, and homogeneity was visually interpreted from residual plots. Additionally, the data were subjected to principal component analysis (PCA) of multivariate parameters via the PRINQUAL procedure of SAS (SAS v. 9.4,

[a]E-mail: embof2@ulaval.ca

SAS Institute Inc., Cary, NC, USA).

Table 1. Organic and inorganic fertilizers used according to the types of fertilization for the 2021 and 2022 seasons.

Fertilizer sources	Composition	N-P-K Content (%)	N-P-K Content (ppm) [a]
Animal	Poultry pellets (Actisol)	5-3-8	
	Feather meal	11-0-0	
	K_2SO_4	0-0-52	30
Vegan	Ez-grow (rock phosphate, soy protein hydrolyzate, ferrous sulfate)	9-1.5-7	
	K_2SO_4	0-0-52	30
Mix	Selectus (alfalfa meal, feather meal, bone meal, mined potassium sulfate, rock phosphate, shellfish meal, seaweed extract, gypsum)	4-2-5	
	K_2SO_4	0-0-52	30
Inorganic	Nutrient solution through drippers	-	42-12-60

[a]Supplied daily through the irrigation system.

RESULTS AND DISCUSSION

Soil chemical analysis

The growing media analysis results (SME) indicate that the pH levels were lower under inorganic fertilizers, measuring 5.10, compared to 5.76 for animal-based fertilization, 5.50 for mixed-based fertilizers, and 5.74 for vegan-fertilizers. This was expected, as organic fertilizers often increase soil pH (Butterly et al., 2013). At p=0.01, EC for the mixed fertilization was significantly higher than for the animal-based and inorganic nutrient treatments (Table 2). The recommended soil EC for blueberries is 0.8 mS cm^{-1}, as established by Messiga et al. (2021). In this study, all treatments maintained EC levels above 0.8 mS cm^{-1}. There was no significant difference in nitrate content (average of 18.09 ppm). Ammonium content was significantly higher with plant-based fertilizers (86.50 ppm), animal-based fertilizers (49.48 ppm), and mixed fertilizers (39.73 ppm), compared to conventional fertilization (20.32 ppm), while plant-based fertilizers were higher than the mixed fertilization. Blueberries are known to absorb NO_3^- less readily than NH_4^+, which has an impact on N nutrition, and ultimately, on overall growth (Eck et al., 1990). The P content was significantly higher in the animal-based and mixed fertilizer treatments compared to the plant-based and inorganic fertilizer treatments, with the lowest content observed in the plant-based treatment.

Microbial activity

Microbial activity was not significantly affected by the fertilizer treatments, although lower FDA activity was observed in inorganic-fertilized 'Bluecrop' highbush blueberry plants when comparing July samples (255.29 $\mu g\ g^{-1}\ h^{-1}$) to August samples (73.52 $\mu g\ g^{-1}\ h^{-1}$). Further evaluation is needed to determine if bacterial and fungal Operational Taxonomic Units (OTUs) exhibit any changes due to fertilizers, similar to the findings of Tan et al. (2023), which showed significant differences in bacterial and fungal communities in blueberries orchards fertilized with organic versus inorganic fertilizers.

[a]E-mail: embof2@ulaval.ca

Table 2. Analysis of variance and mean comparisons (where the effect is significant) were performed on various chemical parameters of the growing medium across four fertilization treatments and three cultivars of highbush blueberries ('Bluecrop', 'Liberty', 'Reka') for the 2021 season (n=48).

		pH		CE (mS cm^{-1})		NO_3^- (ppm)	NH_4^+ (ppm)		P (ppm)		K (ppm)	
Cultivar	Bluecrop	5.61		1.63		18.13	53,53		30,78		251,8	
	Liberty	5.46		1.59		19.52	43,68		28,77		288,2	
	Reka	5.49		1.78		16.64	49,14		28,22		257,5	
Treatment	Animal	5.76	A[z]	1.55	BC	15.50	49,48	AB	40,76	A	265,9	AB
	Mix	5.50	A	2.09	A	14.36	39,73	B	36,29	A	351,9	AB
	Vegan	5.74	A	1.82	AB	22.14	85,60	A	17,68	C	236,9	B
	Inorganic	5.10	B	1.20	C	20.39	20,32	C	22,29	B	208,8	B
ANOVA –P values												
Cultivar (C)		0.476		0.893		0.861	0,600		0,850		0.861	
Treatment (T)		<0.001		0.010		0.260	0,002		<0,001		0.003	
C × T		0.578		0.240		0.460	0,880		0,052		0.366	

[z]Different letters indicate a significant difference between the means for the same factor in the same column at P ≤ 0.05 (protected Fisher's LSD test).

Photosynthesis and plant growth measurements

Leaves of plants under inorganic fertilization had higher chlorophyll content (SPAD) ($P <$ 0.001) than the three types of organic fertilization. The average SPAD value for inorganic leaves was 43.55 (SPAD unit) while organic fertilizers averaged 41.60 (SPAD unit). Regarding chlorophyll fluorescence, there was no effect of fertilizer treatments on the Fv/Fm value. The performance index (PI) of the leaves was significant when looking at the interaction for sampling dates, fertilizers and cultivars for demonstrating that the 3rd sampling date, i.e., June 10, 2022, was lower overall than the measurements carried out on June 15, 2021, August 12, 2021, and August 10, 2022. For example, when looking at the values for the Bluecrop cultivar, decrease of 25% is visible from June 2021 to June 2022 and the two cultivars responded similarly. There was no significant difference in fertilizers within the same sampling date. Several factors could explain these results, including weather conditions on the sampling day or the impact of frost in May 2022, which may have slowed plant growth. The use of SPAD values has been claimed as a useful tool to manage nutrition in blueberries crops (Pinzón-Sandoval et al. 2023) and can successfully quantify nitrogen content in fruit crops. SPAD values from the three Northen cultivars observed in the study were lower than values observed in other experiments with Southern highbush cultivars (Pinzón-Sandoval et al. 2023). Also, the difference between cultivars can be associated to genetic differences as some cultivars have darker tones of green in the leaves and not solely based on good nutrition and physiological status. The SPAD meter was shown to be an effective tool for estimating leaf chlorophyll content in agricultural crops (Jiang et al., 2017). In our study, we observed higher SPAD values in blueberry plants treated with inorganic fertilizers, along with increased yield. This aligns with findings from other experiments indicating that the chlorophyll content index in blueberries is highly correlated with biomass, fruit production, and photosynthetic efficiency (Jiang et al. 2019).

Yield and fruit qualities

A significant interaction between cultivar × fertilizer treatments was observed (P = 0.018) for total yield per plant (Figure 1). For 'Bluecrop', no significant effect of

[a]E-mail: embof2@ulaval.ca

fertilization treatments on fruit yield per plant was found, with an average yield of 1.212 kg/plant. However, fruit size was higher under the inorganic nutrient solution (2.39 g/fruit) compared to organic fertilization treatments (2.07 g/fruit). For 'Liberty', yield and fruit size were higher with inorganic fertilizers (1.889 kg/plant; 2.27 g/plant) compared to animal-based fertilization (1.388 kg/plant; 2.08 g/fruit), and comparable to organic treatments of plant- or mixed sources. The 'Reka' cultivar showed higher yield under inorganic fertilization (2.211 kg/plant) compared to organic treatments (1.416 kg/plant), although fruit size was lower (1.84 g/fruit vs. 1.99 g/fruit). Sellable yield per plant was high at 99% (data not shown). Stirk et al. (2019) reported yields under 2.000 kg/plant for four-year-old 'Liberty' grown directly in soil, while other research on 2-year-old container-grown organic highbush blueberries reported an average yield of 409 g/plant for 'Duke, 'Aurora', and 'Brigitta' (Smrke et al. 2021). The yields in our study are consistent with these findings, indicating that the container system under high tunnels did not negatively impact yields. Soluble sugar content (◦Brix) (average of 10.77 ◦Brix) and anthocyanin concentrations (average of 4.60 mg/g DW) were unaffected by fertilization treatments. Anthocyanin concentrations did vary between cultivars (P < 0.001), with 'Liberty' showing higher levels than 'Bluecrop' and 'Reka' (Figure 1). Polyphenol content was higher in plants fertilized with animal- and plant- based sources compared to conventional fertilization in 2021, though no significant differences were observed in 2022.

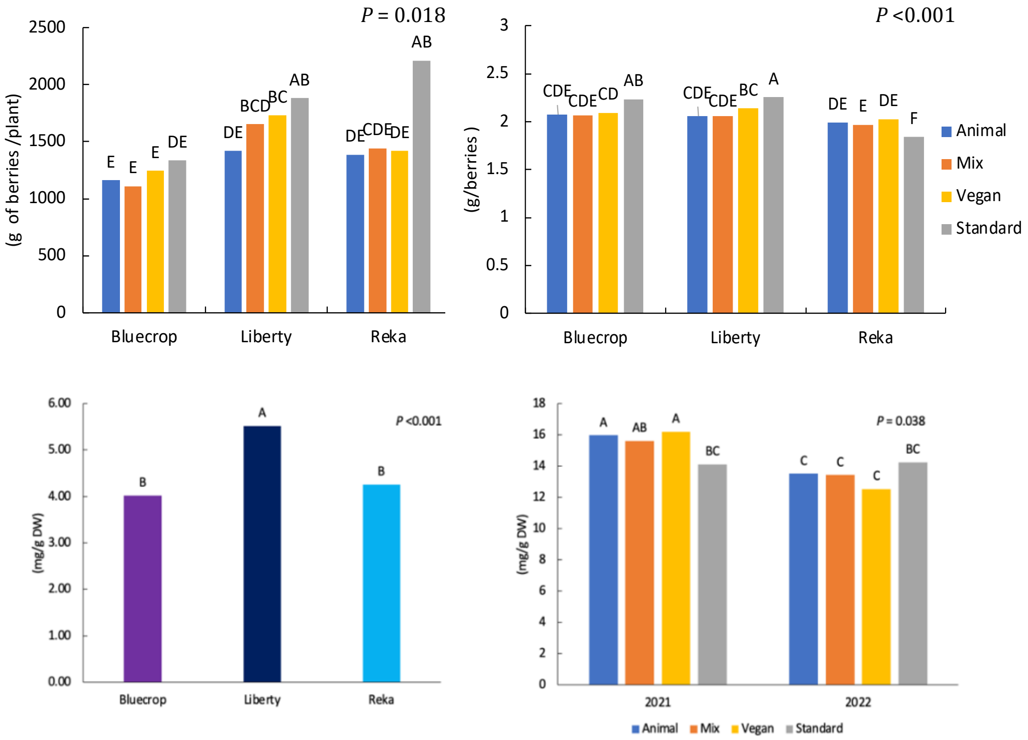

Figure 1. Comparison of means for A) total yield per plant (g plant^{-1}), (B) fruit size (g berries^{-1}) (C) anthocyanin content (mg g^{-1} DW) and (D) polyphenol content (mg g^{-1} DW) across four fertilization treatments for three highbush blueberry cultivars. Different letters indicate significant differences between means at P ≤ 0.05 (protected Fisher's LSD test) (n = 96).

CONCLUSIONS

In conclusion, this research explored the effects of organic fertilizers on growing media, yield, and fruit quality across different highbush blueberry cultivars. Our findings

[a]E-mail: embof2@ulaval.ca

highlight that organic fertilization can positively influence specific growth parameters and fruit quality attributes. The continuation of this project into a third year could substantially benefit highbush blueberry producers both nationally and internationally by supporting the establishment of an organic management plan enhanced with biostimulants (Boudreau-Forgues, et al. 2024). This proposed approach aims to improve yields, microbial diversity within the growing media, fruit quality, and overall crop sustainability in response to the increasing challenges posed by climate change.

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[a]E-mail: embof2@ulaval.ca

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[a]E-mail: embof2@ulaval.ca