EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(4), 116–124
https://doi.org/10.12912/27197050/183169
ISSN 2719-7050, License CC-BY 4.0

Received: 2024.01.02
Accepted: 2024.01.27
Published: 2024.02.25

The Effect of Different Methods of Fertilization with Ammonium Sulfate and Urea on Yield and Fruit Size of Highbush Blueberry (*Vaccinium corymbosum* L.)

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ABSTRACT

The objective of this study was to evaluate the effects of liquid fertilization through drip irrigation with nitrogenous (N) fertilizers, including ammonium sulfate and urea, compared to the application of granular fertilizers on highbush blueberry plants (*Vaccinium corymbosum* L.) cultivar 'Draper' during the first three years of fruit production (2020–2022). Planting of the saplings took place in April 2018, distances were 1.1 m within rows and 2.8 m between rows, 3246 shrubs/ ha. Control variants (no fertilization) were identical for both fertilization methods (liquid and granular). The substrate was a mixture of soil, peat, and pine bark in a 1:1:1 ratio. Both types of fertilizers were used at three N rates, which were increased each year as the plants entered into production (70 to 95, 135 to 190, 195 to 270 kg/ha N). In the first year with liquid fertilization, the yield was 3.8 t/ha, while with granular fertilization, it was 2.7 t/ha, indicating a 29% higher yield with liquid fertilization. Additionally, the yield was 14.8% higher with ammonium sulfate compared to urea. The nitrogen concentration in the leaves with liquid fertilization reached 1.78%, while with granular fertilization, it was 1.67%. Moreover, with ammonium sulfate, it was 1.89%, and with urea, it was 1.73%. Overall, the highest total yield ranging from 16.9 to 25.9 t/ha during the first three years of production was achieved when the plants were fertilized with ammonium sulfate or urea at an annual rate of 70–95 kg/ha N. The conducted research found that liquid fertilization is more efficient in maximizing yield and optimizing the amount of nutrients. Liquid fertilizers were evenly distributed using drip irrigation; this uniform application helps ensure that all plants receive the same amount of nutrients.

Keywords: fertigation, granular fertilizer, ammonium sulfate, urea, yield.

INTRODUCTION

The efficiency of highbush blueberry (*Vaccinium corymbosum* L.) production can be significantly enhanced through controlled application of macro and micronutrient plant nutrition using traditional fertilization methods and fertilization through drip irrigation. Yields were higher when plants were fertilized through drip irrigation compared to other methods (Vargas et al., 2015; Moursy et al., 2023). For the cultivation of highbush blueberry (*Vaccinium corymbosum* L.) a low substrate pH of 4.5–5.5, high organic matter content up to 7–10%, and good substrate aeration are required (Li et al., 2019; Kingston et al., 2017). These plants can thrive in soils rich in organic substrates, such as peat, bark, and leaf mold, or a combination of these substrates (Strik, 2017). Maintaining these three requirements at optimal levels can be challenging for many growers, as a considerable portion of agricultural land does not meet these criteria (Fang et al., 2020).

Drip fertilization optimizes the distribution characteristics of soil water and fertilizer, which also effect physiological and ecological characteristics of root such as root distribution and root activity (Ma et al., 2022). However, some studies have pointed out that applying conventional fertilizers without guidance, can lead to salt accumulation in soil as well as reduce the yield and fruit quality of blueberries (Zeng et al., 2021).

Blueberry plants prefer ammonium (NH_4^+) compared with nitrate (NO_3^-) as the N source. Accumulation of NH_4^+ renders the soil acidic (Alt et al.,. 2017). Furthermore, blueberry was thought to display an N- source preference for NH_4^+, and the 5/1 (NH_4^+/NO_3^-) ratio was recommended to promote the growth and improve the quality of blueberry (Zhang et al., 2021). The pH values (in KCL) between 3.8–4.5 are reported as optimal for soil acidification. Blueberry is an acid-loving plant, and a suitable soil pH for its optimal growth is approximately 4.0–5.0 (Gallegos et al., 2018).

The acidic soil pH and the application of an acidified nutrient solution in highbush blueberry plantations cause significant chemical and microbiological changes in soil properties. In acidic soils, the availability of all macroelements decreases, while the trend is opposite for micronutrients such as Zn, Cu, B, and Mo. As blueberry is an oligotrophic species with shallow root system (Messiga et al., 2018), it prefers ammonium N, and has low requirements for P, K, Ca and Mg (Wu SZ et al., 2019).

Highbush blueberry is a long–lived perennial crop, categorized as calcifuge, well-adapted to acidic soil conditions (pH 4.5–5.5). Therefore, selecting the correct fertilizer is of great importance for promoting growth and increasing the fruit yield of blueberry plants (Clark et al., 2020). Also, it has been reported that the increased NH_4^+ could induce the higher nutrient uptake by the reduction of the pH required for blueberry growth and production (Tamir et al., 2021)

Fertilization through drip irrigation with various liquid N-NH_4 sources, including ammonium sulfate and urea, resulted in increased growth and higher yields compared to conventional fertilization of highbush blueberry with granular fertilizers (Bryla & Machado, 2011; Ehret et al., 2014; Bryla et al., 2015). Previous studies have shown that fertilization has a significant effect on the yield and quality of blueberries. For example, applying wood compost to blueberries cannot only promote their growth and increase their yield (Marty et al., 2019).

Micronutrients, such as Fe, Mn, Zn, and Cu, easily oxidize or precipitate in the soil, making their use less efficient. Chelated fertilizers have been developed to enhance the efficiency of micronutrient utilization. Several factors reduce the bioavailability of Fe, including high soil pH, high bicarbonate content, plant species (grass species are usually more effective than others), and abiotic stresses. Plants have specific mechanisms to take up iron, including transport proteins that are responsible for moving Fe^{2+} across the plasma membrane of root cells. Plants also secrete compounds called "siderophores," which bind to Fe^{3+} and help to solubilize it, making it more available for uptake by plant roots (Kermeur et al., 2023). Iron deficiency often occurs if the soil pH is higher than 7.4. Applied iron can prevent this transformation from Fe^{2+} to Fe^{3+}. Highbush blueberry requires regular applications of nitrogen fertilizers to maximize growth and fruit production (Banados et al., 2012). These plants primarily take up nitrogen as NH_4, so the most common fertilizers applied to highbush blueberry are ammonium sulfate and urea. However, urea requires higher temperatures (>20ºC) for complete breakdown in the soil. It is suggested to apply ammonium sulfate to highbush blueberry when the soil pH is greater than 5.5 or a mixture of urea and ammonium sulfate when the soil pH is less than 5.0. The aim of this study was to determine the effect of liquid fertilization through drip irrigation and granular fertilization for plants irrigated with a microsprinkler system, using different nutrient solutions containing macro and micronutrients for highbush blueberry.

MATERIALS AND METHODS

Experimental site

The experiment was conducted from 2020 to 2022 in a highbush blueberry orchard of the 'Draper' cultivar planted in 2018. The orchard is located in the Vitomiricë village, Pejë municipality, situated between the northern latitude 42° 39' 47" N and the eastern longitude 20° 58' 30" E. Peja is nestled in the valley of Lumbardhi, surrounded by the Albanian Alps. Positioned on the Neogene alluvial terrace, Peja and the entire Dukagjin Plain have an altitude ranging from 505 to 520 m above sea level. The area is characterized by its north-western location on the edge of the Dukagjin plain. The average annual temperature is 10.6°C, with a temperature during the vegetation period of 16.9°C. The hottest months are August with 21.7°C and July with 21.6°C, while the coldest month is January with 0.5°C. Annual precipitation reaches 822 mm, with 366.8 mm during the vegetation period.

The experimental design used was a randomized block design (RBD). Planting distances were 1.1 m within rows and 2.8 m between rows (3246 shrubs/ ha). The substrate was a mixture of soil, peat, and pine bark in a 1:1:1 ratio. The substrate used for planting seedlings in raised beds (soil, peat, and pine bark) underwent laboratory analysis, resulting in a pH of 5.8 for soil, pH (H_2O) of 4.5–5.5 for peat, pH ($CaCl_2$) of 4.0–5.0, and pH of 4.36 for pine bark. The raised beds were constructed with a height of 0.35 m and a width of 0.9 m, using a bed former attached to a tractor. The surface above the raised beds was covered with polypropylene foil to inhibit the growth of unwanted vegetation and influence substrate warming. Below the foil, drip irrigation pipes were placed. Fertilization was carried out through the drip irrigation system using a manifold through which liquid fertilizers were injected.

Treatments

Treatments were arranged in a design with rows separated by a combination of two nitrogen sources (ammonium sulfate and urea) and two fertilizer application methods (weekly liquid fertilization and dry granular fertilization). Liquid fertilization with N sources was performed once a week during the vegetative growth season, starting from the end of March until the end of June, with eight equal weekly applications. Amonium sulfate $(NH_4)_2$ SO_4, containing 20% N and 24% S, and urea (46% N) were used as liquid fertilizers. Granular fertilizers were applied on both sides of the plants along the raised beds in one row spaced 0.2 m from the base of the plants, in three separate applications from the end of March to mid-June, using microsprinklers. The microsprinklers were placed between rows (attached to a wire), and in this way, water was sprayed onto the surface near the plants.

Fertilizer application

Each fertilizer was applied at three nitrogen (N) rates, increasing each year as the plants matured, and compared with the non-fertilized control (0 kg/ha N). Both liquid and granular fertilizers were applied at initial rates during the first two years after planting of plants (2018–2019) at rates of 0, 50, 100, and 150 kg/ha N. In the third year until year five (2020–2022), as mature plants, the rates increased for every years.

Control variants (no fertilization) were identical for both fertilization methods (liquid and granular). Fertilization was not applied at the end of the growth season (approximately from mid-July to early September) to favor vegetative growth, reduce fruit bud initiation, and mitigate the risk of damage and freezing of unripe shoots, which fail to lignify properly. Blueberries have low phosphorus requirements; therefore, annual guidelines for phosphorus are low, in the form of ammonium phosphate ($NH_4H_2PO_4$). P is involved in the metabolism t excessive) P fertilizer can increase the yield blueberry (Zhou YW., 2021). The use of potassium chloride was also avoided, as blueberries are highly sensitive to chloride (Bryla et al., 2021). Iron was supplied in the form of chelates, such as diethylene triamine penta-acetate (DTPA 6%), to increase its availability in the soil solution and prevent deposition by carbonates or bicarbonates, which bind iron and make it unavailable to the plant. Plants typically use iron as $(Fe)^{2+}$.

Irrigation

The blueberries were irrigated from the end of May to the end of September each year, using a drip irrigation system. During the vegetative growth, irrigation was applied at a rate of 25 mm/m^2 per week, while during the fruit growth and ripening period, up to 50 mm/m^2 of water was applied per week. The irrigation water had a pH of 5.0, with an electrical conductivity (EC) of 1.5 on hot days as well as 1.3 and 1.1 on other days.

Higher EC inhibits nutrient uptake by increasing osmotic pressure in the nutrient solution and increases nutrient discharge into the environment.

Leaf sampling

Nitrogen content (N) in leaves was determined during the three years. Representative leaf samples (40 leaves from each combination) were taken during the second half of July each year, a period favorable for assessing the nutritional status of blueberries. The nitrogen content in leaves was determined using the Soil Kjeldahl Nitrogen Method S-8.10. The experiment was repeated four times, with repetitions conducted on 10 shrubs, resulting in 4 combinations × 10 shrubs × 4 repetitions = 160 plants.

Statistical analysis

The data were processed using three-factorial ANOVA analysis. The data were used to make comparisons between the two non-fertilized variants (0 kg/ha N) irrigated with drip irrigation and microsprinklers, as well as factorial comparisons between nitrogen rates and interactions between fertilization method and rate (M × N), as well as interactions between fertilization method and nitrogen fertilizer sources (M × S) at a significance level of $\alpha = 0.05$ and $\alpha = 0.01$ according to Vukadinović, where the F coefficient values were significant.

RESULTS AND DISCUSSION

In the conducted research, the results showed significantly higher yields as a result of the application of the liquid fertilization method through the drip irrigation system, compared to granular fertilization for the plants irrigated with microsprinklers. Meanwhile, for non-fertilized plants, the yield remained similar each year between plants irrigated with drip irrigation or microsprinklers. Two nitrogen sources, ammonium sulfate, and urea, were used for plant fertilization. As a result of liquid fertilization through drip irrigation, the yield increased 29%, compared to granular fertilizer application for the plants irrigated with microsprinklers. Moreover, it was 14.8% higher with ammonium sulfate than with urea. Due to the interaction of the fertilization method, it was observed that the yield was lower with ammonium sulfate than with urea when applied in granular form. It decreased even more at high nitrogen rates during the year 2021, from 7.8 to 6.6 t/ha. After three years of research, the overall yield was 4.8 t/ha higher with liquid fertilization through drip irrigation than with granular fertilization for the plants irrigated with microsprinklers. However, the differences in yield were similar between nitrogen sources and applied rates.

In most treatments, nitrogen fertilizers increased the yield compared to untreated variants (Table 1). However, the yield decreased linearly in the third year (2022) with the increase in nitrogen rates (270 kg/ha N) (Table 1). Some studies have found that high nitrogen rates can be detrimental to fruit production in highbush blueberries, including the ‘‘Bluecrop’ cultivar in Oregon (Banados et al., 2012). The plants were fertilized each year with three rates of ammonium sulfate and urea using liquid fertilization through drip irrigation and granular fertilization for the plants irrigated with microsprinklers. Each symbol represents the average of the four repetitions. The same symbols do not represent significant differences, while different symbols represent significant differences at the level of statistical confidence (α=0.05 and $\alpha = 0.01$). Significant differences were observed in yield in the years 2020–2022 and overall for three years as a result of fertilization methods and nitrogen sources (Figure 1 and 2).

During the first year of research (2020), ANOVA analysis (Table 1) showed that the yield was significantly higher with liquid fertilization through the drip irrigation system, where a yield of 3.8 t/ha was achieved compared to granular fertilization, 2.7 t/ha, meaning it was 29% higher with liquid fertilization. This indicates that, based on the fertilization method, significant differences were observed in yield at the level of statistical importance ($\alpha = 0.05$ and $\alpha = 0.01$). In the second year of the study (2021), the yield reached 7.8 t/ha as a result of liquid fertilization and 6.6 t/ha through granular fertilization, 15.4% higher with liquid fertilization. This shows that significant differences were observed in the second year as well, regarding yield based on fertilization methods. In the third year of the study (2022), the yield of highbush blueberries with tall shrubs through liquid fertilization, with drip irrigation, reached 14.3 t/ha, while with granular fertilization, it was 11.8 t/ha, respectively 17.5% higher with liquid fertilization. This confirms that even in this year, significant differences were observed at the level of statistical importance ($\alpha = 0.05$ and $\alpha = 0.01$) regarding yield based on the fertilization method.

Liquid fertilization through drip irrigation has been shown to offer superior results compared to surface nitrogen applications, perhaps due to the easy availability of nitrogen placed in the root zone. Since granular fertilizers result in higher levels of $N–NO_3$, blueberries prefer more $N–NH_4$ than $N–NO_3$, and $N–NO_3$ is highly mobile in soil, which may leach during winter in the treatments with granular fertilizers compared to the treatments where fertilization is done through drip irrigation (Bryla &Machado, 2011) Also, the type of fertilizer had an effect on yield growth. ANOVA analysis (Table 1) shows that during the third year of the study (2022), in the ammonium sulfate-treated variant, the yield reached 14.2 t/ha, compared to the urea-treated variant, where the yield reached 12.1 t/ha. This indicates that in

Table 1. Effects of different methods, of nitrogen (N) fertilizer on yield of ‘Draper’ blueberry during the first 3 years of fruit production (2020–22)

Factors	Yield t/ha 2020	2021	2022	Average (AB)	Average (A)
No fertilizer					
Drip	2.4	5.3	9.2	5.63	5.76 Ns
Microspinklers	2.6	5.7	9.4	5.90	
Average AC	2.5	5.5	5.76		
Factor A - Method (M)					
Liquid fertilizer	3.8	7.8	14.3	8.63	7.83**
Granular fertilizer	2.7	6.6	11.8	7.03	
Average AC	3.25	7.2	13.05		
Factor B - Source (S)					
Ammonium sulfate	4.1	6.8	14.2	8.36	8.03*
Urea	3.8	7.2	12.1	7.7	
Average AC	3.95	7.0	13.15		
Factor C -N -rate (N)					
70–95 kg/ha	3.4	7.9	13.9	8.4	
135–190 kg/ha	3.2	7.2	12.7	7.7	7.84*
195–270 kg/ha	2.9	7.6	11.8	7.43	
Average C	3.16	7.56	12.8		

Average BC*					Average B**	
5.76 Ns	7.83**				6.79*	
8.03*	7.84*				8.03 *	

Factors		A*	B**	C*	AB*	AC*	BC**	Interactions ABC*	
LSD	1%	0.179	0.150	0.2942	0.2136	0.465	0.395	0.292	0.587
	5%	0.130	0.120	0.2342	0.1783	0.293	0.246	0.220	0.369

Note: differences were demonstrated at significance level LSD 0.05 and 0.01%. Legend: Ns – not significant, * – significant, ** – highly significant.

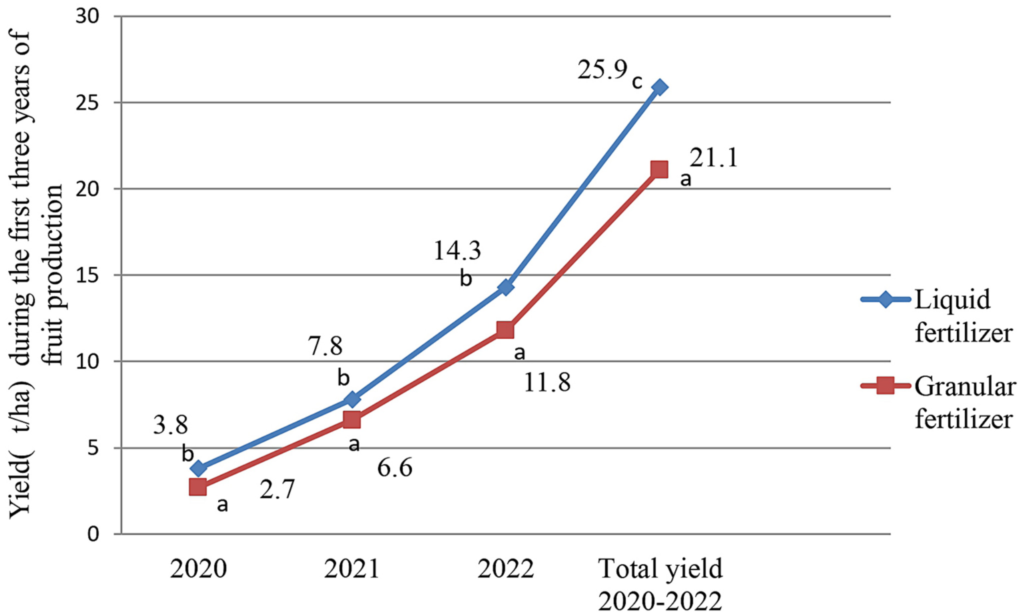

Figure 1. Effect of fertilization method on yield according to years

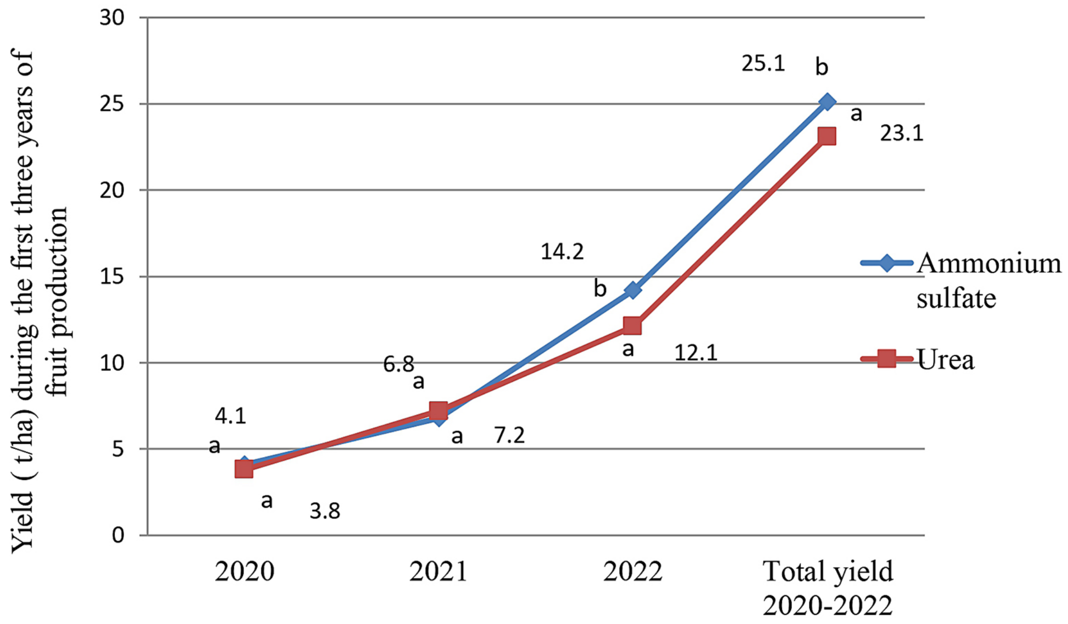

Figure 2. Effect of nitrogen sources on yield according to years

Table 2. Effects of different methods, of nitrogen (N) fertilizer on berry weight of 'Draper' blueberry during the first 3 years of fruit production (2020–22)

<table>
<tr><td colspan="2" rowspan="2">Factors</td><td colspan="4">Berry wt (g)</td><td colspan="2" rowspan="2">Average (AB)</td><td colspan="2" rowspan="2">Average(A)</td></tr>
<tr><td colspan="2">2020</td><td>2021</td><td>2022</td></tr>
<tr><td colspan="2" rowspan="3">No fertilizer
Drip
Microspinklers</td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td colspan="2" rowspan="3">1.66 Ns</td></tr>
<tr><td colspan="2">1.67</td><td>1.79</td><td>1.46</td><td colspan="2">1.64</td></tr>
<tr><td colspan="2">1.71</td><td>1.83</td><td>1.53</td><td colspan="2">1.69</td></tr>
<tr><td colspan="2">Average AC</td><td colspan="2">1.69</td><td>1.81</td><td>1.49</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="3">Factor A - Method (M)
Liquid. fertilizer
Gran.fertilizer</td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td colspan="2" rowspan="3">1.67 Ns</td></tr>
<tr><td colspan="2">1.78</td><td>1.75</td><td>1.56</td><td colspan="2">1.69</td></tr>
<tr><td colspan="2">1.67</td><td>1.72</td><td>1.63</td><td colspan="2">1.64</td></tr>
<tr><td colspan="2">Average AC</td><td colspan="2">1.72</td><td>1.73</td><td>1.59</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="3">Factor B - Source (S)
Ammonium sulfate
Urea</td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td colspan="2" rowspan="3">1.66 Ns</td></tr>
<tr><td colspan="2">1.71</td><td>1.73</td><td>1.52</td><td colspan="2">1.65</td></tr>
<tr><td colspan="2">1.69</td><td>1.74</td><td>1.58</td><td colspan="2">1.67</td></tr>
<tr><td colspan="2">Average AC</td><td colspan="2">1.7</td><td>1.73</td><td>3.1</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="4">Factor C -N -rate (N)
70–95 kg/ha
135–190 kg/ha
195–270 kg/ha</td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td colspan="2" rowspan="5">1.63*</td></tr>
<tr><td colspan="2">1.76</td><td>1.79</td><td>1.53</td><td colspan="2">1.69</td></tr>
<tr><td colspan="2">1.67</td><td>1.72</td><td>1.50</td><td colspan="2">1.63</td></tr>
<tr><td colspan="2">1.63</td><td>1.64</td><td>1.45</td><td colspan="2">1.57</td></tr>
<tr><td colspan="2">Average C</td><td colspan="2">1.68</td><td>1.71</td><td>1.49</td><td colspan="2"></td></tr>
<tr><td colspan="2">Average BC*</td><td colspan="2"></td><td></td><td></td><td colspan="4">Average B*</td></tr>
<tr><td>1.66 Ns</td><td>1.67 Ns</td><td colspan="2"></td><td></td><td></td><td colspan="4">1.66 Ns</td></tr>
<tr><td>1.66 Ns</td><td>1.63*</td><td colspan="2"></td><td></td><td></td><td colspan="4">1.64*</td></tr>
<tr><td rowspan="2">Factors</td><td rowspan="2"></td><td rowspan="2">A</td><td rowspan="2">B**</td><td rowspan="2">C*</td><td rowspan="2">AB</td><td rowspan="2">AC*</td><td>BC*</td><td colspan="2">Interactions</td></tr>
<tr><td></td><td colspan="2">ABC</td></tr>
<tr><td rowspan="2">LSD</td><td>1%</td><td>0.479</td><td>0.264</td><td>0.398</td><td>0.432</td><td>0.247</td><td>0.436</td><td>0.282</td><td>0.487</td></tr>
<tr><td>5%</td><td>0.359</td><td>0.128</td><td>0.276</td><td>0.282</td><td>0.193</td><td>0.325</td><td>0.197</td><td>0.367</td></tr>
</table>

Note: differences were demonstrated at significance level LSD 0.05 and 0.01%. Legend: Ns – not significant, * – significant, ** – highly significant.

the ammonium sulfate–treated variant, the yield was higher by 14.8% compared to the urea-treated variant, showing significant differences based on nitrogen sources.

The obtained results are in line with those reported by other authors (Ehret et al., 2014), who found similar results in the 'Duke' cultivar in British Columbia and concluded that fertilization with ammonium sulfate was more effective. The interaction between fertilizer application method (M) and nitrogen rate (N) factor (AC) was also significant at the level of statistical importance ($\alpha = 0.05$ and $\alpha = 0.01$). This is attributed to the fact that the yield increased when lower nitrogen rates were applied (Table 1) with liquid fertilization through drip irrigation, but the yield decreased linearly at higher nitrogen rates (up to 270 t/ha) when fertilizers were applied in granular form. High yield reduces the size of fruits in highbush blueberries, explaining why the fruit weight was lower in the third year of production (2022) when the yield was higher compared to previous years, especially with liquid fertilization through drip irrigation, where the average weight of berries reached 1.46 g/berry (Table 2). Also, the size of the fruits decreased with the use of high N rates in the third year (Table 2). Excess nitrogen results in greater vegetative growth of blueberries and can reduce fruit size (Banados et al., 2012).

Nitrogen concentration in leaves increased along with nitrogen rate and, in general, was higher in the variants fertilized through drip irrigation by 1.78% compared to the variants fertilized with granular fertilizer for the plants irrigated with microsprinklers by 1.67% (Table 3). While nitrogen concentration values in leaves were also higher based on nitrogen sources. In the variant fertilized with ammonium sulfate, the

Table 3. Effects of different methods of nitrogen (N) fertilizer on leaf N concentration in 'Draper ' blueberry during the first 3 years of fruit production (2020–22)

<table>
<tr><td colspan="2" rowspan="2">The factors</td><td colspan="4">Leaf N (%)</td><td colspan="2" rowspan="2">Average (AB)</td><td colspan="2" rowspan="2">Average (A)</td></tr>
<tr><td colspan="2">2020</td><td>2021</td><td>2022</td></tr>
<tr><td colspan="2" rowspan="3">No fertilizer
Drip
Microspinklers</td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td colspan="2" rowspan="3">1.33Ns</td></tr>
<tr><td colspan="2">1.37</td><td>1.41</td><td>1.19</td><td colspan="2">1.32</td></tr>
<tr><td colspan="2">1.43</td><td>1.38</td><td>1.26</td><td colspan="2">1.35</td></tr>
<tr><td colspan="2">Average AC</td><td colspan="2">1.4</td><td>1.39</td><td>1.22</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="3">Factor A - Method (M)
Liquid. fertilizer
Gran. fertilizer</td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td colspan="2" rowspan="3">1.68**</td></tr>
<tr><td colspan="2">1.78</td><td>1.79</td><td>1.61</td><td colspan="2">1.72</td></tr>
<tr><td colspan="2">1.67</td><td>1.81</td><td>1.49</td><td colspan="2">1.65</td></tr>
<tr><td colspan="2">Average AC</td><td colspan="2">1.72</td><td>1.8</td><td>1.55</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="3">Factor B - Source (S)
Ammonium sulfate
Urea</td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td colspan="2" rowspan="3">1.72**</td></tr>
<tr><td colspan="2">1.89</td><td>1.83</td><td>1.58</td><td colspan="2">1.76</td></tr>
<tr><td colspan="2">1.73</td><td>1.76</td><td>1.57</td><td colspan="2">1.68</td></tr>
<tr><td colspan="2">Average AC</td><td colspan="2">1.81</td><td>1.79</td><td>1.575</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="4">Factor C -N -rate (N)
70–95 kg/ha
135–190 kg/ha
195–270 kg/ha</td><td colspan="2"></td><td></td><td></td><td colspan="2"></td><td colspan="2" rowspan="5">1.81*</td></tr>
<tr><td colspan="2">1.73</td><td>1.78</td><td>1.80</td><td colspan="2">1.77</td></tr>
<tr><td colspan="2">1.85</td><td>1.81</td><td>1.84</td><td colspan="2">1.83</td></tr>
<tr><td colspan="2">1.92</td><td>1.83</td><td>1.78</td><td colspan="2">1.84</td></tr>
<tr><td colspan="2">Average C</td><td colspan="2"></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="2">Average BC*</td><td colspan="2"></td><td></td><td></td><td colspan="4">Average B*</td></tr>
<tr><td>1.33Ns</td><td>1.68**</td><td colspan="2"></td><td></td><td></td><td colspan="4">1.50**</td></tr>
<tr><td>1.72**</td><td>1.81*</td><td colspan="2"></td><td></td><td></td><td colspan="4">1.76**</td></tr>
<tr><td rowspan="2">Factors</td><td rowspan="2"></td><td rowspan="2">A*</td><td rowspan="2">B**</td><td rowspan="2">C*</td><td rowspan="2">AB*</td><td rowspan="2">AC*</td><td rowspan="2">BC*</td><td colspan="2">Interactions</td></tr>
<tr><td colspan="2">ABC*</td></tr>
<tr><td rowspan="2">LSD</td><td>1%</td><td>0.384</td><td>0.276</td><td>0.361</td><td>0.486</td><td>0.532</td><td>0.327</td><td>0.279</td><td>0.583</td></tr>
<tr><td>5%</td><td>0.216</td><td>0.189</td><td>0.287</td><td>0.263</td><td>0.364</td><td>0.283</td><td>0.183</td><td>0.396</td></tr>
</table>

Note: differences were demonstrated at significance level LSD 0.05 and 0.01%. Legend: Ns = not significant, * = significant, ** = highly significant nitrogen concentration in leaves reached 1.89%, compared to the variant fertilized with urea, which reached 1.73% (Table 3). The obtained research results are in line with other authors (Hart et al., 2006). The interaction between the fertilizer application method (M) and nitrogen rate (N) factor (AC) was also significant in the nitrogen concentration in leaves. However, the rate did not interact significantly in both fertilization methods and nitrogen sources.

Liquid fertilization through drip irrigation increases nitrogen absorption in many crops by improving the timing and placement of nitrogen in the substrate, and therefore often increases nitrogen concentration in leaves in the variants fertilized with granular fertilizers (Bryla & Vargas, 2015). The substrate EC increases linearly with a rate of 2 dSm^{-1} for every g L^{-1} of ammonium sulfate. Also, urea fertilization affects the increase in EC in the substrate, but generally less than ammonium sulfate fertilization (Machado et al., 2014). Ammonium sulfate is more acidifying than urea because it produces twice as many H^+ ions from the nitrification process (Hart et al., 2013).

CONCLUSIONS

In general, the liquid fertilization method through drip irrigation resulted in a higher yield increase compared to the granular nitrogen fertilization method during the first three years of production. However, higher nitrogen rates did not have significant effects on yield increase over the three years of production. In fact, they led to lower yields and smaller average fruit weights during the third year of the study (2020) when fertilizers were applied in granular form. Nitrogen rates ranging from 70 to 95 kg/ha are optimal for maximizing fruit production when applied in liquid form through drip irrigation or in granular form for the plants irrigated with microsprinklers. Yields during the first fruiting year (2020) ranged from 2.4 to 4.1 t/ha and reached values up to 14.3 t/ha in the third year of production (2022).

Ammonium sulfate, compared to urea, resulted in higher cumulative yields by 7% when fertilizers were applied in liquid form, while yields were lower when fertilizers were applied in granular form. Additionally, nitrogen concentration in leaves was higher with ammonium sulfate when fertilizers were applied in liquid form compared to the application of granular fertilizers.

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