Effect of different growth media on water use, yield and soil properties of blueberry cultivated under shade net

Report

to the Water Research Commission (WRC)

by

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EXECUTIVE SUMMARY

BACKGROUND

Blueberry (*Vaccinium corymbosum*) is a perennial plant belonging to the family Ericaceae and genus Vaccinium. The genus comprises both wild and cultivated species distributed across regions worldwide and is known for its significant agronomic and economic importance. (Bhatt & Debnath, 2021). The domestication of blueberries began in the early 1900s under the initiative of Dr Frederic Coville, an American botanist, and Elizabeth White, a blueberry farmer in New Jersey, with the intention to promote the cultivation and commercialization of blueberries. (Giordano et al., 2020). All domesticated varieties were exclusively native to North America, and blueberries were predominantly cultivated in the Northern Hemisphere's continents, such as North America, Asia, Europe, and some countries of the Southern Hemisphere, such as Argentina, Uruguay, South Africa, New Zealand, Chile, and Australia. (Routray & Orsat, 2011). In South Africa, the most commonly cultivated blueberries are Southern Highbush, Rabbiteye, and Northern Highbush varieties. The local consumption of fresh blueberries in South Africa increased by 80% during the 2016-2017 season, compared with the 440 tons produced at the end of the 2015-2016 season. This was attributed to the increase in health-conscious consumers, which exacerbated the rise in demand because of the inherent health benefits of blueberries, including antioxidant properties, cardiovascular support, improved blood pressure, reduced blood sugar levels, and enhanced brain function. (SABPA, 2018; Leech, 2018).

Blueberries are high in carbohydrates, minerals, and vitamins. They are widely recognised for their high nutritional value in livestock diets, contributing to enhanced livestock milk production, improved growth performance, and better overall health maintenance in livestock (Agric-Site, 2020). These beneficial properties of blueberries have over the last five years. Additionally, at least 70% of South African blueberries are exported, which is a terrific addition to the country's Gross Domestic Product (GDP). The Western Cape Province is the main blueberry-producing province in South Africa (SA), with a contribution of sixty percent (60%) to the production, followed by Limpopo (15%), North-West (10%), Gauteng (8%), Eastern Cape (4%), Free State (2%), and Mpumalanga (1%) (SABPA, 2018).

In recent years, inadequate availability of water due to drought has negatively affected blueberry production in South Africa. Global warming brings about climate fluctuations, limited water resources, and water restrictions for agricultural activities, which compels producers to consider alternative crops and/or cultivars and adjust agricultural management practices that are more adapted to the potentially unfavourable future climate (Botai et al., 2017; Galindo et al., 2018; Otto et al., 2018; Burls et al., 2019). Cultivation practices on farms must adapt to the fluctuating climate, including policies, as this is a requirement for reducing negative effects and obtaining benefits from land cultivation (Olesen & Bindi, 2002). Moreover, field management such as irrigation scheduling is critical to minimising the impact of weather patterns on crop production (Olesen, 2006). In Western Cape agriculture, water constraints are expected to increase in the future due to projected increases in temperature and evaporation driven by climate change (Otto et al., 2018; Beck et al., 2016). These conditions, in turn, will result in an increased irrigation demand from crops. The increasingly unstable climate change means there may be more frequent drought periods in the future, just as the one recently experienced in 2015-2017 (Otto et al., 2018; Burls et al., 2019). A significant reduction in stream flow after the rainy season has been predicted for the Western region of South Africa, where several Western Cape water management areas are already water-stressed. The forecasts on water demand and supply for Berg water management and Olifants-Doom water management, respectively, show a high (-20% and -80%) and moderate to low (0% to -20%) gap between the existing supplies in the year 2010 and the anticipated demand in 2030. Hence, more efficient water use, application, and productivity in the agricultural sector is necessary to make allowance for the anticipated higher water demand for human use, agricultural, and industrial production by the year 2030 (Bester, 2011). To overcome these challenges, water conservation practices should be implemented with the adaptation of water management, which is water quality and quantity (Olesen, 2006; Taparauskiene & Miseckaite, 2014).

The use of improved growth media can be a crucial strategy for reducing water use and improving blueberry production. Mulching materials such as peat, pine bark, and sawdust are usually used as a pre-plant soil amendment. It is commonly used during orchard establishment and land preparation to increase the organic matter content of the soils, reduce soil pH, promote homogeneity of root distribution, and increase the water-holding capacity of the soil. (Fang et al., 2020). According to (Agrawal et al., 2021), a combination of different growing media benefits the crop as the growing media contains different properties that are required for plant growth in a soilless cultivation system.

Blueberries are classified as a nitrogen-demanding crop; they require sufficient and well-balanced nitrogen supply for proper growth, fruit development, and yield. (Bryla et al., 2010). However, the effectiveness of different nitrogen forms, particularly when used in combination with water-use-efficient substrate, remains insufficiently studied in South Africa. This necessitates research on blueberry water requirements and cultivation practices without compromising the fruit quality and yield. Limitations in the availability of natural resources, like water and soil, as well as the proper field management, hinder the expansion of blueberry production in South Africa. (Botha, 2022). Therefore, it is critical to investigate cultivation and water-conservation practices in blueberry production using single and combined growth media in the Western Cape Province of South Africa, which has the highest blueberry production.

AIM AND OBJECTIVES

The main aim of the project was to evaluate the impact of different types of single and combined use of growth media (coir, mushroom compost, zeolite, and peat moss) on water use, growth, yield, nutrient content, and quality of blueberries.

Specific objectives:

1. To assess the water application/demand on blueberry plants when cultivated using different types of solid growing media.
2. To assess the effect of the different types of growing media on growth, yield, fruit quality, and water productivity of blueberry plants.
3. To assess the nutrient content of the different types of growth media.
4. To assess the microbial enzyme activities (β-glucosidase, phosphatase & urease) of the different types of growth media.
5. To assess the effect of nitrogen sources on yield and nutrient attributes.

METHODOLOGY

The experiment was conducted at the Department of Agriculture, Agricultural Hub, Cape Peninsula University of Technology, Wellington Campus (S 33°37’55.08” E 19°00’37.4”) under a 70% shade net tunnel. The blueberry plants were obtained from a commercial nursery and transplanted into 45L growing bags that were elevated with bag stands. Growth media compositions were as follows: T_1-100% coir, T_2- 80% coir + 20% zeolite, T_3- 60% coir +40% mushroom compost, T_4- 60% coir + 40% peat moss, T_5- 40% coir + 20% zeolite + 20% mushroom compost, T_6- 40% coir + 20% zeolite + 40% peat moss, T_7- 40% coir + 30 mushroom compost + 30% peat moss. The field capacity (FC) of each composition was obtained before transplanting, and the water replenishment level was set at 75% FC. Data on water usage for each treatment were collected daily using DFM moisture probes linked to real-time software, and the application was performed as per FC replenishment requirements. All other growth parameters were recorded biweekly. The assessment of nitrogen sources was done using ammonium sulphate, calcium nitrate, and urea on growth and yield attributes of blueberries. Mineral content (macro and micronutrients) and secondary metabolites of blueberry fruit were assessed after each harvest. The activity of the three enzymes (β-glucosidase and phosphatase) was measured, and the nematode population count of each treatment was also assessed.

This report includes data from the project’s inception in 2022 to 2025, covering water use, vegetative and yield parameters, mineral content, secondary metabolites, ideal nitrogen source, nematode population, and enzyme activities.

RESULTS AND DISCUSSION

The results of this research project, as per the objectives, indicated that crop water use is critical to water management and conservation. In this study, the use of growth media combinations on blueberry cultivation significantly conserved water. Media combinations with zeolite had less water demand compared to the other treatments used in this research project. T_2 (80% coir + 20% zeolite) had the least water requirement with 4L of water, while the control (T_1 -100% coir) had the highest water requirement at 75% FC with 4.25L daily. This may be attributed to the high cation exchange capacity and water holding ability of zeolite, which enhances the retention of both water and nutrients within the root-zone. Consequently, substrate combinations incorporating zeolite can improve substrate moisture stability, reduce irrigation frequency, and contribute to water conservation in T_2.

The cultivar used in the project was deciduous, and this influenced the vegetative growth patterns from the data collected from 2022 to 2025. Generally, for all treatments, vegetative growth starts in spring, gradually increases as the summer season continues, and declines as leaves are shed in winter. As a result of high-water demand with blueberries cultivated using coir, these plants had the highest vegetative growth compared to other treatments, probably due to the greater water availability resulting from frequent irrigation. Contributing to more cell expansion, nutrient transport, and photosynthetic activity, resulting in the enhancement of vegetative development T_1.

The study also revealed variation in the mineral composition of berries harvested across all treatments. Indicating substrate composition and water management influenced nutrient uptake and accumulation in fruit. Differences in the composition and properties of the growing media may have contributed to these variations, affecting nutritional quality, storage characteristics, and consumer health benefits.

Nitrogen sources influenced plant performance; ammonium sulphate significantly improved all the vegetative and reproductive parameters measured, as blueberries prefer ammonium-based nitrogen forms, which promote efficient nitrogen assimilation with improved root growth and nutrient uptake, enhancing both vegetative development and performance. Furthermore, secondary metabolites varied across treatments, nitrogen sources, and the season of harvest. The highest phenolic was observed in blueberries cultivated on sole coir growth media, reflecting the influence of physiological stress factors associated with higher irrigation demands and substrate properties.

Similarly, enzyme activity and nematode population counts were significantly influenced by different treatments. The highest β-glucosidase activity was observed in T_4 (60% coir and 40% peat moss), which also exhibited relatively lower water demand compared to control (T_1 -100% coir). Indicating that water stress in crops can influence enzyme activity based on the substrate organic matter and the crop's water demand.

IMPLEMENTATION OF THE PROJECT OBJECTIVES

All the project objectives were diligently investigated as stipulated in the contract. The data on water monitoring and application throughout the project across the different treatments were obtained (Objective 1). The vegetative and yield data of berries, weight per pot, total weight, berry size, fresh fruit mineral content and water productivity were obtained (Objective 2). The growing media mineral content (initial and final) and the secondary metabolites analysis were done. Additionally, the results of the initial physiochemical properties of zeolite, mushroom compost and peat moss were obtained (Objective 3). The activities of soil β-glucosidase, phosphatase, and urease enzymes, known to play crucial roles in C, P, and N cycling, respectively, and serve as a growing media quality index, were determined. The nematode population under different growth media was obtained (Objective 4). Furthermore, the assessment of different nitrogen sources on blueberry growth and yield on growth media combinations was determined (Objective 5). The detailed information on the results is highly elaborated in the results and discussion chapter in the main report.

Other outputs include:

- Two dissertations for students under the project (1) PhD (anticipated completion December 2026), (2) MSc candidate (anticipated completion April 2026).
- One review article has been published.
- Two conference proceedings
- Bulletin (short communication)

Pathways to future adoptions of project findings by potential beneficiaries.

This study aligns well with Goals 1, 2, 6, 12, and 13 of the Sustainable Development Goals (SDGs) that South Africa has adopted in its national development agenda, which are:

- SDG 1: End poverty in all its forms everywhere, aiming to eradicate extreme poverty.
- SDG 2: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture

- SDG 6: Clean water and sanitation ensures the availability of sustainable management of water for sustainable agriculture
- SDG 12: Ensure sustainable consumption and production patterns
- SDG 13: Climate action, calls for urgent action to tackle climate changes

The project investigates the effect of different growth media, water use efficiency, yield, media properties, and nutritional and antioxidant properties of blueberries cultivated under shade net conditions. Aiming to identify suitable growth media combinations that improve water-use efficiency and crop productivity (SDG 2). The study supports sustainable agricultural practices in scarce water regions like South Africa (SDG 6). The finding will contribute to the improvement of resource management and increased sustainable blueberry production (SDG12). The study addresses the issue of effective irrigation and substrate management, which can help farmers maintain production under changing climatic conditions (SDG13). These align with the objectives of the Water Research Council (WRC) in terms of innovation and sustainable water usage

CONCLUSIONS

Determination of the field capacity of any growing medium is critical for water conservation. The findings from this study showed that substrate composition plays a critical role in regulating water use, plant growth, nutrient uptake, and fruit quality in blueberry production. The age of the blueberry plants had an impact on the yield accumulation. A significant increase in yield for all treatments was observed in the second year after transplanting. This also improved other parameters such as berry size, mineral content, and enzyme activity.

The integration of zeolite with growing media combinations significantly reduced water usage and increased the water-holding capacity of the media. Water monitoring tools, such as moisture probes, can be used to manage irrigation efficiently to sustain blueberry production. The media combination of 80% coir and 20% zeolite, as well as 60% coir and 40% peat moss, showed potential for water conservation and also improved water productivity. Ammonium sulphate demonstrated the most effective N source, improving vegetative and reproductive parameters, therefore enhancing blueberry production, particularly in regions where water resources are limited.

RECOMMENDATIONS

For potted blueberry plants, it is ideal to use a growing medium combination that conserves water, which is a scarce natural resource, especially in South Africa. The media combination also improves the mineral content of the berry, as water and nutrient uptake are effective.

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List of Abbreviations

Abbreviations	Explanation
ADL	Allowable depletion levels
CPUT	Cape Peninsula University of Technology
CEC	Cation exchange capacity
CU	Chill units
DI	Deficit irrigation
EC	Electric conductivity
ETc	Crop Evapotranspiration
FC	Field capacity
IS	Irrigation scheduling
SABPA	South African Berry Producers Association
NR	Nitrate reductase
NiR	Nitrite reductase
NUE	Nitrogen use efficiency
PAC	Proanthocynadin content
PAW	Plant available water
PRD	Partial root drying
RDI	Regulated deficit irrigation
TFC	Total flavonoid content
TPC	Total phenolic content
WP	Water productivity
WRC	Water Research Commission
WUE	Water use efficiency

List of Symbols and Units

Symbol/unit	Description
NO_3^-	Nitrate
NH_4^+	Ammonium
N	Nitrogen
mm	Millimetre
L	Litre
cm	centimetre
C	Carbon

CHAPTER 1: INTRODUCTION

1.1. Background

South Africa continues to face significant water scarcity challenges, as demonstrated by the previous prolonged drought that affected the Western Cape Province between 2015 and 2017 (Otto et al., 2018). The Western Cape Province is characterised by hot, dry summers and cold, rainy winters. (Calverley CM & Welther, 2022). The prolonged periodic drought is particularly vulnerable to the fruit production industry, especially in Western Cape Province, which contributes significantly to national food security and export earnings. This highlights the necessity for effective water storage facilities and techniques to ensure a good water supply and management during the active growing season for sustainable fruit production in South Africa.

In general, soil is the primary growing medium for crop production; however, due to soil fertility challenges and poor land management, cultivating crops in a soilless medium is critical. (Smrke et al., 2021). The practice of soilless culture has been identified as a potential solution to mitigate arable land challenges, especially in food production. (Sengupta & Banerjee, 2012). The cultivation of crops in soilless culture was common in growing vegetables in hydroponics systems; however, currently, various crops are cultivated using growing medium as a substrate. (Hussain et al., 2014). The type of growing media and the physical and chemical properties of the growing media are critical, as they influence water and nutrient uptake, which essentially influence the growth potential of the plant (Durand et al., 2023).There has been a need to cultivate blueberries in growing media due to the plant's requirement for acidic soils, and this is usually limited in soils (Clark & Zheng, 2020; Smrke et al., 2021).

Irrigation management of various crops, including blueberries, is critical as this affects both the yield and quality of the fruit (Bryla et al., 2009). A decrease in fruit firmness and soluble solids content was recorded when a drip irrigation system with constant water application was used, thereby compromising fruit quality during the harvesting and storage period for the fresh market. (Bryla et al., 2009). An increase in yield was observed on highbush blueberry plants when the irrigation supply was increased to 125% of the crop evapotranspiration (ETc); however, a decrease in soluble solids content was observed at this percentage due to the dilution effect in the fruit. (Holzapfel & Hepp, 2002).

The issue of climate change and excessive water use during blueberry production in many regions of the world, including South Africa, is a challenge due to a lack of efficient and sustainable water resources for crop irrigation. In addition, crop growth and yield potential are further impacted by nitrogen depletion in soils as a result of improper fertilizer application practices. (Zhang & Sun, 2014). Blueberries, being a nitrogen-demanding crop, require adequate nitrogen levels for optimal growth, fruit development, and yield. (Bañ et al., 2012). Nitrogen deficiency can lead to stunted plant growth, reduced fruit quality, and diminished economic returns for farmers. The expansion of blueberry production in South Africa necessitates the adoption of sustainable agricultural practices that address both water scarcity and nitrogen depletion.

This project focused on the water use efficiency of blueberries cultivated on different growth media combinations. The project titled "Effect of different growth media on water use, yield, and soil properties of blueberry cultivated under shade net" aims to investigate the water requirement of blueberries and its impact on yield, fruit quality, and water productivity.

1.2. Project Aims

- To assess the water application/demand on blueberry plants when cultivated using different types of solid growing media.
- To assess the effect of the different types of growing media on yield, fruit quality, and water productivity of blueberry plants.
- To assess the nutrient content of the different types of growth media.
- To assess the microbial enzyme activities (β-glucosidase, phosphatase & urease) of the different types of growth media.
- To assess the effect of nitrogen sources on yield and nutrient attributes

1.3. Research Approach

The research project employed a quantitative approach, including a field experiment and laboratory analysis. Also, with the identified research team with diverse expertise, ranging from basic agronomic practices, media analysis, secondary metabolites, nematode population, and enzyme activity analysis, the project's work was made more efficient. The data collected included reading from the DFM software for water monitoring and replenishment.

Regular project deliverables were submitted to address specific objectives of the project twice a year, and there were also annual meetings to present progress of the previous year and to receive guidance from the reference group members.

The project also supported two postgraduate students in obtaining their qualifications. One towards a Master's degree and the other for a Doctoral degree in Agriculture at the Cape Peninsula University of Technology, Department of Agriculture.

1.4. Scope of the Project

The project was funded for a period of four years from April 2022 to March 2026. The research project was awarded to Prof Francis Lewu of the Department of Agriculture, Cape Peninsula University of Technology (CPUT), Wellington campus. The total amount of funding by WRC was R1 150 000.00 and was distributed according to the scheduled deliverables for the duration of the project. In total, 8 deliverables were submitted to address the project aims and objectives.

The overall aim of the research study was to evaluate the impact of single and combined use of growth media on water use, chemical and physical properties of growth media, vegetative, yield parameters, and chemical composition of berry fruits. This was achieved through the data collected on the monitoring of water use of the different growing media used for blueberry cultivation, and the evaluation of the blueberry crops in response to the different growth media combinations, nematode population counts, and the activity of the three enzymes in the growing media treatment was recorded accordingly.

CHAPTER 2: LITERATURE REVIEW

2.1. Blueberry production and nutritional components

The global production of blueberries dates to the early 1900s, and it has gained increasing interest as commercial production increased in the year 2000 (Devetter et al., 2015). According to Brazelton & Strik, (2013), North American countries contribute to the largest areas of blueberries production in hectares for commercialization, followed by South America, Europe, Oceania, Asia and Africa, respectively. In Africa, South Africa leads in the production of blueberries, with over 2,803 hectares in production in the year 2024, mainly targeting export markets to European countries. (Brazelton et al., 2024).

The Department of Statistics in South Africa (SA) issued the latest population figures in the year 2022, of 11.31% increase from the previous evaluation cycle in 2016, and this is estimated to increase to 16% by 2050 (Stats SA, 2022). This increase in population affects natural resources and arable land for agricultural purposes. (Luan et al., 2014). The decrease in arable lands worldwide is due to various factors, including urbanization, soil degradation, water scarcity, and climate change. (Du Preez et al., 2011; Olsson et al., 2025). This has necessitated producers to explore alternative agricultural practices to meet population demands and ensure food security. (Pingali, 2001).

In recent times, fresh blueberry consumption has increased worldwide, which is attributed to the growing awareness of a healthy lifestyle due to the high nutritional and medicinal value of blueberries (Huamán et al., 2023). Blueberries are high in carbohydrates, minerals, and vitamins (C and K) and are characterised by their high antioxidant properties. They are highly famous for their superior nutritional value in livestock diets, which allows for improved livestock milk production, growth, and health maintenance (Kalt et al., 2020; Martău et al., 2023). These beneficial properties, among others, have led to a significant increase in blueberry production in the last five years. In addition, at least 70% of South African blueberries are exported, which is a great addition to the country's Gross Domestic Product (GDP). In South Africa, the Western Cape contributes about

60% of the total blueberry production, followed by Limpopo, 15%, North-West, Gauteng, Eastern Cape, Free State, and Mpumalanga (SABPA, 2018).

2.2. Agronomic and conservation practices

Blueberry orchards are commonly established in spring or autumn, with one-to two-year-old plants (Bañados, 2009), with an intra-row spacing of 0.9 m and 3 m between rows (Strik, 2007). Highbush blueberry cultivars are deciduous and prefer the Mediterranean climate, as they require chilling units (CU) in winter during dormancy, and insufficient accumulation of CU results in delayed bud break and uneven fruiting (Meyer & Prinsloo, 2003), also at temperatures below 0ºC at the beginning of the growing season, can damage flowers (Webb, 1981). According to Rafie & Mcclintock, (2018). The Northern Highbush variety 'Legacy' requires CU that ranges between 800-1000 units to ensure bud break and flowering. The growth attributes of different blueberry cultivars are greatly influenced by the environmental conditions under which these cultivars are cultivated (Stringer et al., 2018). The plants prefer acidic soils with a pH of 4.5 to 4.8 and soils that are high in organic matter (Davies & Johnson, 1982). Elementary sulphur should be applied to lower the soil pH, prior to planting (Bañados, 2009).

Blueberry species are commonly cultivated under controlled environments such as tunnels to better manage/manipulate the microclimate, pests, and other cultivation practices, thereby improving fruit quality and yield (Fang et al., 2020). The benefits of such a controlled environment are well-documented (Ogden & Van Iersel, 2009; Santos & Salame-Donoso, 2012; Fang et al., 2020). Conventionally, blueberries are planted on raised beds that are well-prepared to ensure root growth and water drainage (Zietsman, 2020). However, this system limits plant growth due to the unavailability of natural resources that are essential for blueberry optimum growth (Fang et al., 2020). Mulching materials are commonly used for blueberries to retain soil moisture and reduce weed growth (Webb, 1981; Taparauskiene & Miseckaite, 2014). The plant root system is shallow and restricts water uptake (Gough, 1980; Bryla, 2011). Environmental factors and cultivation practices influence the plants' water requirement, which subsequently influences vegetative and reproductive growth (Holzapfel et al., 2004). According to

Palvis. (2006), soil and leaf analysis are essential when determining the plant's nutrient requirements. Blueberry plants mainly require an ammonium form of nitrogen and the most common form applied is ammonium sulphate and urea (Claussen & Lenz, 1999; Bryla et al., 2012; Bryla & Strik, 2015). According to Vargas et al. (2015), fertigation is more effective and increases yield by up to 40% compared to granular fertilizer application.

Blueberry plant breeding began in the early 1900s, with much focus on plant vigour, disease resistance, flavour, storage potential, and early maturing varieties (Hanson & Hancock, 1996). The variety 'Legacy' is one of many cultivated in South Africa due to its adaptation to climatic conditions (Meyer & Prinsloo, 2003). This variety has the following characteristics, namely vigorous, upright, semi-bush spread canes, self-pollinating, medium to large fruit size, and power-blue fruit colour (Figure 1). According to Martin et al., (2022), honeybees are effective insect pollinators that ensure fruit set and fruit development that are of good quality.

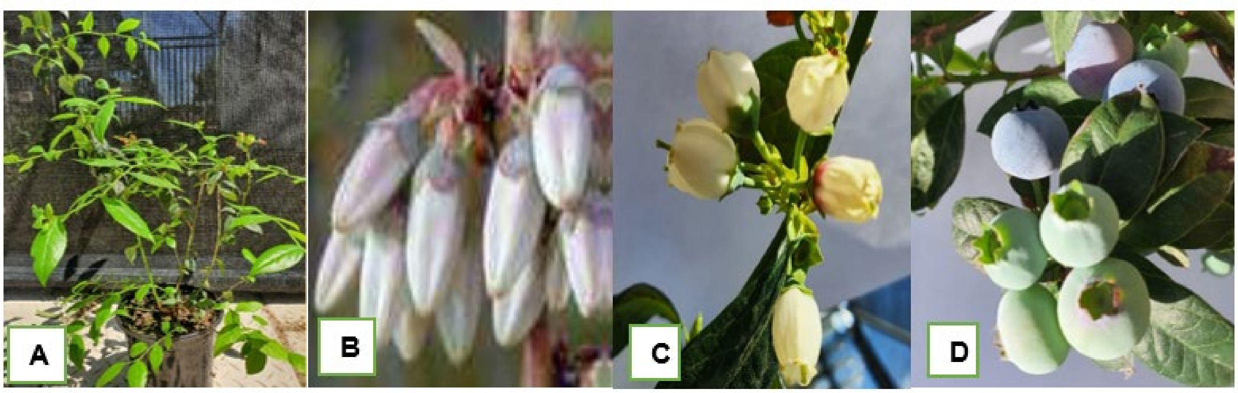

Figure 1. Legacy morphological characteristics: A- vegetative growth, B- flowering, C- fruit set, D- fruit development. Adapted from (Bryla et al., 2011)

Blueberry plants can reach full production within 3 to 4 years and can be reproductive for up to 15 years (Zietsman, 2020). Under South African conditions, the blueberry harvest season begins as early as September till the end of February, mainly targeting the export market (Sikuka, 2020). Primarily, to the European countries in the Northern Hemisphere due to the demand when it is off-season (Meyer & Prinsloo, 2003). Sustainable blueberry production is mainly dependent on environmental factors and conservation practices in the ever-changing climate (Lobos & Hancock, 2015).

2.3. Water requirement for blueberry plants

According to Wilk et al., (2009), the blueberry plant requires 20 – 40 mm of water per week during the growing season for optimum growth and yield. Blueberry water requirement depends on the crop factor, stage of growth, and climatic conditions (Holzapfel, 2009; Ortega-Farias et al., 2021). The fruit development stage of blueberry is important as it determines size and quality; therefore, water supply is critical from fruit set until harvest (Spiers et al., 1985). Thus, moisture stress restricts fruit size as the growth period stretches over a prolonged period of about six weeks, depending on the cultivar (Webb, 1981). Contrarily, Mingeau et al., (2001) found that moisture stress did not affect fruit size on the highbush variety 'Bluecrop'. Commercially, blueberry plants are watered through overhead sprinklers or drip irrigation systems that are automated on a daily or weekly basis (Bryla, 2008). The drip irrigation system is ideal for blueberries at 100% of the estimated crop evapotranspiration requirement (Table 1).

Table 1. Common irrigation systems, replenishment levels, and recommendations on blueberry production.

Replenish level (% of ET^{O*})	Irrigation system	Recommended level and system	References
50, 75, 100, 125	microspray and trickle	75 & 100%; microjet	(Holzapfel & Hepp, 2002)
50, 100, 150	sprinkler, microspray, & drip	150%, sprinkler & microspray	(Bryla & Linderman, 2007a)
50, 100, 150	sprinkler, microspray & drip	100%, drip	(Bryla, 2008)
50, 100, 150	sprinkler, microspray, & drip	100%, drip	(Bryla & Machado, 2011)
50, 75, 100, 125	drip	100 & 125%; drip	(Ortega-Farias et al., 2021)
70, 100, 130	drip	100 & 130%; drip	(Muñoz et al., 2022)

*ET_O = Evapotranspiration

The drip irrigation system increases the effective wet area, ensuring a continuous supply of water directly to plants and thereby increasing vegetative and reproductive growth.

(Bryla, 2008). The plant root system is sensitive to water stress, therefore reducing growth, while over-irrigation reduces root functioning and may lead to root rot infections. (Bryla & Linderman, 2007b; Bryla, 2011). According to Davies & Johnson, (1982) and Rho et al., (2012)Water stress on blueberry plants results in stomatal closure, therefore, affecting the ability of the plant to photosynthesize, reducing leaf area and plant weight. Nevertheless, highbush blueberry plants can recover from water stress if rehydrated after 5 to 10 days without water (Ameglio *et al*., 2000). As previously stated, the blueberry root system is shallow, water supply and distribution are important as they will have a direct impact on the plant's vegetative and reproductive growth ((Gough, 1980; Holzapfel, 2009).

Crop coefficient (K_C) and evapotranspiration (ET_O) are the two main indicators used for irrigation scheduling and management. (Hunt et al., 2008). However, using the crop coefficient can be inconsistent and is influenced by cultivar and environmental conditions. (Keen & Slavich, 2012). Water scarcity worldwide has prompted research into water management strategies for various fruit crops. (Galindo et al., 2018). Management techniques such as deficit irrigation (DI), regulated deficit irrigation (RDI), and partial root-drying (PRD) have been effective. They are dependent on the crop's stage of growth and the alternating application of water. They depend on the crop's stage of growth and on alternating water applications, thereby conserving the total quantity applied. (Keen & Slavich, 2012; Lepaja et al., 2019).

2.4. Substrate for cultivation

There has been a need to cultivate blueberries in growing media because the plant requires acidic soils, which are often limited in natural soils. (Clark & Zheng, 2020; Smrke et al., 2021). Blueberries are now largely grown in media because the plant requires acidic soil, which is often not readily available. Growing media such as peat moss, coconut coir, and perlite are commonly used for blueberries grown in pots. (Fang et al., 2020; Zietsman, 2020). According to Kingston et al., (2017) peat moss and coir increase water-holding capacity as plants grown in soilless substrates experience drought stress. These findings are in agreement with research conducted for the variety 'Legacy.' (Ortiz-

Delvasto et al., 2023). Improved use of growth media can be a crucial strategy improve blueberry production. The physical and chemical characteristics of the substrate used on blueberries are of great importance, as they will determine the overall growth. (Ortiz-Delvasto et al., 2023). These include bulk density, total porosity, porosity ratios, pH, and electrical conductivity (EC), which directly influence plant growth. (Xie & Wu, 2009). Using different substrate composition ratios in potted blueberry plants is effective, as each substrate contributes useful attributes for plant growth. (Kingston et al., 2020).

The decomposition of these organic materials (growth media) or crops. Mulching materials can produce allelochemicals that improve crop growth and productivity. The use of these soil amendments has potential and is used as one of the cropping techniques that is used commonly for different crops in conserving water and an increase in soil temperature (Zegada-Lizarazu & Berliner, 2011), and improving crop growth and plant pest (Radicetti et al., 2013). Insufficient water supply at critical stages of crop development is a critical factor affecting total yield (Krüger et al., 2002). A study done by Taparauskiene (2006) showed that soil moisture reduction on harmed strawberry production by affecting both vegetative and reproductive parameters. Organic growth media significantly reduce the loss of moisture from the soil when incorporated into the soil, and consequently, an increase in a homogeneous, sustainable soil moisture regime (Ramakrishna et al., 2006). Li et al., (2004), stated that the application of organic plant material is effective in reducing soil evaporation and saving water. Several of these organic materials improve blueberry biomass as well as improve water use efficiency and can lower irrigation requirements by up to fifty percent (Li et al., 2021). The application of compost enhances water permeability and thereby reducing evaporation (Zhang & Sun, 2014). Some authors (Costello & Sullivan, 2014) evaluated compost suitability for strawberries in a pot trial (soil amended with 30% compost). They recorded reduced weed growth, lower soil pH, maintenance of uniform soil moisture, and an increase in growth rate and yield.

Growing media such as peat moss, coconut coir, and perlite are commonly used for blueberries grown in pots. (Fang et al., 2020). However, other growth media, such as peat, also create physical conditions that are more favorable to root growth (e.g., increased aeration and water-holding capacity) and can lower pH in the root environment (Strik *et al*., 2011). The development of an organic market for blueberry production has recently generated attention in using organic growth media for the provision of organic matter, nutrients, and stimulating favourable soil microbial enzyme activities (Gale et al., 2006).

Studies on strawberries and tomatoes show that the use of different mulching materials affects yield and fruit traits such as total soluble solids, fruit firmness, and the content of phenolic compounds (Fandi et al., 2008; Ameri et al., 2012), but no published study exists currently on blueberries (Fang et al., 2020). Due to rising consumer interest, water scarcity in the country, and various health/economic benefits of blueberries, research on the use of different growth media (such as sandy soil, mushroom compost, peat moss, and zeolite) will reduce water need. However promoting high-yielding and high-quality fruits is necessary. It is advised that the material used should be easily accessible and also meet the requirements of a specific crop (Barrett et al., 2016).

2.5. Nitrogen sources and overview

Plants primarily rely on two N forms, NH_4^+ and NO_3^-, which are derived from various soil processes such as mineralization and nitrification. (Zhang et al., 2018). Nitrogen is available in the atmosphere, primarily in its gaseous form (N_2), which constitutes about 78% of the Earth's atmosphere. (Glass & Rousk, 2024). Nitrogen fixation occurs through a symbiotic relationship between root nodule-dwelling N-fixing bacteria (rhizobia) and plants, in which the plant provides the bacteria with carbohydrates. In contrast, bacteria fix N_2 into a form that the plant can use (Ahmadi, 2023). Another way that some plants may obtain nitrogen for their nutrition is through nitrite (NO_2^-) from the atmosphere (Bashir et al., 2024). NO_2- is a significant air pollutant produced in the soil when N-containing substances break down under low oxygen conditions (Ye et al., 2022). However, most of it is produced by the combustion of fossil fuels (in vehicles, power plants, and industrial processes). In soil, NO_2^- availability is generally low, and at high concentrations, it becomes toxic to plants (Bashir et al., 2024).

2.6. Ammonium (NH_4^+) as a Nitrogen source

Ammonium N (NH_4^+) is present in soils through mineralization of soil organic N and is applied as a product of urea hydrolysis. NH_4^+ uptake is mediated by both high- and low-affinity transport systems, possibly via an NH_4^+ uniport or K^+ channel (Jose et al., 2023). NH_4^+ is the preferred form of N uptake when plants grow under N deficiency. It is rapidly assimilated into amino acids within the roots via glutamine synthetase/glutamate synthase (GS/GOGAT) pathway (Figure 2), which requires less energy than NO_3^- assimilation (Zhang et al., 2018). Due to its positive charge, NH_4^+ is adsorbed by negatively charged soil colloids (clay and organic matter) and thus is less prone to leaching. Uptake of NH_4^+ causes rhizosphere acidification due to H^+ exchange (Imler et al., 2019). The most used single N (NH_4^+) is ammonium sulphate, containing 21% N and 24% sulphur (S).

2.7. Nitrate (NO_3^-) as a nitrogen source

Most agricultural soils allow plant roots to absorb N mainly as NO3-, even though NH4+ might be more readily available in certain soil types. This is mainly due to the higher concentration of NO_3^- in soils as compared to NO_2^- and NH_4^+. Additionally, due to its (NO_3^-) negative charge, it remains in the soil solution rather than binding to negatively charged soil particles, allowing for high mobility and plant uptake (Pinheiro et al., 2020). NO_3- is absorbed via a NO_3^-/H^+ symport (Figure 2), involving three transport systems (Muratore et al., 2021), and the uptake of NO_3^- leads to rhizosphere alkalinization (Imler et al., 2019).

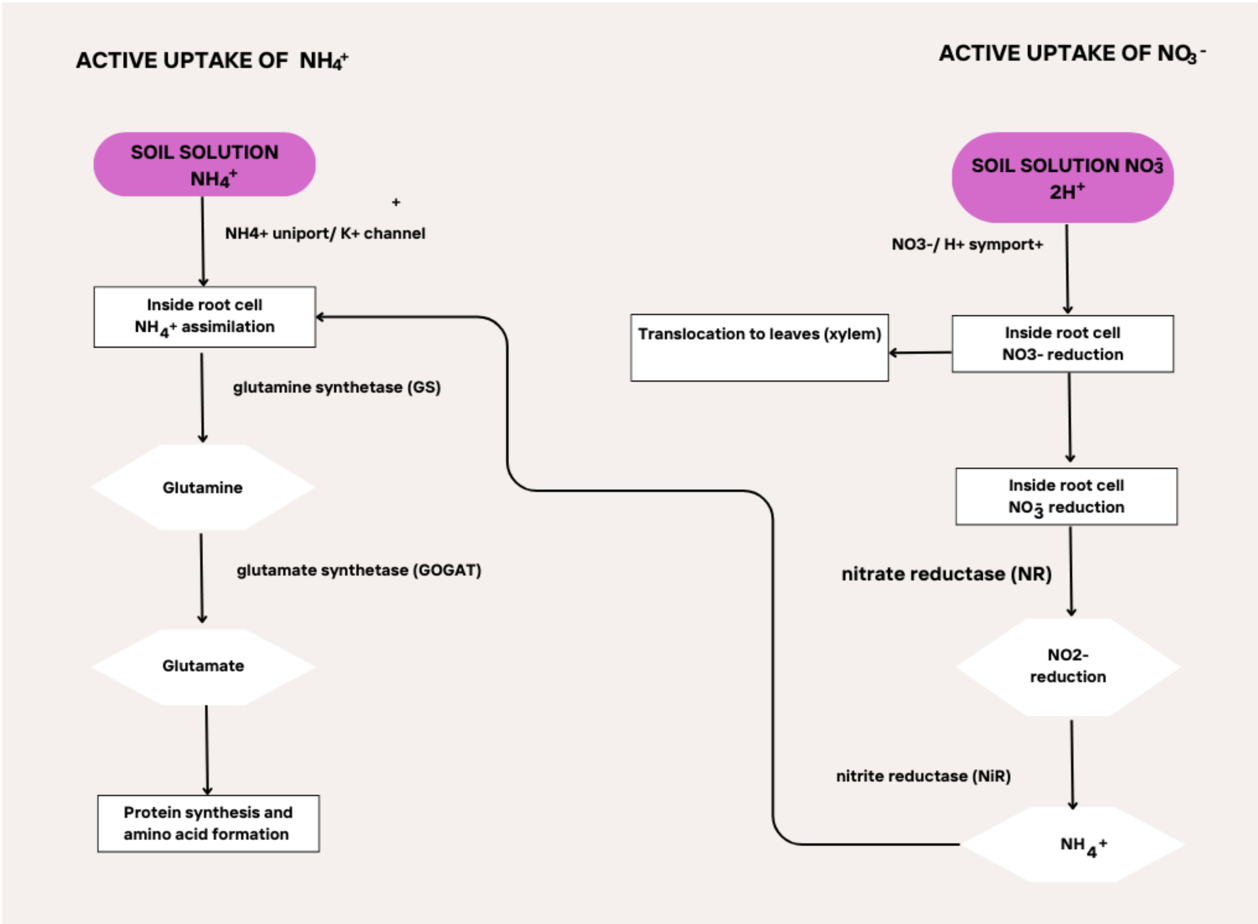

Figure 2. Shows the assimilation of the two nitrogen sources, as NH_{4+} undergoes glutamine synthetase and NO_{3}- through a reduction process by nitrate reductase. Adapted from (Imler et al., 2019; Muratore et al., 2021; Jose et al., 2023).

The conversion of NO_3^- to NH_4^+ and amino acid synthesis for protein synthesis depends on nitrate reductase enzyme activity, which is inefficient in blueberries. (Kishorekumar et al., 2020). Blueberry plants demonstrate N form and concentration sensitivity in acidic NH_4^+ dominant soils; however, they thrive best at pH 4.0 to 5.5, which supports acidic soil conditions that favour NH_4^+ uptake as their preferred N source (Yang et al., 2022). Sensitivity of young blueberry plants to high ammonium sulphate applications may be due to ammonium toxicity, which is linked to increased electrical conductivity (EC) in the soil solution, with growth suppression observed at EC levels above 1.5 $dS \cdot m^{-1}$ (Machado et al., 2014).

2.8. Effects of nitrogen sources on water-use efficiency and drought tolerance in plants

The different N sources influence water-use efficiency (WUE), transpiration, and osmotic adjustment in blueberry plants. These are key processes for maintaining water status under drought. (Ruiz-Romero et al., 2024). NH_4^+ nutrition enhances blueberry plant drought resistance through multiple physiological processes. The increased root abscisic acid content in drought-stressed NH_4^+ fed plants leads to better WUE (Ding *et al*., 2016). The accumulation of osmolytes such as proline and soluble sugars helps sustain root development to reach deeper soil water (Zaher-Ara et al., 2016). Highbush blueberry cultivars exhibited varying levels of drought resistance following a reduction in drought stress, accompanied by enhanced photochemical efficiency and increased proline content. (Balboa et al., 2020).

Under water-limited conditions, NH4+ nutrition controls stomatal conductance to minimize excessive water loss through transpiration while allowing sufficient CO_2 uptake for photosynthesis to support plant development. (Torralbo et al., 2019). The drought resistance of *Malus prunifolia* increased with higher NH_4^+ uptake but lower NO_3^- uptake, indicating the importance of NH_4^+ in drought tolerance. (Huang et al., 2018). Likewise, in other crops, high NH4+ concentrations cause ion imbalances, which lead to toxicity and reduce the plant's water stress tolerance. Research conducted by Faralli et al. (2023) demonstrated that NO3- based fertilization enhances plant development under sufficient irrigation by improving transpiration efficiency. The positive effects of NO_3^- nutrition on transpiration peaked when water availability was sufficient, yet NO3- does not confer drought tolerance to the same extent as NH_4^+. Plants that received NH_4^+ nutrition demonstrated superior drought tolerance compared to those receiving NO_3^- under water-stressed conditions (Ding et al., 2016). However, plants treated with NO_3^- still maintained positive hydration status because NO_3^- enabled appropriate stomatal conductance for efficient CO_2 uptake and reduced water loss during photosynthesis (Ding et al., 2016).

2.9. Influence of nematodes in cropping systems

Nematodes are pests that affect agricultural production systems; however, expertise and the extent of potential damage remain under-researched in Africa. (Coyne et al., 2018). Proper analysis and classification should be conducted to identify free-living nematodes that are critical for decomposition of organic matter and thereby improving soil health. (Shokoohi, 2023). The availability and presence of nematodes are primarily influenced by cultivation practices across different cropping systems. The modern cropping systems greatly influence the occurrence and prevalence of these microorganisms. The plant-parasite-nematodes (PPNs) mainly target the root system, which is a critical plant structure that facilitates the absorption of water and minerals. (Phani et al., 2021). In a study conducted by Rivera et al., (2015), it was found that the occurrence and abundance of PPNs on cultivated blueberry plants were less compared to wild blueberry varieties.

2.10. Enzyme activity

Soil enzymes play a key role in nutrient recycling, specifically the macronutrient transformation of these nutrients to the simplest form that is used by the plant. (Daunoras et al., 2024). The substrate used in crop cultivation influences microorganisms' activity, including enzymes responsible for carbon recycling, phosphatase release, and the conversion of urea to the nitrogen form used by plants (Tuxun et al., 2025; Daunoras et al., 2024). The use of growing media in soilless cultivation is widely used for horticultural crops, which directly removes the soil as a substrate. This results in a substrate with low fertility and accumulation of salts due to the overuse of synthetic inputs, and this directly influences the availability and activity of the microorganisms responsible for nutrient recycling (Fussy & Papenbrock, 2022).

2.11. Summary

Blueberry cultivation and consumption have increased in South Africa over the years due to the health benefits associated with the crop and its monetary returns, as 70% of the blueberries produced in the country are exported. However, water scarcity limits the production of agricultural commodities, especially blueberries, as drought conditions restrict plant growth and reproductive structures. Therefore, there is a need for the efficient use of limited water resources in South African cropping systems. Implementing water conservation practices in blueberry production and growth media management can reduce water use and irrigation needs by up to 50%. Peat moss, compost, and coir are commonly used as soil amendments to increase the organic matter content of soils, promote uniform root distribution, and increase the media's water-holding capacity. To minimise the amount of water used in blueberry production and maintain improved yield and quality, water conservation strategies such as improved growth media usage need to be employed. Moreover, further research into conservation practices to ensure optimal water use and management for sustainable blueberry production is warranted. The cultivation of blueberries using the above-mentioned substrates creates an ideal physical environment that is favourable to root growth, as the plant thrives in acidic soils. The combination of NH_4^+ with NO_3^- or NH_4^+ alone results in superior plant growth and fruit quality compared to NO_3^- alone, particularly when the soil conditions are acidic, which are favourable for blueberry cultivation. The management practices implemented in cropping systems influence the availability of microorganisms, which is critical for nutrient recycling for sustainable production.

CHAPTER 3: MATERIALS AND METHODS

3.1. Introduction

Water management for blueberry production has been an increasing challenge in recent times due to a lack of proper knowledge of the water requirement, induced water scarcity, physiological sensitivity, and intensive production methods, that is demanding for a precise, consistent and frequent water supply (Holzapfel, 2009). The water requirement of blueberry plants is influenced by various factors such as variety, growth stage, soil type, and climate. No blanket water requirement can be endorsed (Ortega-Farias et al., 2021). The use of technology can be an effective strategy for monitoring and correctly applying water when required by the potted plant (Bacci et al., 2008). These technologies can be in the form of hardware and software components, which can be physically placed in orchards or fields for moisture reading, and then can be downloaded for irrigation scheduling (Sharifnasab et al., 2023). The hardware components regularly collect data from the soil profile. These are sent in real time to ensure accuracy and better control (Zhao, 2022). Blueberries require constant moisture conditions for optimal growth, which essentially influences yield and are classified as a water-intensive crop due to their shallow root systems and the growing media in which blueberries are commonly cultivated (Carroll et al., 2024). Therefore, the research study aims to evaluate the impact of single and combined use of growth media on the properties of growing media, water conservation and yield of blueberry under shade nets.

3.2. Description of the experimental site

The research study was conducted at the Department of Agriculture, Cape Peninsula University of Technology, Agricultural Hub, Wellington Campus (S 33°37’55.08” E 19°00’37.4”) as shown in Figure 3. The Wellington region is characterised by a Mediterranean climate with cold and wet winters and dry, hot summers.

Figure 3. Experimental site (Source: Google Earth).

3.3. Experimental design and layout

3.3.1. Experiment 1

Two-year-old blueberry plants (cultivar Legacy) were obtained from a commercial nursery, Defynne, in Paarl in the Cape Winelands region of the Western Cape Province. The plants were cultivated under a cooling tunnel covered with a polythene roof and a 40% white shade net, with a cooling fan that automatically switches on when temperatures increase, maintaining 25 ºC inside the tunnel (Smrke et al., 2021). The plants were transplanted into 45 L bags in October 2022, and the bags were elevated using bag stands. Four different growth media combinations were used to evaluate blueberry water use per medium, which consisted of coir, zeolite, peat moss & mushroom compost (Table 2).

The field capacity (FC) of each treatment composition was determined before transplanting, and the replenishment level was set at 75% of the plant-available water (PAW) for each treatment. Figure 4, below, illustrates the experimental setup from plants that were received from the nursery (A), growing media weighing (B), growing media composition mixture (C), distribution (D), the FC was done for all treatments in the tunnel (E), and the transplanting process (F).

Table 2. Treatment composition

Treatments	Media
1	100% coir (control)
2	80% coir + 20% zeolite
3	60% coir + 40% mushroom compost
4	60% coir + 40% peat moss
5	40% coir + 20% zeolite + 40% mushroom compost
6	40% coir + 20% zeolite + 40% peat moss
7	40% coir + 30% mushroom compost + 30% peat moss

Figure 4. Experimental set-up (Plants from the nursery (A), growing media weighing (B), growing media composition mixture (C), distribution (D), field capacity per treatment (E), and the transplanting process (F).

The maximum soil water content was at 100% pot capacity (PC). From this, an allowable depletion level (ADL) of 25% was permitted before irrigating the soil back to 100% PC. Moisture monitoring and readings were recorded with the DFM continuous logging probes, which send real-time data via repeaters to the DFM Software.

3.3.2. Experimental layout and treatment application

The pot experiment was a randomised complete block design (RCBD) with five replications (Table 3). Four different growth medium combinations, comprising seven treatments, were used to evaluate blueberry water use per medium. Three plants per treatment were replicated five times, with a total population of 105 blueberry plants. Pot spacing was 70 cm between pots and 1m between replicates. The two-year-old Legacy blueberry cultivar was transplanted into different growth media compositions as indicated in Table 2. The initial media analysis results indicated that all media used were classified as sandy with pH values of 3.8, 4.2, 6.4, 3.3, 6.6, 4.7, and 6.1, respectively.

Table 3. Treatment layout and design

Replicate 1						
T1	T2	T3	T4	T5	T6	T7
Replicate 2						
T2	T3	T4	T5	T6	T7	T1
Replicate 3						
T3	T4	T5	T6	T7	T1	T2
Replicate 4						
T4	T5	T6	T7	T1	T2	T3
Replicate 5						
T5	T6	T7	T1	T2	T3	T4

3.3.3. Cultivation practices of blueberry production

Irrigation scheduling and application were implemented according to (Mfeka et al., 2023) methodology. The fertilization was as follows: 9 g N per pot (ammonium sulphate) applied in the first year (2022/2023), while 12 g N per pot (ammonium sulphate) was applied in the second (2023/2024) and third (2024/2025) seasons. Other minerals were applied uniformly. Cultivation practices such as manual weed control, pH, and EC monitoring were done regularly.

3.3.4. Data collection on the water requirement of blueberries cultivated in different growth media

Data collection on the different treatments, water usage (L), number of leaves, number of branches, and plant height (cm) were recorded over a period of fourteen weeks after transplanting during the growing season. The electrical conductivity (EC) for monitoring the salinity of the media and pH were recorded weekly after transplanting (Frias-Ortega et al., 2020). Water usage for each treatment was recorded daily using DFM moisture probes, and application was performed according to FC replenishment requirements (Table 4). Water replenishment quantities in litres were as shown in the table below:

Table 4. Water replenishment quantities in litres

Treatment	Water replenishment (L)
1	4.25
2	4
3	4.5
4	3.7
5	4.5
6	4.25
7	4.5

The probe readings were taken from three depths: 10 cm (topsoil), 20 cm (root zone), and 30 cm (buffer zone). Readings were taken from 13:00-15:00 pm, which is when plants are relatively stable in terms of water flux and water status for approximately an hour or two after solar noon. (Blum, 2010). Vegetative data was collected twice a month during the active growing season.

3.3.5. Mineral analysis of media combination

The growing media samples to be transplanted were analysed for physical and chemical parameters, as shown in Table 5. The samples were sent to the commercial Bem Lab (https://www.bemlab.co.za/) for analysis before transplanting.

Table 5. Initial growing media physical and chemical analysis.

			%		mg/kg							
Treatment	**pH (KCl)**	**Stone Volume**	**C**	**Na**	**N**	**P**	**K**	**Cu**	**Zn**	**Mn**	**B**	**Fe**
T1	3.8	0.93	19.74	2.13	53.7	5.4	159	0.33	3	4.4	0.32	43.1
T2	4.2	1.52	11.81	14.86	73	2.6	553	0.33	1	4.9	0.37	24.8
T3	6.4	1.93	20.78	6.44	6.4	154	225	1.6	23.4	22.7	0.69	83.8
T4	3.3	0.93	21.88	1.81	132	6	148	0.33	2.8	2.9	0.32	50.1
T5	6.6	0.93	11.59	9.66	11.2	118	484	1.2	19.4	19	0.38	62.6
T6	4.7	0.93	18.44	30.23	87.4	6.2	196	0.33	2.5	5.1	0.62	32.6
T7	6.1	0.93	22.38	4.35	30.1	109	765	1.8	5.8	60.7	0.89	19.3

3.3.6. Data collection on mineral properties of blueberry fruits.

For mineral analysis, fresh samples were harvested and stored frozen at -20°C (Zhang et al., 2014) until analysis. Fruit mineral analysis was done at Bem Lab, a commercial laboratory in the Western Cape Province, to determine total N (3 g per sample) using the Kjeldahl’s method, P, K, Ca, Mg, Na, Mn, Fe, B, Al, and Zn (2 g per sample) using the standard plasma emission spectrometer.

3.3.7. Data collection on enzyme analysis

The growing media samples were air-dried and stored at 4°C. Before conducting the analysis, the media were sieved using a 2mm sieve to standardize the samples. The activity of β-glucosidase was analysed using a method by (Eivazi & Tabatabai, 1988). Urease activity was estimated using the colorimetric determination of release, as outlined by Kandeler & Gerber, (1988). Acid phosphatase was assayed by a colorimetric method of (Tabatabai & Bremner, 1969) but was optimized using a homogenised reaction of 1.0 mL 25 mM p-nitrophenol phosphate (substrate), 4.0 mL MUB and 0.25 mL toluene, and the product p-nitrophenol was extracted with 4.0 mL of 0.5 M NaOH at pH 6.5.

3.3.8. Data collection on nematode population.

The growing media samples were collected using a soil auger. 500g of the different growing media combinations using the modified Cobb (1981) method, of the seven treatments were sampled and put in a plastic bag, labeled, and taken for analyses in the laboratory at the Agricultural Research Council (ARC) in Stellenbosch. The nematode population count was obtained using a stereomicroscope, and characterization was performed using a compound microscope (Daramola et al., 2019).

3.3.9. Statistical analysis

Univariate Analyses (ANOVA) were performed using the GLM procedure in SAS statistical software (version 9.4, SAS Institute Inc., Cary, NC, USA). Multivariate analyses (Correlations, PCA, MFA) were done using XLStat (Lumivero (2025) XLSTAT statistical and data analysis solution. https://www.xlstat.com/en). Means were done using Duncan's Multiple Range Test (DMRT) and Fisher's Least Significant Difference (LSD).

3.4. Experiment 2

3.4.1. Experimental layout and treatment application

The experiment comprised 100% coir and 80% coir:20 % zeolite as the growing media (Glencairns, Paarl, and Agring Consultants, Heidelberg, South Africa). Uniformly healthy plants, free of pests or disease, were transplanted into 45L bags (23cm upper diameter, 23cm lower diameter, 15.6 cm height, and 124.8cm length), with one plant per pot. After 30 days of adaptive pre-culture, the plants were fed three N sources: [(NH4)2SO4] (N 21.1%), [$Ca(NO_3)_2$] (N 16.6%), and (H_2NCONH_2) (N 46%). Each N source was applied to both growth media treatments, resulting in six treatment combinations. Each treatment was replicated three times, with three pots per replicate, and the experiment was a factorial design in a randomised complete block design, as shown in Table 5. During cultivation, fertilizer was applied once a week, with 1 L of water applied to each bag. The total amount of N applied to each blueberry plant was kept consistent. A 500 g dry sample of growth media from each treatment was submitted to a commercial facility (BemLab, Strand, South Africa) for initial and post-harvest analysis of the physical and chemical properties. The analyses for pH, Cation exchange capacity (CEC), organic matter content, organic carbon, available nitrogen forms (NH_4^+ and NO_3^-), as well as other macro and micronutrients (P, K, Ca, Mg, Na, Fe, Zn, Mn).

Table 6. Experimental Layout

Replicates	**Treatment Layout**					
Rep 1	T_1	T_2	T_3	T_4	T_5	T_6
	T_1	T_2	T_3	T_4	T_5	T_6
	T_1	T_2	T_3	T_4	T_5	T_6
Rep 2	T_2	T_3	T_4	T_5	T_6	T_1
	T_2	T_3	T_4	T_5	T_6	T_1
	T_2	T_3	T_4	T_5	T_6	T_1
Rep 3	T_3	T_4	T_5	T_6	T_1	T_2
	T_3	T_4	T_5	T_6	T_1	T_2
	T_3	T_4	T_5	T_6	T_1	T_2

T1 –100% Coir + ammonium sulphate (Control), T2 – 80% coir: 20% zeolite+ ammonium sulphate, T3– 100% coir + calcium nitrate, T4– 80% coir: 20% zeolite + calcium nitrate T5 – 100% coir + urea, and T6 – 80% coir: 20% zeolite + urea, Rep – replicate

3.4.2. Data collection on nutrient use efficiency of blueberry

The harvest was done manually at the peak of the ripening period, with berries harvested weekly between October and December in both the 2023 and 2024 growing seasons. Following each harvest, the berries per shrub were weighed using a weighing scale to determine the total fresh weight per plant and placed in properly labelled bags. Nitrogen use efficiency (NUE) was determined from berry yield per unit of nitrogen applied and was calculated using the following formula (Fixen *et al*., 2012):

NUE = $(\text{Yield (g)})/(\text{Quanitity of N applied (g)})$

Equation 1. NUE

3.4.3. Sample extraction and extracts preparation

To preserve the berries, they were immediately frozen and stored at −80 °C after harvesting. Berry samples were freeze-dried (−40 °C; 0.050 mbar vacuum) in a VirTis SP Scientific Wizard 2.0 freeze-dryer (SP Industries, Warminster, PA, USA) and ground into powder form using a mortar and pestle. Thereafter, the extract was obtained from the blueberry powdered samples by adding 5 mL of 80% MeOH with glacial acetic acid (1 mL of 100% acetic acid per 1 L of 80% MeOH) to 0.5 g of ground samples, vortexed for 30 seconds, and left for 24 hours. After 24 hours, the mixtures were centrifuged at 2000 rpm for 15 min (Centrifuge Lasec). The final supernatants of each treatments were transferred to 10 mL vessels, properly labelled, and stored at −80 °C for the determination of phenolic compounds.

3.4.4. Determination of total phenolic content (TPC)

The TPC for the different treatments was determined using the Folin-Ciocalteu assay method (Jimoh *et al*., 2019) with slight modifications. The supernatants of 0.5 mL were mixed with 2.5 mL of 10% Folin–Ciocalteu`s reagent in 10 mL test tubes. Next, 2 mL of 7.5% saturated sodium carbonate solution was added, vortexed, and shaken for 5 min, then incubated at 40 °C for 30 min. The absorbance values were measured at 750 nm using a microplate reader spectrophotometer (Microplate reader model 680, BIORAD, USA). A blank was prepared with distilled water. A standard curve was prepared to estimate the total phenolic content using gallic acid at a concentration range (0.063-2.0 mg/ml). The total phenolic content was expressed as mg per gallic acid equivalent (GAE)/g dry matter from the standard curve y=0.0179x +0.0473, R^2=0.9852. The experiment was done in triplicate.

Determination of total Flavonoid Content (TFC)

The TPF was determined using the coulometric assay (Elufioye *et al*., 2019) with slight modifications. 0.5 mL of supernatant was mixed with 3 mL of distilled water, 0.3 mL of 5% sodium nitrite, and after 5 min, 0.3 mL of 10% aluminium chloride was added. In 6 minutes, 2 mL of 1 M sodium hydroxide was added, and finally, 5 mL of water was added, and the mixtures were vortexed after each addition. The absorbances were measured at 510 nm using a microplate reader spectrophotometer (Microplate reader model 680, BIORAD, USA). A standard curve was prepared using graded concentrations of quercetin (0.063-2.0 mg/ml) to estimate the total flavonoid content, and the results were expressed as mg quercetin equivalent per gram dry weight from the calibration curve y=0.0141x + 0.0473, R^2= 0.9591. The experiment was done in triplicate.

3.4.5. Determination of proanthocyanidin content (PAC) (condensed tannin)

The proanthocyanidin content was determined according to the previously reported procedure (Elufioye *et al*., 2019) with slight modifications. 0.5 ml of berry extracts (mg/ml) was mixed with 3 ml of vanillin (4%) in a methanol solution. Thereafter, 1.5 ml of hydrochloric acid (1.5%) was added, the mixture was mixed thoroughly, and it was incubated for 15 minutes at room temperature. 250 microliters of each of the extract solutions and graded concentrations of the gallic acid were pipetted into a 96-well microplate, and absorbance was measured at 490 nm with the aid of the microplate reader model 680, BIORAD, made in the USA. A blank was prepared with distilled water. A standard curve of gallic acid at a concentration range (0.063-2.0 mg/ml) was used to determine the proanthocyanidin content expressed as mg gallic acid equivalent per gram dry weight from the calibration curve y=0.011x + 0.0403, R^2=0.9689. The experiments were carried out in triplicate.

3.4.6. Statistical analysis

Analysis of variance ANOVA at 95% confidence limit and comparison of means were carried out on the parameters measured. Analysis of the plant data collected using IBM SPSS Statistics 22.0. Means separation was done using the Duncan Multiple Range Test (DMRT) and Fisher`s Least Significant Difference (LSD).

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1. Introduction

Irrigation scheduling (IS) is the practice of monitoring the frequency and quantity of water applied to plants to optimise efficiency, minimise energy wastage, and maximise crop yield, thereby preventing water stress and overwatering. In recent years, these have been automated, linking the sensors to the irrigation system and considering field capacity and the quantity to be applied. (García et al., 2020), which relies on strategies for a specific crop's water requirements. Different factors influence irrigation scheduling, which relies on strategies tailored to a specific crop's water requirements. (Annandale et al., 2011). IS is based on three factors: plant, soil, and the atmosphere (García et al., 2020). Plant-based factors refer to all the physiological responses due to changes in water availability, while growth factors refer to the effects of the soil on the plant's growth. In contrast, soil-based factors refer to the effects of the soil on the plant's growth. In contrast, soil-based factors refer to the effects of the soil on the plant's growth. In contrast, soil-based factors refer to the effects of the soil on the plant's growth. In contrast, soil-based factors refer to the effects of the soil on the plant's growth. In contrast, soil-based factors refer to the effects of the soil on the plant's growth. In contrast, soil-based factors include water potential, which is affected by soil particles and influences the availability of water to plants. (Annandale et al., 2011; Fernández, 2017; Jones, 2004). Lastly, the atmospheric changes due to temperatures, humidity, and crop evapotranspiration (Holzapfel, 2009). Irrigation scheduling not only reduces water application on crops, but it also reduces the number of days to maturity, enhancing early maturity (Sharifnasab et al., 2023).

Moisture monitoring and irrigation scheduling are critical in water conservation for sustainable crop production (Ortega-Farias et al., 2021). There are different irrigation systems and methods that can be used to make informed decisions on irrigation timing and volumes that are required by plants (Zhang et al., 2018). Recent research has mainly focused on the use of technology for moisture monitoring and automated water applications (Zhang et al., 2018). Such technologies monitor soil water potential and quantities to be applied (Jones, 2004). Blueberries are now commercially grown in media due to the plant's requirement for acidic soil, which is often not easily attainable in the soil (Clark & Zheng, 2020). Growth mediums such as peat moss, coconut coir, and perlite are mostly utilized for blueberries grown in pots (Fang et al., 2020).

The use of coir as the sole growing medium in the cultivation of blueberries for potted systems should be investigated. Therefore, this study explored possible alternative growing methods in addressing issues of water usage for sustainable crop production.

4.2. EXPERIMENT 1

4.2.1. The monthly and overall blueberry water use

The different treatment media compositions influenced all measured parameters (Table 7). Treatment $_1$ (100% coir) required the highest monthly water replenishment (4.25 L) compared with all the other treatments on an average daily basis. This is related to the physical and chemical properties of the media in relation to the particle size distribution and water-holding capacity (Fang et al., 2020). Further findings from the previous studies showed that coir has the largest air spaces with less capability to retain water. These findings are in agreement with those of (Wang et al., 2018). In contrast, (Prakash et al., (2021), found that coir incorporated into the soil has the potential to conserve soil moisture. It was also observed that all treatments with mushroom compost required the highest water replenishment quantities, as stated in the methodology section; however, the frequency of application was reduced compared to the other treatments. Treatment 2 (80% coir and 20% zeolite) required less water replenishment, even though it was not significantly different ($p>0.05$) from treatments 3, 5, 6, and 7. Sindesi et al. (2023) concluded that zeolite has the potential to reduce water demand for plants due to its high water-holding capacity. Zeolite has been identified as a mineral that significantly improves soil properties, including cation exchange capacity, saturated hydraulic conductivity, and water-holding capacity. (Cataldo et al., 2022). The coir-zeolite composition increased the water-holding capacity. The results show that the cumulative water use for treatment 1 was the highest and significantly higher ($p<0.05$) than that of the other treatments.

Table 7. Effect of the different growing media compositions on water requirements and vegetative growth of blueberry

Treatment	Water use/monthly (L)	Acc Water use/ season (L)
1	77.43[a]	384.67[a]
2	43.67[d]	222.83[d]
3	62.06[bc]	308.44[bc]
4	57.97[bc]	287.52[bc]
5	54.75[c]	270.94[cd]
6	61.80[bc]	304.94[bc]
7	66.56[b]	330.19[b]
LSD	9.61	50.32

T1- 100% coir, T2- 80% coir + 20% zeolite, T3- 60% coir +40% mushroom compost, T4- 60% coir + 40% peat moss, T5- 40% coir + 20% zeolite + 20% mushroom compost, T6- 40% coir + 20% zeolite + 40% peat moss, T7- 40% coir + 30 mushroom compost + 30% peat moss; , LSD- lease significant difference; L- liters.

It is crucial that blueberry plants do not experience prolonged moisture stress, as this leads to stomatal closure and, therefore, reduces overall plant productivity (Améglio et al., 2000). Hence, in this study, the moisture levels were replenished to 100% only, as outlined in Table 3. Blueberry plants are characterized as having shallow, fine, and fibrous root systems of approximately 30 cm; therefore, the effective absorption potential is restricted (Holzapfel, 2009; Wilk et al., 2009).

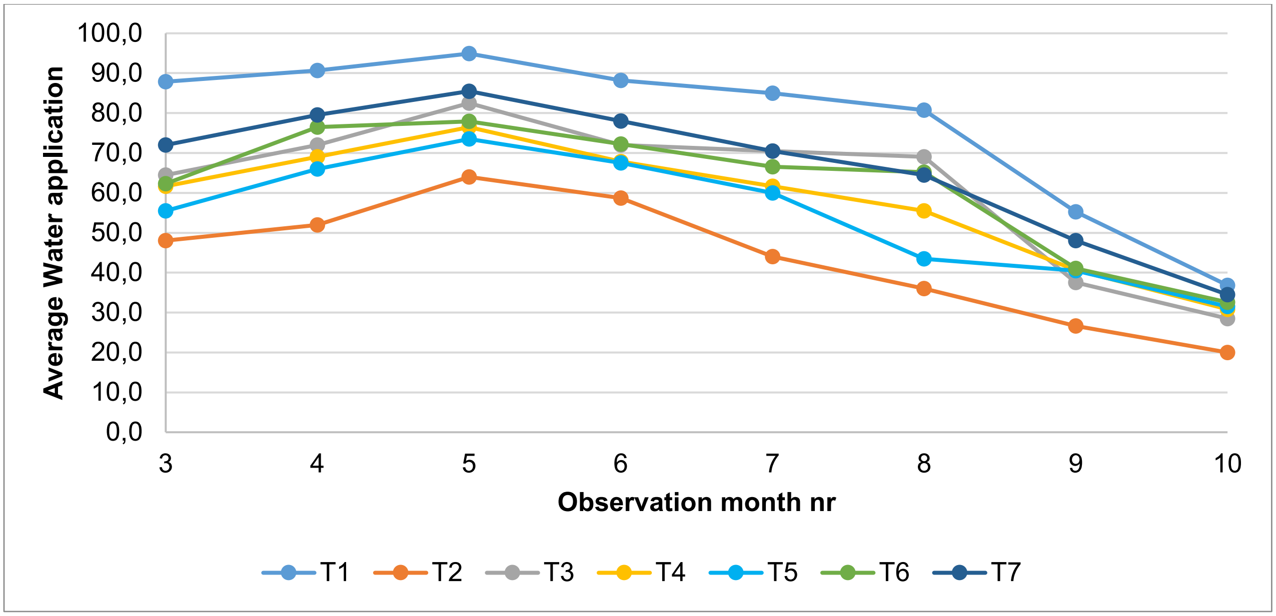

Figure 5. Evaluation of blueberry water use from the active growing season to the winter season (Nov- June).

Blueberry water use for all treatments increased during the active growing season, and a notable increase in water use was observed in January (Figure 5). This increase may be attributed to the climatic conditions during this period, as temperatures significantly increase in the Western Cape. Water demand drops significantly in June for all treatments.

Figure 6 illustrates water use across the three growing seasons, and it can be observed that treatment 1, irrespective of season, had the highest water replenishment. This could be associated with the increase in temperatures during the active growing season. Holzapfel (2009) concluded that the water requirements of blueberry plants are influenced by various factors such as plant size, plant spacing, developmental stage, and climatic conditions. The water requirement of the cultivar Legacy in a study conducted by Ortiz-Delvasto et al. (2023) was 4 L/hour for 5 minutes during the active growing season and was later reduced to 2 minutes.

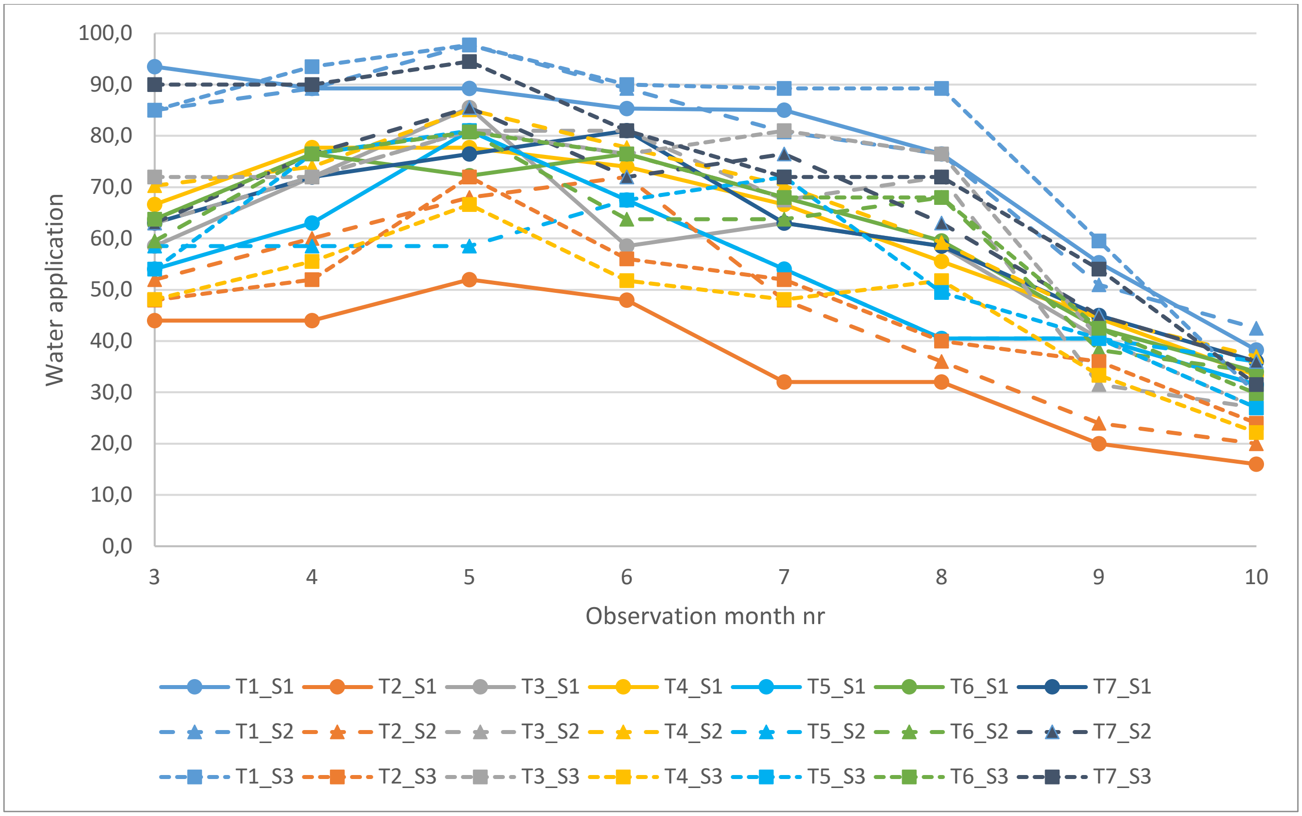

Figure 6. The effect of the different growing media on water use over the three seasons.

4.2.2. Influence of the different growing media on blueberry vegetative growth

Treatment 4 obtained the highest number of leaves, but the difference was not significant ($p>0.05$) from treatments 2 and 3. These findings are consistent with those of Ortiz-Delvasto et al. (2023), who concluded that the composition of coir and peat moss gave less growth and yield compared to coir as an exclusive combination of coir and peat moss resulted in lower growth and yield compared to coir as the sole growing medium. According to Yang et al. (2022), the number of leaves in plants increases their photosynthetic output, thereby increasing biomass, and is a good indicator of plant health. The composition of 80% coir and 20% peat moss significantly increased the number of branches and plant height compared with all other treatments (Table 8). Similar results were obtained in a study conducted by Wang et al. (2018), where coir improved all the vegetative parameters of the Northern Highbush cultivar. The highest height of 63.75 cm was obtained from treatment 4. However, in a study conducted by Singh *et al*. (2017), 53.90 cm was the maximum plant height of the cultivar Legacy.

Table 8. Effect of the different growing media compositions on the vegetative growth of blueberry

Treatment	NL	NB	PH (cm)
T1	121.69 ±70.67^{d}	3.53 ±0.83^{c}	56.68 ±19.79^{b}
T2	298.67 ±216.88^{ab}	4.33 ±1.73^{b}	48.28 ±12.34^{c}
T3	304.47 ±222.82^{ab}	4.30 ±1.53^{b}	49.23 ±12.96^{c}
T4	318.26 220.51^{a}	5.26 ±2.64^{a}	63.74 ±21.09^{a}
T5	195.83 140.12^{c}	3.53 ±1.18^{c}	42.79 ±10.73^{d}
T6	251.93 ±184.20^{bc}	3.87 ±1.75^{bc}	44.25 ±9.34^{cd}
T7	214.87 ±171.23^{c}	4.47 ±2.69^{b}	49.61 ±15.99^{d}
LSD	0.11	0.84	0.67

T1- 100% coir, T2- 80% coir + 20% zeolite, T3- 60% coir +40% mushroom compost, T4- 60% coir + 40% peat moss, T5- 40% coir + 20% zeolite + 20% mushroom compost, T6- 40% coir + 20% zeolite + 40% peat moss, T7- 40% coir + 30 mushroom compost + 30% peat moss; , LSD- lease significant difference; NL- number of leaves, NB- number of branches, PH- plant height, cm- centimeters.

A pH of more than 5.5 can negatively impact the growth parameters of blueberry plants, as they thrive best in acidic soils (Gallegos-Cedillo et al., 2018). The growing media analysis results from the current study showed that treatments 3, 5, and 7 had media pH values greater than 5.5, which could have restricted all the growth parameters, as the ideal pH range for optimum growth and development of blueberries is 4.5 to 5.0 if all protocols are diligently observed(Tamir et al., 2019).

4.2.3. Effect of the different growing media on blueberry yield parameters

The highest yield was obtained in treatment 4 (60% coir plus 40% peatmoss), irrespective of the season (Figure 7). A selective picking method was used to harvest ripe blueberries, and this was grouped into three categories: H_1 (October), H_2 (November) and H_3 (December). Yield parameters increased during the second season across all treatments. This is associated with more developed reproductive structures. According to Salvo et al.

(2012), blueberry yield is influenced by various internal and external factors; however, flower bud numbers increase during the second year after planting.

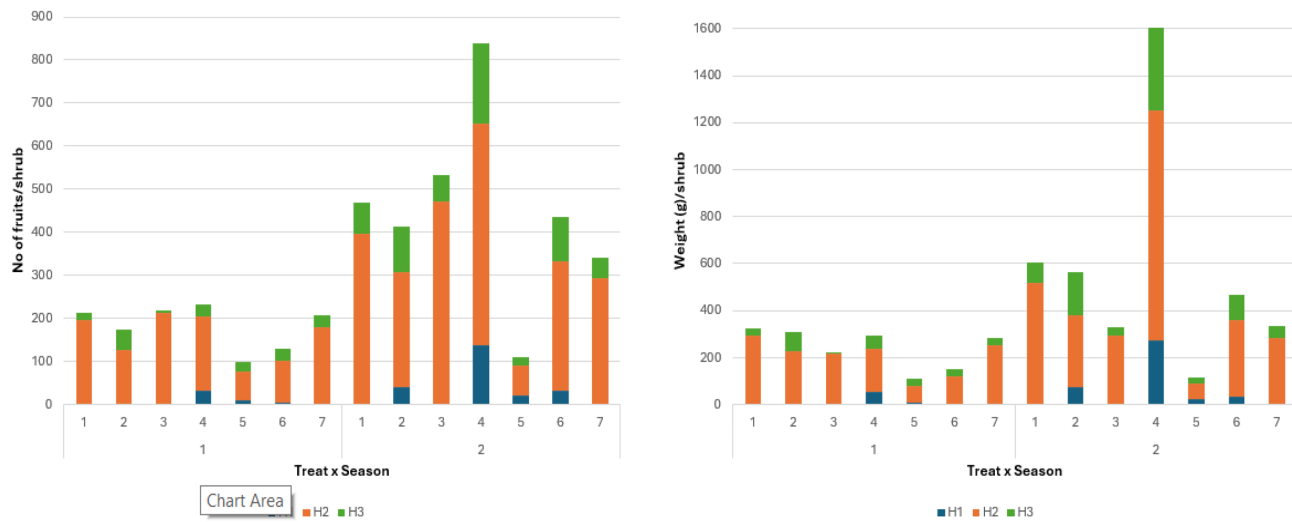

Figure 7. The effect of treatment of number of fruits harvested and total weight over the two seasons

The different treatments significantly influenced ($p<0.05$) the blueberry size across the two harvesting seasons, which may be attributed to the differences in water retention, nutrient availability, and pH of the different growth media combinations, which may have influenced crop yield as well as their interaction with the environment, as the size of blueberries is one of the most important traits, especially for fresh consumption (Gilbert et al., 2014).

Similarly, the fruit diameter was also significantly influenced ($p<0.05$) across the different treatments and seasons of blueberry cultivation. Interestingly, the same trend was recorded with T_4 having the largest diameters during the second season of harvest, attributing to the factors that collectively influence plant physiological processes such as photosynthesis, cell expansion, and assimilate partition, which determine fruit diameter.

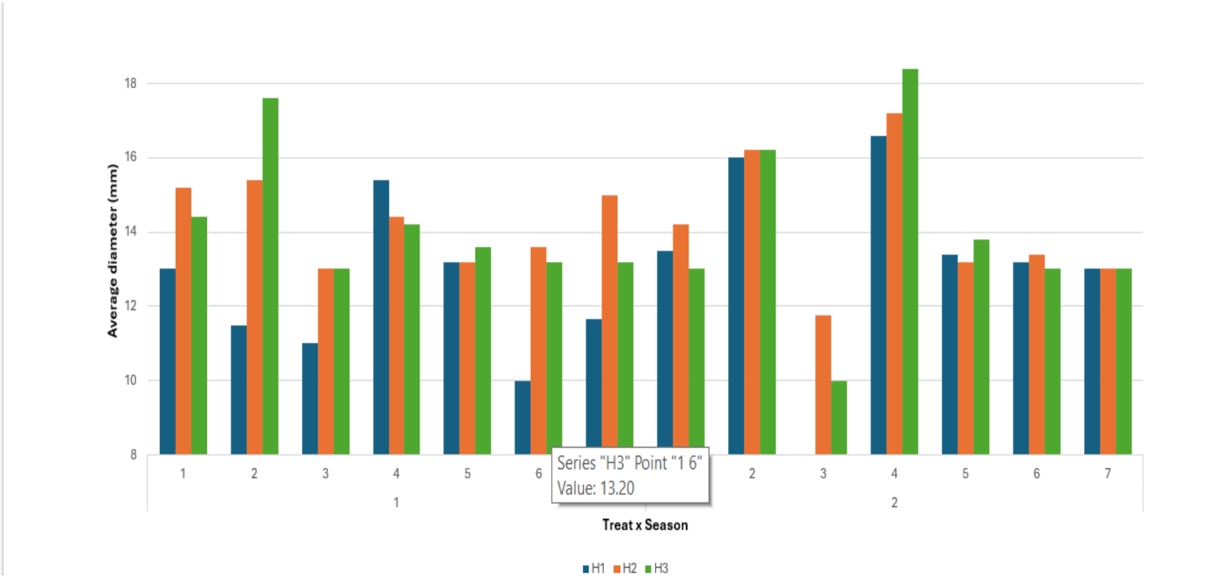

Figure 8. The effect of treatment on fruit diameter over the two seasons (2023/2024)

4.2.4. Mineral content of blueberry fruits

Twelve mineral elements of the blueberry cultivar Legacy were investigated overall, and detailed results are presented below (Tables 9 and 10). Fruit cultivated in a media combination containing either peat moss or mushroom compost had the highest content of N. It was significantly different ($p<0.05$) from berries cultivated in media containing coir and zeolite. The treatment containing 60% coir and 40% mushroom compost had the highest P and K contents. The highest Na concentration of 676.6 mg kg-1 was attained on berries cultivated on the growing media with 40% coir, 20% zeolite, and 40% peat moss. There was no significant effect on minerals Ca and Mg across the different media used in the study. Data from the present study indicated that the twelve mineral elements were influenced by the different growing media used. The highest concentration of nitrogen was obtained in the treatment with coir, zeolite, and mushroom compost; this can be attributed to the physical and chemical properties of the three media and their nitrogen uptake efficiency (Noble et al., 2024; Tuckeldoe et al., 2023). However, it must be noted that zeolite does not directly contribute to the concentration of nitrogen or any other element, as its main function is to retain water and act as a carrier of the minerals in mineral uptake (Jarosz et al., 2022). Additionally, nitrogen availability in Vaccinium species enhances renewal, overall production, and flower bud initiation and development for the following season, especially on deciduous blueberry types (Sandler & DeMoranville, 2008). Phosphorus content was observed on the berries. However, the quantities were lower than all macro-minerals investigated. This is because phosphorus is available in the substrate. These findings align with those of Kingston et al. (2020), where two blueberry cultivars were evaluated, and phosphorus had the lowest concentration across all measured macro mineral elements. The highest percentage of potassium was obtained in the treatment containing coir and mushroom compost. Potassium is regarded as one of the macronutrients critical for blueberry plants as it facilitates the movement of calcium and magnesium in xylem vessels (Moraes et al., 2021). A significantly higher sodium concentration was obtained from berries grown in 40% coir, 20% zeolite, and 40% peat moss mixture; this can be strongly associated with the high sodium available in the growing media before planting. The sodium percentage of 30.23 was obtained.

Table 9. Influence of growing media on the macro minerals of blueberry fruits.

	%					mg/kg
Treatment	**N**	**P**	**K**	**Ca**	**Mg**	**Na**
T1	0.55±0.41^{b}	0.07±0.002^{c}	0.47±0.002^{abc}	0.14±0.090^{a}	0.38±0.002^{a}	38.8±1.35^{c}
T2	0.82±0.32^{b}	0.1±0.002^{ab}	0.47±0.008^{abc}	0.38±0.002^{a}	0.38±0.002^{a}	345±26.47^{b}
T3	1.47±0.00^{a}	0.12±0.002^{a}	0.53±0.003^{a}	0.82±0.003^{a}	0.38±0.002^{a}	70±5.08^{c}
T4	1.6±0.69^{a}	0.09±0.000^{b}	0.48±0.186^{abc}	0.5±0.000^{a}	0.38±0.002^{a}	30±1.00^{c}
T5	1.71±0.29^{a}	0.1±0.017^{ab}	0.43±0.618^{bc}	0.21±0.109^{a}	0.38±0.002^{a}	95.4±22.06^{c}
T6	1.27±0.18^{a}	0.1±0.007^{ab}	0.41±0.037^{c}	0.48±0.002^{a}	0.38±0.002^{a}	676.6±42.70^{a}
T7	1.41±0.33^{a}	0.12±0.008^{a}	0.52±0.031^{ab}	0.78±0.002^{a}	0.42±0.003^{a}	54.8±6.62^{c}
LSD	0.27	0.02	0.02	NS	NS	8.8

T1- 100% coir, T2- 80% coir + 20% zeolite, T3- 60% coir +40% mushroom compost, T4- 60% coir + 40% peat moss, T5- 40% coir + 20% zeolite + 40% mushroom compost, T6- 40% coir + 20% zeolite + 40% peat moss, T7- 40% coir + 30 mushroom compost + 30% peat moss.

The different growing media had a significant influence across all microminerals observed (Table 10). The highest concentration of Fe, with 37.79 mg kg^{-1}, was obtained on berries cultivated on media containing 40% coir, 20% zeolite, and 40% mushroom compost(T_6).

A combination of coir, mushroom compost, and peat moss had the highest Zn concentration at 6.27 mg kg^{-1}. This study showed a significantly high Mn concentration (42.09 mg kg^{-1}) in berries cultivated in a medium containing 40% coir, 20% zeolite, and 40% peat moss (T_6). In comparison, the lowest concentration, 8.13 mg kg-1, was obtained in T_3 (60% coir and 40% mushroom compost). The fruit B concentration ranged from 4.73 to 6.32 mg kg-1, with the highest concentration observed with 60% coir and 40% peat moss. Aluminium concentration varied for treatments; however, the lowest concentration was obtained. Aluminium (Al) concentration varied across treatments; however, the lowest concentration was observed in T_4 (60% coir plus 40% peat moss). Berry fruits cultivated on a combination of coir, zeolite, and mushroom compost had the highest Cu concentration (Table 10).

Table 10. Influence of growing media on the micro minerals of blueberry fruits

	mg/kg					
Treatment	**Fe**	**Zn**	**Mn**	**B**	**Al**	**Cu**
T1	20.12±0.34^{bc}	4.83±0.20^{ab}	27.78±2.83^{b}	6.21±0.234^{a}	7.95±0.85^{a}	0.69±0.008^{abc}
T2	19.1±0.59^{bc}	5.29±0.24^{ab}	26±2.50^{b}	4.73±0.212^{b}	7.93±0.26^{a}	1.2±0.355^{ab}
T3	16.24±1.26^{c}	5.4±0.32^{ab}	8.13±0.35^{c}	5.02±0.171^{b}	8.54±0.95^{a}	0.56±0.323^{cd}
T4	23.92±1.91^{b}	4.43±0.12^{b}	20.51±2.54^{c}	6.32±0.091^{a}	5.14±0.34^{b}	0.58±0.321^{cd}
T5	37.79±5.40^{a}	5.92±0.78^{a}	17.92±1.18^{cd}	4.85±0.008^{b}	7.44±0.47^{a}	1.31±0.281^{a}
T6	16.53±1.62^{bc}	5.63±0.68^{ab}	42.09±0.96^{a}	6.14±0.227^{a}	8.96±0.71^{a}	0.89±1.492^{bc}
T7	17.5±1.29^{bc}	6.27±0.28^{a}	14.12±1.08^{d}	6.01±0.268^{a}	7.44±0.49^{a}	0.46±0.465^{d}
LSD	0.29	0.4	5.89	0.12	2.3	0.1

T1- 100% coir, T2- 80% coir + 20% zeolite, T3- 60% coir +40% mushroom compost, T4- 60% coir + 40% peat moss, T5- 40% coir + 20% zeolite + 40% mushroom compost, T6- 40% coir + 20% zeolite + 40% peat moss, T7- 40% coir + 30% mushroom compost + 30% peat moss.

The growing media combination containing 40% coir, 20% zeolite, and 40% mushroom compost (T_5) generally recorded the highest percentage of iron and copper, respectively, across the different treatments. This trend was also observed in nitrogen concentration on the macro minerals, which relates to the physical and chemical properties of these growing substrates. T_6 (40% coir, 20% zeolite, and 40% peat moss) had the highest manganese concentration across all treatments. These findings agree with those of (Ochmian et al., 2009) in the mineral composition of blueberry production.

4.2.5. Correlation analysis

The correlation analysis is presented in Table 11 below. The correlation analysis revealed strong interactions among macro and micronutrients, reflecting coordinated nutrient availability and a synergistic relationship within the media system. Nitrogen (N) showed a strong positive correlation with phosphorus ($r = 0.752$, $p < 0.01$) and a moderate correlation with potassium ($r = 0.403$, $p < 0.05$), indicating synchronised nutrient dynamics likely influenced by fertilization practices. Similarly, P was significantly correlated with K ($r = 0.547$, $p < 0.01$) and magnesium ($r = 0.452$, $p < 0.01$), highlighting the close association among essential macronutrients involved in plant metabolic processes.

Zn exhibited a strong positive correlation with N, P, Mg, and Cu, suggesting a co-mobilization mechanism. However, the strong P-Zn relationship may also indicate a risk of micronutrient imbalance under high phosphorus availability. Manganese showed a significant negative correlation with N, P, and K, suggesting potential antagonistic effects under high-macronutrient conditions, possibly linked to changes in the pH or aeration status of the growth media. Sodium was positively correlated with Mn, suggesting similar mobilization under specific media conditions. At the same time, calcium and aluminium showed weak correlations with most nutrients, indicating relatively independent behaviour.

Table 11. Correlation analysis of the twelve mineral elements in blueberry 'Legacy.'

Elements	N	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	B
P (%)	.752**										
K (%)	.403*	.547**									
Ca (%)	.117	0.087	-.265								
Mg (%)	.289	.452**	.364*	.141							
Na (mg/kg)	-.078	.125	-.294	-.185	-.025						
Fe (mg/kg)	.112	-.295	-.295	.237	-.084	-.282					
Cu (mg/kg)	.313	.341*	.022	.241	.104	.379*	0.145				
Zn (mg/kg)	.590**	.775**	.427*	.187	.528**	.203	-.171	.533**			
Mn (mg/kg)	-.302	-.312	-.373*	-.110	.060	.728**	-.137	.253	-.034		
B (mg/kg)	-.103	-.279	.003	-.122	.314	-.042	-.173	-.517**	-.176	.430**	
Al (mg/kg)	-.296	-.009	-.176	.049	-.134	.315	-.123	.032	.156	.160	-.128

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

4.2.6. Influence of treatment on chemical composition of the media after harvest

The highest nitrogen percentage was obtained from the treatment combination containing coir, mushroom compost, and peat moss. According to Shu et al., (2025) reported that incorporating mushroom compost into a substrate improves the functional profile, increasing nutrient recycling and, therefore, improving the carbon percentage. The other macro elements analysed in this study varied as shown in Figure 9.

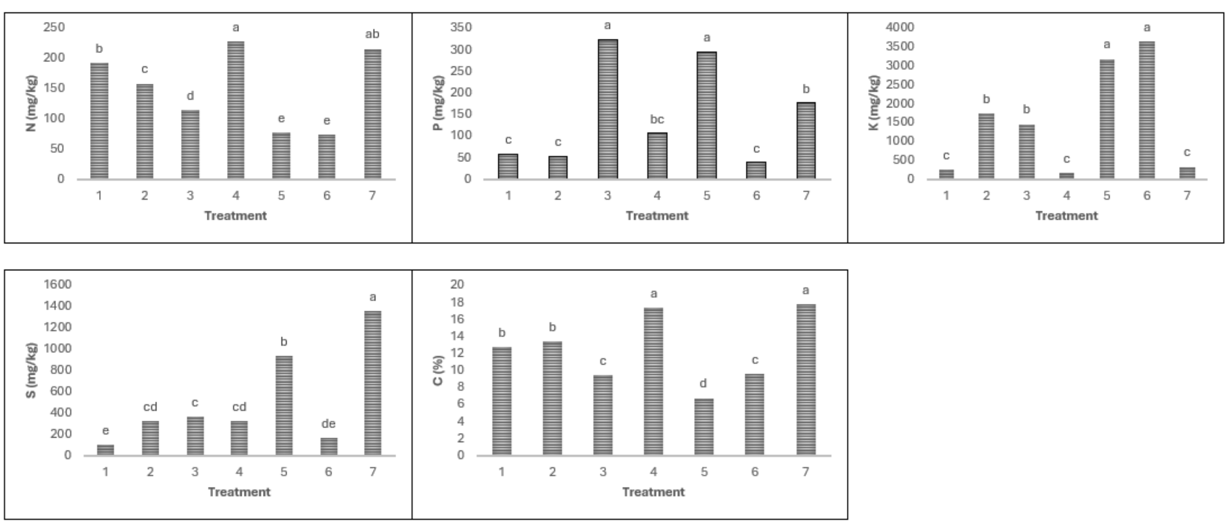

Figure 9. Growing media macro chemical composition after harvest

The microchemical composition varied across all treatments. However, treatment 7 (40% coir, 30% mushroom compost, and 30% peat moss) increased all the microelements analyzed (Figure 10).

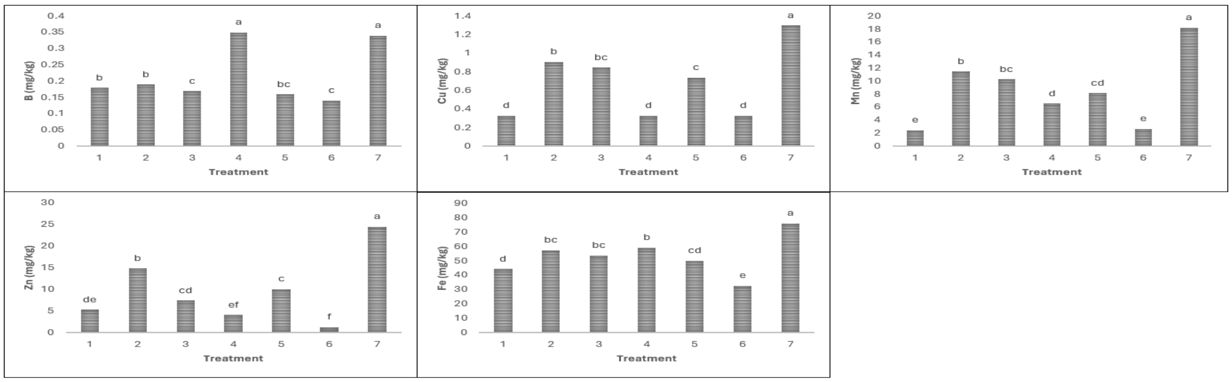

Figure 10. Growing media micro chemical composition after harvest

The results of the principal component analysis (PCA) showed that treatments 2, 3, 4 and 7 had a strong positive relation with media minerals such as carbon, boron, nitrogen and magnesium (Figure 11). Notably, no relations were observed with all the minerals analyzed when coir was solely used to cultivate blueberries.

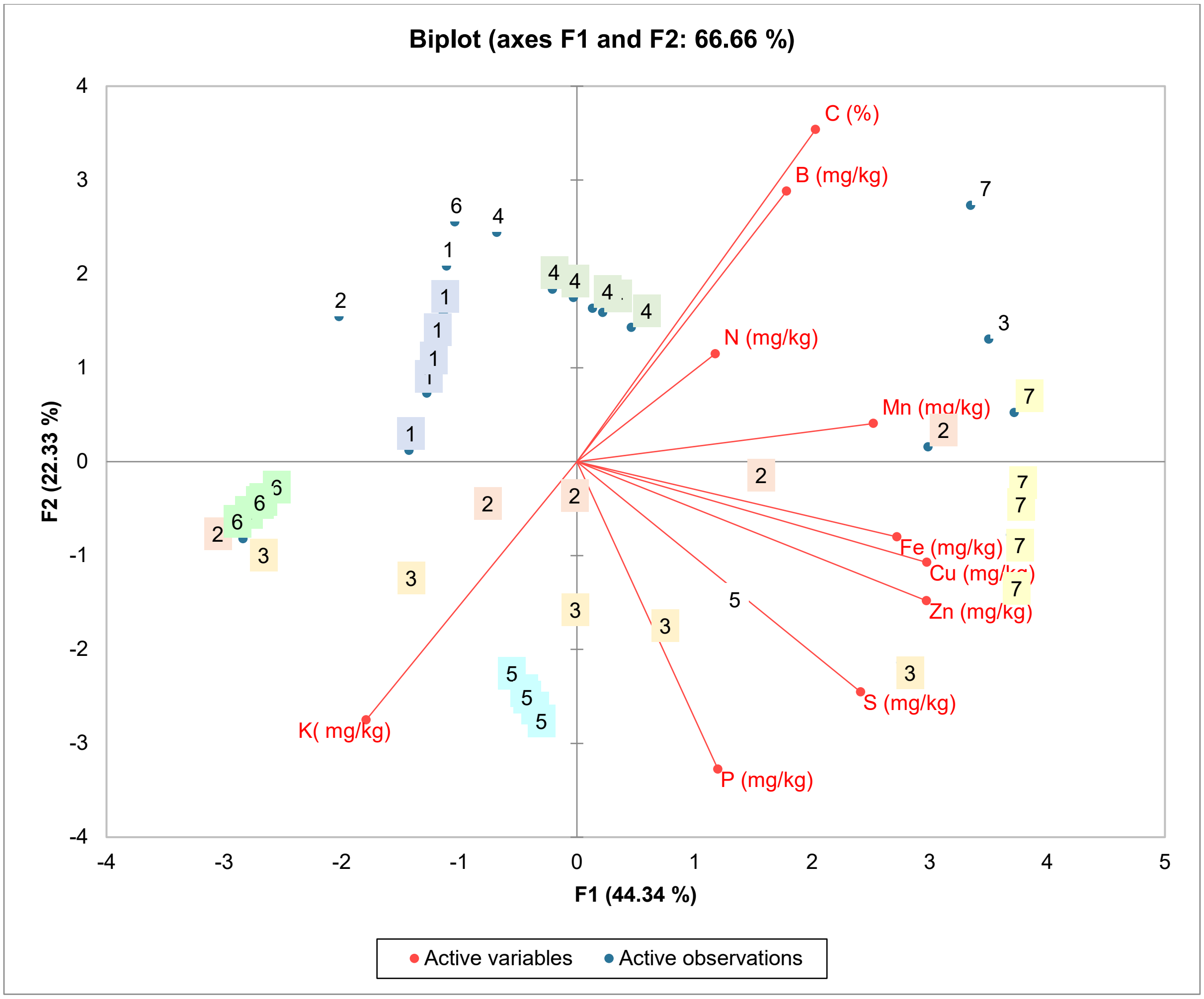

Figure 11. The principal component analysis (PCA) analysis of the correlation between treatments and growing media chemical composition.

4.2.7. Influence of the different growing media on enzyme activity in blueberry cultivation.

The growing media containing 60% coir and 40% peat moss significantly improved the β-glucosidase activity (Table 11). According to Su et al., (2021), growing substrates in β-glucosidase activity indicate a biologically active, healthy soil with a high rate of carbon cycle that is involved in cellulose hydrolysis. This is also supported by the high C percentage for this treatment combination, as presented in Figure 9, above. In this study, the results show that the phosphatase and urease activity varied across all treatments. However, a notable enzyme activity was observed in the treatment combination containing 40% coir, 30% mushroom compost (MC), and 30% peatmoss. The use of mushroom compost as a substrate in the media contributes to the hydrolysis of urea and increases urease activity as MC is an organic fertilizer (Gil-Sotres et al., 2005).

Table 12. Enzyme activity in response to the different growing media

Treatment	β-glucosidase (μg PNP g^{-1})	Phosphatase (μg PNP g^{-1})	Urease (μg NH_{4+} g^{-1})
1	50.84^{ab}	7.13^{a}	4.90^{c}
2	37.57^{b}	2.70^{c}	14.04^{a}
3	39.42^{b}	6.12^{a}	9.89^{abc}
4	74.86^{a}	5.49^{ab}	6.16^{bc}
5	51.45^{ab}	3.57^{bc}	11.76^{a}
6	36.98^{b}	3.43^{bc}	11.06^{ab}
7	62.08^{ab}	7.57^{a}	12.12^{a}
LSD $_{(0.05)}$	25.17	2.53	5.58

Principal Component Analysis (PCA) of the growing media chemical composition and enzyme activity. A strong positive correlation was observed between β-glucosidase, carbon, and nitrogen percentage (Figure 12). B-glucosidase is the main enzyme responsible for nitrogen and carbon recycling.

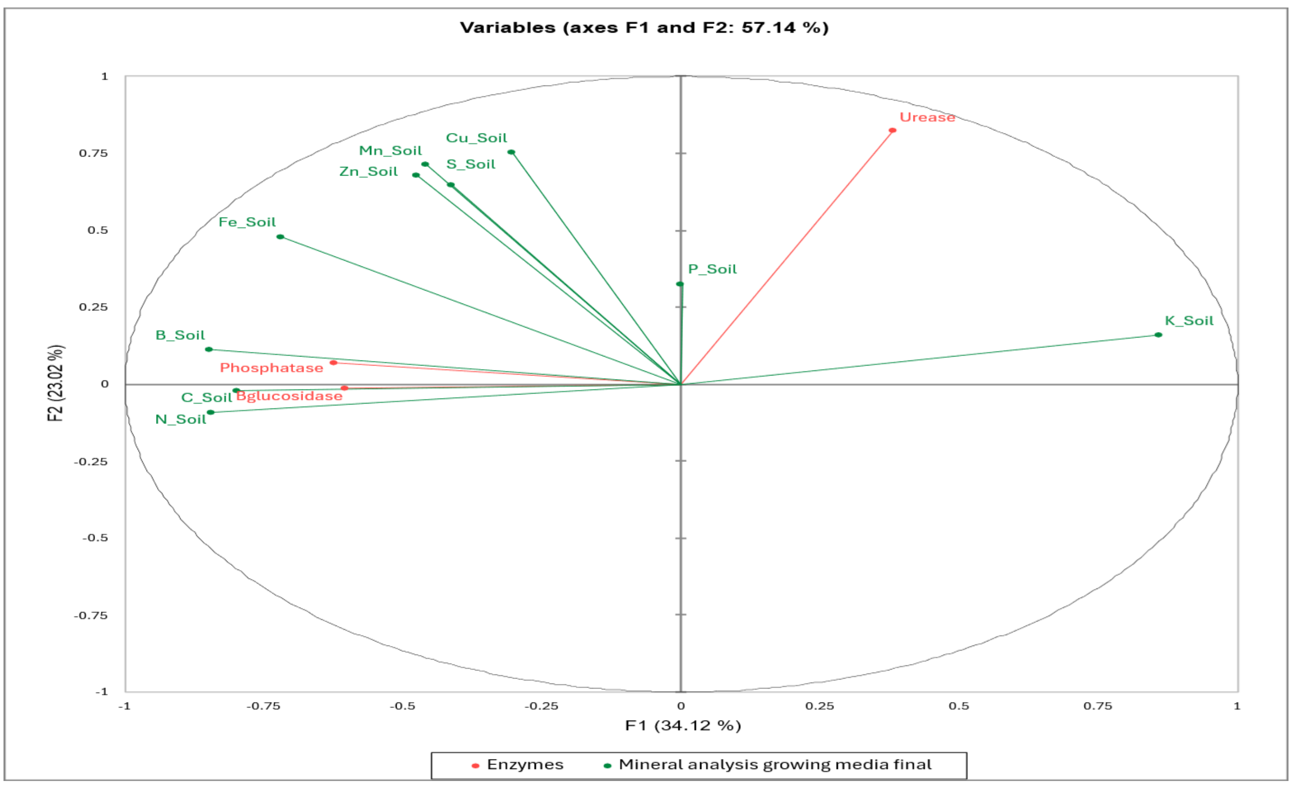

Figure 12. Principal Component Analysis (PCA) of the growing media chemical composition and enzyme activity

4.2.8. Effect of growing media on nematode population

The nematode identification results showed that free-living plant nematodes were present across all treatments, and only T_6 was identified as containing the Lesion parasitic nematode (*Pratylenchus sp.*). The highest nematode population was observed in T_7 (40% coir, 30% mushroom compost, and 30% peat moss) and was not significantly different from T_3 (Figure 13). The composition of these treatments both contains mushroom compost, which indicates that mushroom compost enhances the population of free-living nematodes. In the study done by (Ferreira et al., 2022)It was concluded that incorporating mushroom compost into the growing media significantly reduces parasitic nematodes that are not ideal for plant growth. Free-living nematodes are an ideal indicator for soil fertility, which is critical for nutrient mineralization and enhances biological activities.

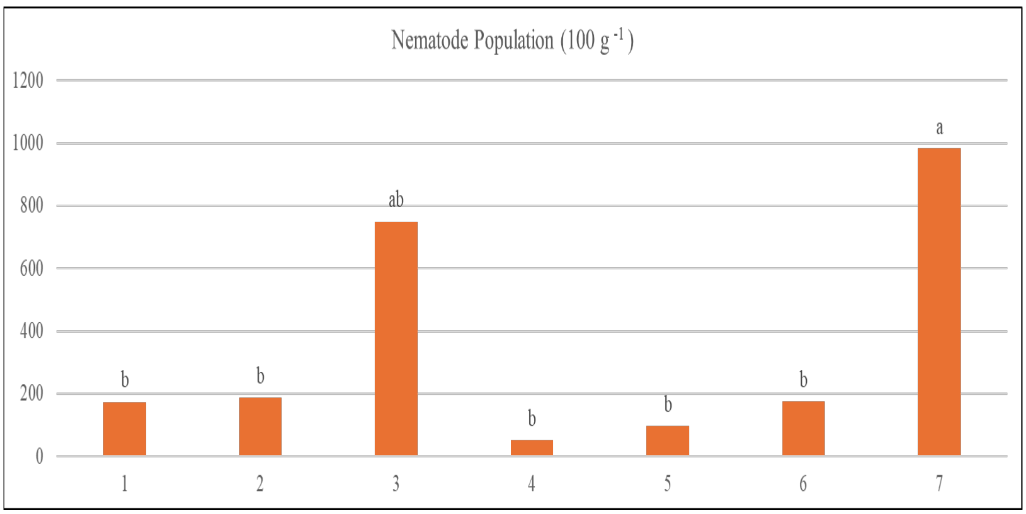

Figure 13. Free-living nematode population

4.3. EXPERIMENT 2

4.3.1. Influence of nitrogen sources and growth media on the growth parameters of blueberry.

The growth parameters investigated in this study were influenced by nitrogen (N) sources and growth media (Table 13). During the 2023 cultivation season, plant height, number of leaves, and stem diameter showed significant differences ($p<0.05$) among the different treatment applications. However, the number of branches and chlorophyll content did not differ significantly ($p > 0.05$) among the different treatment applications. T_3 (100% coir +

calcium nitrate) had the most impact on the number of leaves and number of branches, with an 80% and 14% increase, compared to the control (T_1=100% Coir + ammonium sulphate). However, T_5 (100% coir + urea) decreased the number of leaves and branches by 11.7% and 8.3%, respectively (Figure 14 B-C). Notwithstanding, T_1 outperformed the most on plant height, followed by T_5, and the least by T_4 (80% coir: 20% zeolite+ calcium nitrate). Furthermore, T_4 showed the greatest effect among the treatments for stem diameter and chlorophyll content index (CCI), with increases of 46% and 29%, respectively, compared to the control (T_1).

Interestingly, during the 2024 cultivation season, the growth parameters investigated had a significant difference ($p < 0.05$) among all treatment applications (Table 13).T_2 (80% coir: 20% zeolite+ ammonium sulphate) achieved the highest leaf number, with a 19% increase compared to T_1, and accumulated the greatest CCI, which was 33% higher than T_3 (Figure 14 A-B). Additionally, T_2 also increased plant height by 35% compared to the lowest-performing treatment, T_4. However, T_1 maintained the highest overall performance in terms of plant height, CCI, and number of branches, producing 52.78 branches per plant, compared to 48.78 branches in T_2. Stem diameter was the thickest under T_4 application, which exceeded T_1 by 8%.

Despite seasonal variation in treatments, the control treatment (T_1) consistently promoted plant height and the number of branches. In 2023, T_3 had the strongest effect on leaf number and branching, whereas in 2024, T_2 emerged as the most effective for leaf number. Stem diameter improved under T4 applications in both cultivation seasons, whereas T5 generally had a suppressive effect on growth.

Table 13. Influence of nitrogen sources and growth media on growth parameters of blueberry during two cultivation seasons.

Cultivation seasons	Treatment	Plant height (cm)	Stem diameter (mm)	No. of leaves/ plant	No. of branches
	T_1	42.44±14.38^{a}	9.4±4.4^{b}	80.67±49.48^{b}	33.67±21.57^{a}
	T_2	28.72±13.16^{b}	12.5±2.1^{ab}	85.56±64.33^{b}	34.22±6.08^{a}
	T_3	22.51±4.12^{b}	9.6±3.6^{b}	145.56±65.57^{a}	38.44±6.58^{a}
2023	T_4	31.67±9.51^{b}	13.7±3.6^{a}	91.33±46.11^{ab}	32.22±9.37^{a}
	T_5	32.00±8.63^{b}	13.7±4.4^{a}	71.22±59.23^{b}	30.87±4.35^{a}

	T_6	29.78±7.29^{b}	11.8±3.9^{ab}	79.33±66.37^{b}	31.67±4.61^{a}
	LSD	6.21	0.2	8.11	NS
2024	T_1	75.57±12.17^{a}	18.4±6.7^{ab}	148.61±87.92^{ab}	52.78±18.86^{a}
	T_2	62.32±17.38^{b}	19.6±5.8^{a}	176.39±106.36^{a}	48.78±24.69^{a}
	T_3	46.47±5.63^{de}	17.0±1.6^{b}	133.78±66.64^{bc}	34.31±11.57^{b}
	T_4	46.02±10.38^{e}	19.9±1.0^{a}	98.17±44.54^{d}	31.42±10.99^{b}
	T_5	52.60±8.32^{c}	16.9±3.8^{b}	77.86±52.43^{d}	30.33±13.58^{b}
	T_6	51.82±12.10^{cd}	19.1±3.9^{a}	104.44±49.97^{cd}	34.72±9.88^{b}
	LSD	0.45	0.1	20.31	1.09

Values are means ± standard deviation at ($P<0.05$). Means with different letters in the same column are statistically significant at $P < 0.05$, P– probability, LSD– Least Significant Difference, S.D– standard deviation, cm– centimeters, mm- millimeters, No.–number, NS– Not significant, T1 –100% Coir + ammonium sulphate (Control), T2 – 80% coir: 20% zeolite+ ammonium sulphate, T3– 100% coir + calcium nitrate, T4– 80% coir: 20% zeolite + calcium nitrate T5 – 100% coir + urea, and T6 – 80% coir: 20% zeolite + urea.

4.3.2. Influence of nitrogen sources and growth media on blueberry water use.

Water applications seasons showed significant differences ($p<0.05$) among the treatments used in the study across seasons (Table 14). The treatments with 100% coir (T_1, T_3, and T_5) had to the treatments with 80% coir: 20% zeolite (T_2, T_4, and T_6) across the different seasons.

Water availability is among the most limiting factors blueberry plants grown in soilless substrates (Muñoz et al., 2022). In a pot experiment, Mfeka et al. (2023) reported that 80% coir and 20% zeolite (v/v) growth media significantly enhanced water retention. This seems to resemble the present study; it was observed that water application was consistently reduced in zeolite-amended treatments (T_2, T_4, and T_6) compared to 100% coir (T_1, T_3, and T_5), confirming the ability of zeolite to reduce water demand in plants through its high cation exchange capacity (CEC) (Jabbar, 2025; Sindesi et al., 2023). Despite zeolite reducing water demand, plants grown in T_1 had greater growth and development (Table 14), suggesting that 100% coir is more conducive to early shoot expansion due to super-aeration and root expansion. These results are similar to those of Evans & Stamps, (1996), who showed that plants grown in coir flowered sooner compared to other substrates.

Chlorophyll is an essential pigment that plays a crucial role in photosynthesis, a photochemical process that is indispensable for plant growth and development. (Kim et al., 2020). In 2023, T_3 (39.08 CCI) accumulated the highest chlorophyll content index (CCI), whereas during the 2024 cultivation season, T_1 was superior (42.11 CCI), followed by T_2 (39.17 CCI) and T_6 (37.61 CCI) treatments (Figure 14 A). This year-to-year variation suggests that the N sources and environmental conditions had an impact on chlorophyll accumulation as the plants were still acclimatising in 2023, whereas by 2024, they had developed resilience and shown enhanced growth.

Table 14. Influence of nitrogen sources and growth media on blueberry water use during two cultivation seasons.

Treatment	2023	2024
	Water application (L)	Water application (L)
T_1	85± 3.68^{a}	76.85±16.74^{a}
T_2	50.67±8.72^{b}	46.67±16.26^{b}
T_3	85± 3.68^{a}	76.85±16.74^{a}
T_4	50.67±8.72^{b}	46.67±16.26^{b}
T_5	85± 3.68^{a}	76.85±16.74^{a}
T_6	50.67±8.72^{b}	46.67±16.26^{b}
LSD	34.33	30.18

Values are means ± standard deviation at (P<0.05). Means with different letters in the same column are statistically significant at P < 0.05, P– probability, LSD– Least Significant Difference, S.D– standard deviation, L– liters, NS– Not significant, T1 –100% Coir + ammonium sulphate (Control), T2 – 80% coir: 20% zeolite+ ammonium sulphate, T3– 100% coir + calcium nitrate, T4– 80% coir: 20% zeolite + calcium nitrate T5 – 100% coir + urea, and T6 – 80% coir: 20% zeolite + urea.

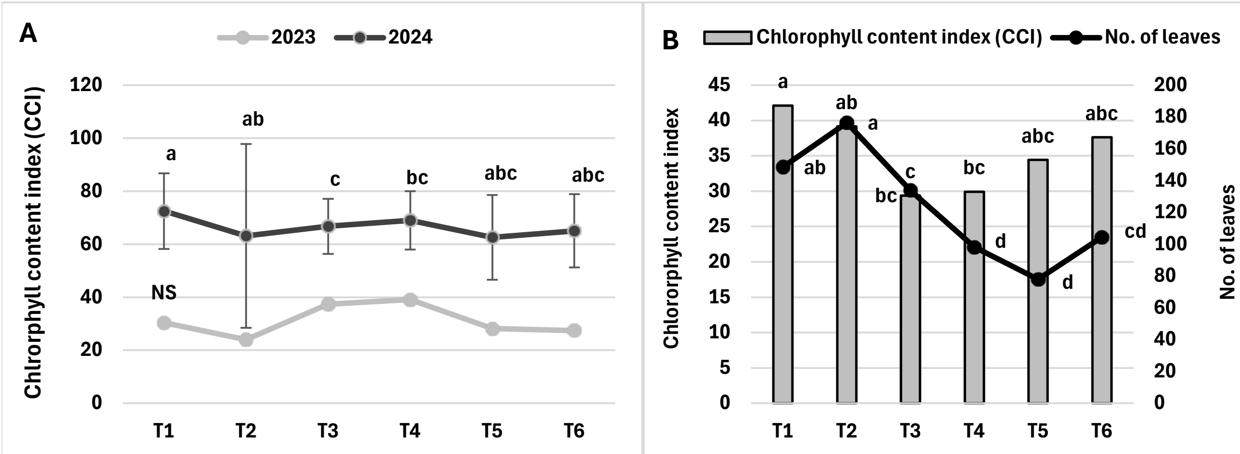

Figure 14. The effect of nitrogen sources and growth media on (A) chlorophyll content index (CCI) during 2023 and 2024 cultivation seasons and (B) the interactive trend between the number of leaves and CCI during the 2024 cultivation season.

The different letters above the columns and line markers indicate significant differences among the treatments at p<0.05. T1 –100% Coir + ammonium sulphate (Control), T2 – 80% coir: 20% zeolite+ ammonium sulphate, T3– 100% coir + calcium nitrate, T4– 80% coir: 20% zeolite + calcium nitrate T5 – 100% coir + urea, and T6 – 80% coir: 20% zeolite + urea.

4.3.3. Influence of nitrogen sources and growth media on yield and nitrogen use efficiency (NUE) of blueberry.

The yield attributes measured in this study were influenced differently ($p<0.05$) by N source and growth medium across the two cultivation seasons (Table 14). In 2023, N sources and growth media had no significant effect ($p>0.05$) on most yield parameters, except for fruit diameter and fruit weight per diameter. The control treatment (T_1) had the largest fruit diameter and fruit weight per diameter compared to all the different treatments (Figure 15A). There was a decrease in average fruit weight by 28% for T_4 and 19% for T_3 and T_6 relative to T_1. A similar pattern was observed for total fresh yield, where T_1 (25.47 g) exceeded T_3, T_4, and T_6 by 59-69%. Furthermore, nitrogen use efficiency (NUE) was highest under T_1, nearly double that recorded for T_3, T_4, and T_6, despite no statistical differences ($p>0.05$) in most yield attributes (Figure 15 B).

In 2024, treatment effects became more evident with varied differences observed in fruit diameter, total fresh yield, and NUE (Table 14). Notwithstanding, T_1 outperformed all other treatments and had the largest berries (16mm) (Figure 15 A) with the greatest single fruit weight (1.81 g). This represented a 20-40% increase compared to T_3, T_4, and T_6. Total fresh yield under T_1 was substantially higher, exceeding T_3 by more than 117% and T_4 by over 300%. NUE followed a similar trend, with T_1 achieving the greatest efficiency (0.56 g yield per g N applied). Although T_2 produced yields that were statistically comparable to T_1, its NUE value was 42% lower, indicating less efficient N utilization despite relatively high yields (Figure 15 B).

Seasonal variation was also evident in both cultivation seasons during the harvest period; yield peaked in November, while in December, the number of fruits per diameter continued to increase, but with reduced fruit diameter and weight, resulting in lower overall yield and NUE (Figure 15C-D).

Table 15. Influence of N sources and growth media on the number of fruits per plant, average fruit diameter, average weight per fruit, number of fruit diameters per plant, total fresh yield, and NUE during two growing seasons

Cultivation Season	Treatment	No. of fruits per plant	Average weight/fruit (g)	Mean fruit diameter/plant	Total fresh yield (g)/ plant	NUE (g yield/ g N applied)
2023	T_1	18.78±13.59^{a}	1.34±0.41^{a}	6.63±7.31^{ab}	25.47±21.57^{a}	5.66±4.79^{a}
	T_2	15.22±6.70^{a}	1.20±0.30^{ab}	5.91±4.23^{b}	17.05±9.15^{ab}	3.79±2.03^{ab}
	T_3	14.11±6.23^{a}	1.08±0.22^{bc}	7.47±6.10^{ab}	13.58±6.14^{b}	3.02±1.36^{b}
	T_4	13.56±6.21^{a}	0.97±0.15^{c}	10.17±6.45^{a}	12.38±5.67^{b}	2.75±1.26^{b}
	T_5	13.67±8.60^{a}	1.18±0.29^{abc}	5.59±3.54^{b}	15.23±11.43^{ab}	3.38±2.54^{ab}
	T_6	10.44±5.32^{a}	1.08±0.22^{bc}	5.53±3.69^{b}	10.79±6.65^{b}	2.39±1.48^{b}
	LSD	NS	0.11	NS	NS	NS
2024	T_1	107.78±93.58^{a}	1.81±0.80^{a}	20.25±16.86^{a}	185.08±187.3^{a}	20.56±20.81^{a}
	T_2	67±43.93^{ab}	1.69±0.78^{a}	13.38±9.75^{a}	107.58±95.2^{ab}	11.95±10.57^{ab}
	T_3	72.89±46.05^{ab}	1.56±0.67^{ab}	17.26±23.58^{a}	85.23±64.56^{b}	9.47±7.17^{b}
	T_4	48.89±33.78^{b}	1.29±0.47^{b}	20±30.34^{a}	45.64±29.15^{b}	5.07±3.24^{b}
	T_5	67.56±25.82^{ab}	1.70±0.77^{a}	14.90±18.08^{a}	79.43±44.31^{b}	8.83±4.92^{b}
	T_6	52.22±24.81^{b}	1.51±0.59^{ab}	13.43±17.05^{a}	58.07±30.49^{b}	6.45±3.39^{b}
	LSD	NS	NS	NS	12.43	1.38

Means with different letters in the same column are statistically significant at $P < 0.05$, P– probability, LSD– Least Significant Difference, and the values are means ± standard deviation at ($P<0.05$). Significant Difference, S.D– standard deviation, mm–millimeters, g– grams, No.–number, NUE– Nitrogen Use Efficiency, N– Nitrogen, NS– Not significant, T1 –100% Coir + ammonium sulphate (Control), T2 – 80% coir: 20% zeolite+ ammonium sulphate, T3– 100% coir + calcium nitrate, T4– 80% coir: 20% zeolite + calcium nitrate T5 – 100% coir + urea, and T6 – 80% coir: 20% zeolite + urea.

Different N forms can affect crop yield; these effects are directly observed in the external physical traits of the fruit. Consumer preference studies showed that larger berries are more desirable and reduce harvest costs (Duan et al., 2023). From an industry perspective, smaller berries water. They have a higher surface area-to-volume ratio, leading to greater water loss, making larger fruits more desirable. In this study, blueberry fruits exhibited the largest fruit diameter, weight per fruit, total fresh yield, and nutrient use efficiency (NUE) under T_1 ($p < 0.05$) compared to the other treatments (Table 15). This suggested that NH4+-based treatments enhance berry size and weight. In contrast, the value of these physical indicators was lowest when NO_3^- was applied as the N source. The number of fruits per plant and the number of fruits per diameter remained consistent across treatments, indicating that enhanced yield under NH_4^+ treatments was driven primarily by increased berry mass rather than berry number.

The evident increase in total fresh yield likely resulted from increased flower initiation per unit surface area and enhanced allocation of assimilates to individual berries. These results are supported by a previous study, which found that flower bud number was increased by N fertilization. (Lafond & Ziadi, 2011). Anwar et al., (2024) reported an earlier initiation of flowering under 50:50 NH_4^+:NO_3^-, suggesting that a balance of N forms was conducive for early bloom and the application of higher NH_4^+ in the 75:25 ratio hastens the flowering stage. It shortens its duration, indicating that plants rely heavily on NH_4^+ as their main N source, thus making it the most effective in enhancing fruit set and later yield of the fruit. Additionally, fruit set and quality decreased with high NO3-application, negatively affecting reproductive traits and yield. (Messiga et al., 2021). However, in apples, increasing the NH_4^+:NO_3^- ratio did not affect fruit size. (Mohammad Sokri et al., 2015), highlighting the varying responses of species to NH_4^+:NO_3^- ratios. Previous studies have shown that the physical traits of blackberry fruits were the largest under NH_4^+ or urea-based treatments. (Duan et al., 2023). Furthermore, in 'Bluecrop' blueberry, application of NH4+ and urea through the fertigation system by the split method significantly increased berry weight (2.22 g and 2.17 g, respectively) and total yield of blueberry plants. (Vargas & Bryla, 2015).

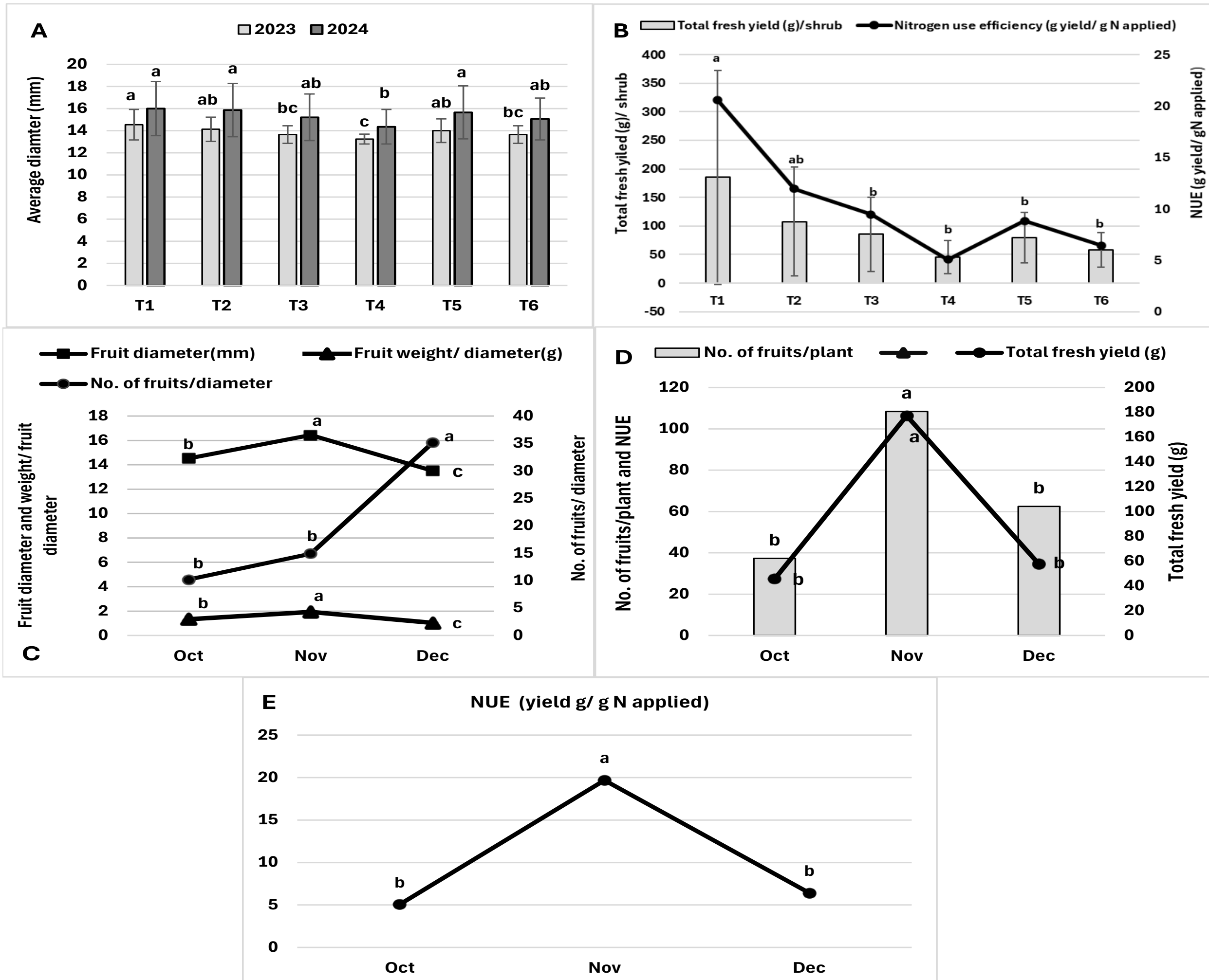

Figure 15. Effect of different nitrogen sources and growth media on (A) average fruit diameter during 2023 and 2024 cultivation seasons, (B) interactive trend between total fresh yield and Nitrogen use efficiency (NUE) during 2024 cultivation. Influence of harvest period on (C) Fruit diameter, fruit weight per diameter, and number of fruits per diameter, (D) number of fruits per plant, total fresh yield, and (E) nitrogen use efficiency (NUE).

The different letters above the columns and line markers indicate significant differences among the treatments at $p<0.05$. T1 –100% Coir + ammonium sulphate (Control), T2 – 80% coir: 20% zeolite+ ammonium sulphate, T3– 100% coir + calcium nitrate, T4– 80% coir: 20% zeolite + calcium nitrate T5 – 100% coir + urea, and T6 – 80% coir: 20% zeolite + urea.

4.4. Conclusion

The field capacity of any growing medium is critical for water conservation. The findings from this study showed that the use of growing media in combination significantly reduced the water-holding capacity of the water media by up to 54% when coir was used exclusively. The combination of coir and zeolite required the least water replenishment compared with the other treatments. Generally, the results showed that the media composition with 60% coir and 40% peat moss increased all measured vegetative and yield parameters.

Varying results were obtained in this study; however, a treatment combination of 40% coir, 20% zeolite, and 40% mushroom compost showed the greatest improvement for most of the microminerals investigated in blueberry fruits. The use of growing media in combination has the potential to improve the berry fruit's nutritional content.

Physiochemical and biological properties of a substrate when cultivating blueberries are critical to ensuring sustainable production. Using a growing media combination for blueberry production has the potential to improve the availability and uptake of minerals. A substrate material suitable for cultivating blueberries should be porous, provide balance with available salts and nutrients to ensure effective nutrient uptake and distribution. The effect of the media combination on the substrate health required further investigation, its impact over a long-term period, including physical and biochemical components.

Different nitrogen source treatments were applied during blueberry growth and development. It was found that ammonium sulphate (NH_4^+) in 100% coir (T_1) produced the best results in both years of cultivation, confirming its role as the blueberry industry standard in the Western Cape. Urea in 100% coir (T_5) also enhanced plant height, supporting the use of NH_4^+ derived N from hydrolysis. In contrast, calcium nitrate (T_3 and T_4) increased stem diameter. Still, it produced fewer branches and a lower chlorophyll content index (CCI), suggesting that NO_3^- treatments promoted structural growth at the expense of photosynthetic capacity, thereby reducing yield. NH_4^+ also had a strong impact on blueberry diameter and weight, whereas the number of berries per plant was not significantly influenced by N sources.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. General conclusions

The research project assessed and investigated the effects of the different growing media on water use, yield, and growing media properties of blueberries. The activities aligned with addressing the set objectives commenced in the year 2022, at the inception of the project.

The growing media combination of 80% coir and 20% zeolite (T_2) recorded the least water replenishment compared to other media combinations used in the study. A significant reduction in blueberry water use was achieved when the growing media were used in combination, compared to the industry common practice of mainly using coir. Results from the study show that the highest quantities and frequency of irrigation for blueberry plants were obtained when coir was used. The findings of this study thus far highlight the importance of using growing media combinations as an effective means of improving water use efficiency while enhancing production.

The study documented critical agronomic practices that can assist in the production of blueberries. Information regarding conducive cultivation conditions is critical. A substrate material suitable for cultivating blueberries should be porous, provide balance with available salts and nutrients to ensure effective nutrient uptake and distribution. The combination of coir and peatmoss improved some of the measured parameters during seasons 1 and 2 of the project. Water usage was significantly reduced during the 2023/2024 growing seasons.

However, the frequent demand for water when coir is solely used increased all the vegetative parameters measured. Inconsistent results regarding nutritional value should be further investigated. Blueberry phenolic constituents, as stress response metabolites, their accumulation differed with N source, growth media, and plant age. The findings indicated that moderate nutrient stress, achieved through careful selection of N sources and growth medium, may enhance the accumulation of phenolic compounds without severely compromising yield. The review concluded that a combination of NH_4^+ with NO_3^-

or NH_4^+ alone, consistently promoted superior growth and fruit quality compared to NO_3^- alone, particularly in acidic media, which is favourable for blueberry cultivation.

The selection of N sources, along with application methods, determines the most effective approach to promoting sustainable blueberry production while maintaining environmental sustainability. Based on these findings, further research should investigate how different blueberry cultivars respond to combinations of N forms under varying levels of acidity. The practice of split fertilizer applications and fertigation systems enhances nutrient utilization efficiency while reducing nutrient loss. However, the long-term effects of continuous NH_4^+ fertilization on soil acidification and associated changes in nutrient dynamics in blueberry production remain under-researched, highlighting the need for further research.

Different nitrogen source treatments were applied during blueberry growth and development. It was found that ammonium sulphate (NH_4^+) in 100% coir (T_1) produced the best results in both years of cultivation, confirming its role as the blueberry industry standard in the Western Cape. Urea in 100% coir (T_5) also enhanced plant height, supporting the use of NH_4^+ derived N from hydrolysis. In contrast, calcium nitrate (T_3 and T_4) enlarged stem diameter but resulted in fewer branches and a low chlorophyll content index (CCI), suggesting that NO_3^- treatments promoted structural growth at the expense of photosynthetic capacity, which resulted in reduced production. NH_4^+ also had a strong impact on blueberry diameter and weight, whereas the number of berries per plant was not significantly influenced by N sources.

5.2. Recommendations

The use of a growing media combination reduces crop water demand, potentially lowering production costs and increasing returns in targeted local and international markets.

Phenolic compounds accumulate naturally with plant age, regardless of the treatment applied. Future management practices should aim to balance stress-induced phenolic accumulations with yield to optimise fruit quality with yield and nutritional value. Furthermore, future studies should explore the suitability of urea in container production, as the application of ammonium sulphate may have long-term negative impacts on soil toxicity due to acidification. The effect of the media combination on substrate health required further investigation, particularly its impact over a long-term period, including physical and biochemical components.

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ANNEXURE A: CAPACITY BUILDING

The aim of postgraduate students' involvement in the project is to increase their research capacity. All researchers involved in the project worked closely with the postgraduate students, training and mentoring them throughout the project's duration. In collaboration with other researchers on the project, the postgraduate students played an important role in knowledge dissemination, as the project's results were published in peer-reviewed journals and presented at conferences.

Students' details

Full name	**Gender**	**Qualification**	**Institution**	**Completion Date**
Ms Nonkululeko Mfeka	Female	PhD	Cape Peninsula University of Technology	December 2026
Ms Asemahle Mshweshwe	Female	MSc	Cape Peninsula University of Technology	Completed, passed with Cum Laude, graduation April 2026

ANNEXURE B: MSc Abstract

ABSTRACT

Globally, blueberry (*Vaccinium* spp.) production has rapidly increased in recent years, driven by consumers' increased demand for this nutritious fruit. This study investigated the interactive effects of different N sources and soilless growth media on water use, growth, yield, and quality of blueberry. A pot experiment was carried out in polythene bags under a white shade net. Three nitrogen sources: ammonium sulphate [$(NH_4)_2SO_4$] (N 21.1%), calcium nitrate [Ca $(NO_3)_2$] (N 16.6%), and urea (H_2NCONH_2) (N 46%) were applied to two soilless substrates growth media (100% coir and a combination of 80% coir: 20% zeolite) in a randomized complete block design replicated three times. Growth, fruit yield, and berry quality parameters were measured. Our results showed that treatment with NH_4^+ at 100% coir yielded higher values for most growth parameters, chlorophyll content index, proanthocyanidin, and the availability of macro- and micronutrients in the soilless substrate. The 100% coir treatment favors early shoot expansion due to superaeration and root expansion, and the addition of zeolite to coir reduced water demand by the test plants. The retention of NH_4^+ by the 20% zeolite treatment was not beneficial to the blueberry plants, hindering chlorophyll content accumulation and photosynthesis. These results suggest the need for further investigation into the influence of different zeolite levels on blueberry cultivation in pots. The application of NH_4^+ increases fruit size and weight, primarily by enhancing photosynthesis through higher N and chlorophyll content in leaves, and ultimately improving nutrient assimilation and nutrient use efficiency.

Keywords: Blueberries, Growth media, Fertilizer, Nitrogen sources, Secondary metabolites

ANNEXURE C: PhD Abstract

ABSTRACT

Changing weather patterns are a major concern worldwide because they affect the availability of natural resources critical to primary agriculture. Water is a natural resource critical to production; however, rising temperatures increase water demand for cultivated crops and, as a result, reduce water availability. The main aim of the study was to evaluate the impact of single growth media on media properties, water conservation, and blueberry yield. A pot experiment was conducted using a randomized complete block design, replicated five times. The growing media treatments comprised of coir, mushroom compost, peat moss, and zeolite. Data on all measured parameters were collected over four years (2022-2025). The data were analyzed using the GLM Procedure in SAS statistical software, and mean separation was performed using Duncan's Multiple Range Test and Fisher's Least Significant Difference. The results of the study showed that blueberry crops cultivated on a growing media combination containing 80% coir and 20% zeolite used less water and had significantly lower ($p<0.05$) than other media throughout the study. The reduction in water use improved the media's water-holding capacity by up to 54% when coir was used exclusively. A media combination containing 60% coir and 40% peat moss improved all yield parameters in both harvesting seasons (2023/2024). The other parameters measured varied depending on the media used.

ANNEXURE D: Published Article under the MSc Study

Journal of Medicinal Plants for Economic Development
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AOSIS

Page 1 of 7 Review Article

Blueberry cultivation under different nitrogen sources: A review

Check for updates

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Background: Global blueberry production has proliferated in recent years, driven by the increasing consumer awareness of its nutritional benefits. Blueberry is considered a rich source of antioxidants, believed to contribute to several health benefits, including maintaining heart health and protecting against cellular damage.

Aim: This review critically evaluated the existing literature on blueberry cultivation using different nitrogen sources and identified research gaps needing further investigation.

Setting: This review provides an overview of blueberry cultivation under different nitrogen sources.

Methods: A literature search for existing information on blueberry cultivation under different nitrogen sources was conducted using online databases via the Cape Peninsula University of Technology (CPUT) library website database.

Results: Findings suggest that nitrogen sources significantly affect the productivity of blueberries, with ammonium producing better results than nitrate. There is a noticeable gap in the literature on how different nitrogen sources influence the biosynthesis of secondary metabolites in blueberries.

Conclusion: The review revealed that there are few research studies on blueberry cultivation under different nitrogen sources. Given the nutritional and antioxidant significance of blueberry secondary metabolites, further research is critical.

Contribution: Information gained can aid in understanding different nitrogen sources of nutrition in blueberries. Insights from this research can inform nitrogen management strategies in blueberry cultivation. This is important for sustaining production trends and ensuring the economic viability of the industry.

Keywords: blueberry; nitrogen sources; fertiliser; phenolic compounds; ammonium.

Introduction

Global blueberry (*Vaccinium* spp.) production has proliferated in recent years, owing to consumers' increased demand for this nutritious fruit (Osorio, Cáceres & Covarrubias 2020). Driven by increasing consumer awareness of nutritional benefits, the worldwide blueberry cultivation area increased significantly from 151 000 tonnes in 2001 to over 1.5 million tonnes in 2021 (Pienaar et al. 2022).

Blueberries are famous for delaying human ageing while providing various health benefits. The antioxidant properties of blueberries protect human health by neutralising free radicals that cause ageing and various diseases, including cancer and cardiovascular disease, as well as immune system deterioration, brain dysfunction and cataracts (Tarkanyi et al. 2019). Nitrogen (N) fertilisation has been shown to influence the accumulation of bioactive compounds, such as phenolics, carotenoids and glucosinolates, in crops, which determines the nutritional value and health benefits of the fruit (Kishorekumar et al. 2020).

Nitrogen is an essential nutrient for plant growth and development, accounting for approximately 50% of yield performance. It is a key component of various metabolic processes in plant physiology involving shoot biomass, root development and N use efficiency (NUE)

Read online:

ANNEXURE E: Conference Proceeding Article under the PhD Study

39th JOHANNESBURG International Conference on "Chemical, Biological and Environmental Engineering" (JCBEE-23) Nov. 16-17, 2023 Johannesburg (South Africa)

Water Requirement of Blueberry Cultivated in Different Growth Media

N Mfeka[1], M Tanga[1], A. R Mulidzi[2] and, F. B Lewu[1],

Abstract—Water scarcity is of great concern because this natural resource is critical in primary agriculture worldwide. The anticipated rise in temperature due to climate change will increase the water demand of plants, thereby reducing water availability. The main aim of this study was to investigate the effects of irrigation requirements on blueberry plants cultivated in different growing media. A pot experiment was conducted using a randomized complete block design that was replicated five times. The following growing media were used: coir, mushroom compost, peat moss, and zeolite. The growing medium significantly ($P<0.05$) affected the irrigation water of blueberry plants. The treatment with 100% coir required the most irrigation replenishment compared with the other treatments. The treatment with 80% coir and 20% zeolite required the least water replenishment. Generally, the vegetative parameters were improved with 60% coir and 40% peat moss. The composition of the growing media can potentially reduce the water requirements of plants.

Keywords— blueberry, water conservation, growth media, production

I. Introduction

Global warming causes climate fluctuations, limited water resources, and water restrictions for agricultural activities, just as it happened in 2015-2017 [2], [6]. Irrigation volume and water use for the agricultural sector are unlikely to increase because the Department of Water and Sanitation (DWS) has capped agricultural allocations to the current level. In addition, a significant reduction in streamflow was predicted for the western region of South Africa, where several Western Cape water management areas are already water-stressed. Hence, improved water usage and productivity in agriculture is a necessity in order to provide the needed water for the projected increased water demand for human consumption and industrial production by 2030 [7]. To overcome these challenges, conservation practices should be implemented with the adaptation of water management [4], [8]. Blueberries are predominantly cultivated in the northern hemisphere and in some other countries of the Southern Hemisphere, such as Chile, Argentina, Uruguay, South Africa, New Zealand, and Australia [9]. In South Africa, the most widely cultivated cultivars are Rabbit Eye, Northern Highbush, and Southern Highbush. The domestic (South Africa) consumption of fresh blueberries increased in the 2016/2017 market year by 80% (800 tons) from 440 tons in the 2015/2016 market year. This was attributed to the increased demand from health-conscious consumers because of the inherent health benefits of blueberries, such as reduction of high cholesterol levels, protection of the heart, and prevention of cancer, among others [10]. Limitations in the availability of natural resources, such as water and soil, as well as management options, hinder the

THE INFLUENCE OF DIFFERENT GROWING MEDIA ON THE MINERAL PROPERTIES OF BLUEBERRY FRUITS

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ABSTRACT
Blueberries are largely grown in media because of the plant's requirement for acidic soils, which is often not attainable in the soil. However, using different growing media influences the chemical composition of blueberries, which essentially influences the overall nutritional content of blueberries as they are mainly consumed fresh. The aim of the study was to evaluate the influence of different growing media combinations on the nutritional content of blueberries. Treatment was comprised of media combination coir, mushroom compost, zeolite, and peatmoss. Berries were hand-harvested during the 2023/2024 harvesting season, and 2.0g per treatment was analyzed for selected macro-micronutrients. Data was captured and examined using SPSS 29.0, and means separation was done using Fisher's LSD test. The media combination significantly influenced primary macronutrients. Treatment 3 obtained the highest P and K percentage; N was highest on T5. The combination of coir, zeolite, and peat moss had the highest Cu content and was significantly different from all treatments. The media significantly influenced micronutrients; notably, T5 had the highest Fe content, T7 had the highest Zn content. An increase in macronutrients was observed for treatments 3, 5, and 6; however, these findings need further investigation.

Keywords: blueberry, growing media, macro and micronutrients.

INTRODUCTION

Blueberry (*Vaccinium corymbosum*) belongs to the Rosaceae family, Fragaria genus, with the wild and

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ANNEXURE F: Flyer

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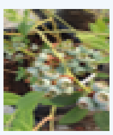
WATER RESEARCH COMMISSION

ARC • LNR

The use of growing media to conserve water on blueberry production

By Prof FB Lewu and Team

2030 Application and productivity in the agricultural sector is necessary to make allowance for the anticipated higher water demand for human use, agricultural and industrial production by



Fresh blueberry consumption has increased worldwide, driven by growing awareness of a healthy lifestyle and the high nutritional and medicinal value of blueberries.

54% Growing media increases water holding capacity & reduces blueberry water use by

80% COIR 20% ZEOLITE This media combination requires 4 litres per day during the active growing season.

Improved use of growth media can be a crucial strategy to reduce water use and improve blueberry production.

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Key findings:
Determination of the field capacity of any growing medium is critical for water conservation. The findings from this study showed that substrate composition plays a critical role in regulating water use, plant growth, nutrient uptake, and fruit quality in blueberry production.
The integration of zeolite with growing media combinations significantly reduced water usage and increased the water-holding capacity of the media.
Water monitoring tools, such as moisture probes, can be used to manage irrigation efficiently to sustain blueberry production.