

INTEGRATED OPTIMIZATION OF SOIL ACIDITY, MULCHING, AND IRRIGATION FOR Highbush Blueberry (*Vaccinium corymbosum* L.) PRODUCTION UNDER HUMID SUBTROPICAL CONDITIONS OF WESTERN GEORGIA

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Abstract. *This study investigates the optimization of agrotechnological practices for highbush blueberry (*Vaccinium corymbosum* L.) cultivation under the humid subtropical conditions of Western Georgia, using Baghdati municipality as a case study during 2021–2024. The research evaluates the combined effects of soil pH regulation, organic mulching, and irrigation management on yield and fruit quality. Results indicate that maintaining soil pH within the optimal range (4.5–5.2), applying organic mulch, and implementing drip irrigation significantly improve productivity. The integrated approach increased yield by 32–41% compared to conventional practices. The findings contribute to sustainable blueberry production strategies in similar agroecological zones.*

Keywords: *blueberry, soil acidity, irrigation, mulching, agrotechnology, Western Georgia*

1. Introduction

Blueberry cultivation has rapidly expanded worldwide due to its high nutritional value and economic importance. The crop is highly sensitive to soil conditions, particularly acidity, organic matter content, and moisture regime [1,4,15].

Blueberries are acidophilic plants that require soil pH between 4.0 and 5.5, with optimal growth observed at 4.5–5.2. Deviations from this range significantly reduce nutrient availability and plant productivity, particularly due to impaired iron uptake and chlorosis [2,13,17].

Western Georgia, characterized by humid subtropical climate and high precipitation, provides favorable conditions for blueberry cultivation. However, excessive rainfall, heavy soils, and unstable pH levels limit productivity. Proper soil management and irrigation strategies are therefore essential [6, 9, 16, 20].

The objective of this study is to optimize agrotechnological practices for blueberry production under regional conditions based on a four-year field experiment (2021–2024).

2. Materials and Methods

2.1 Study Area

The field experiment was conducted during the period 2021–2024 in Baghdati municipality, located in the Imereti region of Western Georgia. The study area is characterized by a humid subtropical climate, which is generally favorable for perennial fruit crops, including highbush blueberry (*Vaccinium corymbosum* L.).

Climatic conditions of the region are defined by relatively mild winters and warm, humid summers. The mean annual precipitation ranges between 1400 and 1800 mm, with the majority of rainfall occurring during the vegetative period. Such conditions ensure adequate water supply for plant growth; however, excessive rainfall often leads to temporary waterlogging and reduced soil aeration, which can negatively affect root development and overall plant productivity.

The soils of the study area are predominantly alluvial and red soils, characterized by moderate to high acidity. Initial soil analysis indicated that soil pH values varied from slightly acidic to moderately acidic conditions, which are generally suitable for blueberry cultivation, although spatial and temporal fluctuations in pH may limit optimal nutrient availability. The soils are also characterized by medium texture and variable organic matter content, influencing their water-holding capacity and nutrient dynamics.

Overall, the agroecological conditions of Baghdati municipality provide a representative model for blueberry production in humid subtropical regions, while also presenting specific challenges related to soil acidity management and moisture regulation.

2.2 Experimental Design

The field experiment was conducted over four consecutive growing seasons using a randomized complete block design (RCBD) with three replications. The experimental layout was established to evaluate the individual and combined effects of key agrotechnological practices on blueberry productivity under local soil-climatic conditions.

Each experimental plot consisted of uniformly established highbush blueberry (*Vaccinium corymbosum* L.) plants of similar age and vigor. Standard agronomic practices, including weed control and pest management, were applied uniformly across all treatments to minimize external variability.

Four treatment variants were investigated:

Treatment	Description
V1	Conventional cultivation practices without soil pH adjustment or mulching
V2	Soil acidification through the application of elemental sulfur
V3	Application of organic mulching (pine bark) to improve soil moisture retention and structure
V4	Integrated treatment combining soil acidification, organic mulching, and drip irrigation

In treatment V2, elemental sulfur was applied to adjust soil pH toward the optimal range required for blueberry growth. Treatment V3 involved the application of organic mulch (pine bark) at a uniform thickness to enhance soil moisture retention, reduce temperature fluctuations, and improve soil structure.

The integrated treatment (V4) combined all the above-mentioned practices, including the installation of a drip irrigation system designed to maintain stable soil moisture conditions throughout the growing season. Irrigation scheduling was adjusted based on soil moisture observations and climatic conditions.

The experimental design allowed for the evaluation of both individual and interactive effects of soil acidity management, mulching, and irrigation on plant growth, yield, and fruit quality.

2.3 Measured Parameters

To evaluate the effects of different agrotechnological treatments on blueberry production, a set of key agronomic, soil, and fruit quality parameters were systematically measured throughout the experimental period.

Yield was determined annually and expressed in tons per hectare (t/ha). The total fruit yield per plot was recorded during the harvesting period and subsequently converted to yield per unit area. This parameter served as the primary indicator of treatment effectiveness.

Fruit weight was measured as the average mass of individual berries (g), based on a representative sample collected from each experimental plot. This indicator was used to assess fruit size and its response to different agrotechnological practices.

Soil pH was monitored periodically using standard potentiometric methods to evaluate the effectiveness of soil acidification treatments and to assess the stability of soil acidity over time. Maintaining optimal pH levels is critical for nutrient availability and plant growth.

Soil moisture content (%) was measured at regular intervals during the growing season using gravimetric methods. This parameter was essential for assessing the impact of mulching and irrigation treatments on water retention and availability in the root zone.

In addition, fruit quality was evaluated based on organoleptic characteristics, including taste, texture, and overall acceptability. These parameters were assessed through sensory evaluation using a standardized scoring system, providing insight into the qualitative effects of the applied treatments.

3. Results

3.1 Soil pH Dynamics

Soil pH dynamics varied significantly among treatments over the experimental period, reflecting the effectiveness of different agrotechnological interventions in regulating soil acidity. In the control treatment (V1), a gradual increase in soil pH was observed, rising from 5.8 in 2021 to 6.2 in 2024. This trend indicates a shift toward less favorable conditions for blueberry cultivation, as values exceeded the optimal range required for acidophilic crops.

In contrast, treatments involving soil acidification demonstrated a consistent decrease in pH values over time. In treatment V2, where elemental sulfur was applied, soil pH decreased from 5.2 in 2021 to 4.7 in 2024, approaching the optimal range for blueberry growth. A similar but less pronounced trend was observed in the mulching treatment (V3), where pH values remained relatively stable within the range of 5.1–5.5 throughout the study period.

The most notable results were obtained in the integrated treatment (V4), which combined soil acidification, organic mulching, and irrigation management. In this variant, soil pH decreased progressively from 5.1 in 2021 to 4.6 in 2024, consistently remaining within or near the optimal range (4.5–5.2) for blueberry cultivation. This indicates that the combined application of these practices not only improved pH adjustment but also contributed to its long-term stabilization.

Overall, the results demonstrate that integrated agrotechnological management is more effective in achieving and maintaining optimal soil acidity compared to single-factor treatments. The observed pH stabilization in V4 is particularly important, as it directly influences nutrient availability and root system functioning, ultimately affecting plant productivity.

Table 1. Soil pH dynamics under different treatments (2021–2024)

Year	V1	V2	V3	V4
2021	5.8	5.2	5.5	5.1
2022	6.0	5.0	5.3	4.9
2023	6.1	4.8	5.2	4.7
2024	6.2	4.7	5.1	4.6

3.2 Yield Performance

Significant differences in yield were observed among the experimental treatments over the four-year study period, clearly demonstrating the impact of agrotechnological practices on blueberry productivity.

In the control treatment (V1), yield increased only slightly over time, from 6.5 t/ha in 2021 to 7.2 t/ha in 2024, indicating limited improvement under conventional management practices. This relatively low productivity reflects suboptimal soil and moisture conditions, particularly in the absence of pH regulation and mulching.

The application of soil acidification (V2) resulted in a noticeable increase in yield compared to the control, reaching 9.8 t/ha by 2024. This improvement can be attributed to enhanced nutrient availability under more favorable soil pH conditions.

Similarly, organic mulching (V3) had a positive effect on yield, which increased from 8.2 t/ha in 2021 to 10.5 t/ha in 2024. The improved performance in this treatment is likely associated with better soil moisture retention and improved soil structure, which support root development and nutrient uptake.

The highest yield values were consistently recorded in the integrated treatment (V4), where soil acidification, mulching, and irrigation were combined. Yield in this treatment increased from 9.5 t/ha in 2021 to 13.5 t/ha in 2024, representing the most substantial improvement among all variants.

Overall, yield improvement in the integrated treatment (V4) reached 32–41% compared to the control (V1), confirming the effectiveness of combined agrotechnological management. The results clearly indicate that while individual practices contribute to yield enhancement, their integration produces a synergistic effect, leading to significantly higher productivity.

Table 2. Yield performance under different treatments (t/ha)

Year	V1	V2	V3	V4
2021	6.5	7.8	8.2	9.5
2022	6.8	8.5	9.0	11.2
2023	7.0	9.2	10.1	12.8
2024	7.2	9.8	10.5	13.5

3.3 Effect of Mulching and Irrigation

The application of organic mulching and drip irrigation had a pronounced effect on soil physical properties and plant performance, contributing significantly to the observed yield improvements.

Organic mulching (V3 and V4) enhanced soil structure by increasing porosity and improving aeration in the root zone. In addition, mulch application contributed to higher soil moisture retention, reducing fluctuations in water availability during the growing season. This effect is particularly important under the humid subtropical conditions of Western Georgia, where irregular rainfall distribution and periods of excessive moisture can negatively impact root function.

Mulching also played a critical role in reducing surface evaporation and stabilizing soil temperature, thereby creating a more favorable microenvironment for root development. Improved microbial activity under mulched conditions further supported nutrient cycling and availability, which are essential for sustained plant growth.

Drip irrigation, applied in the integrated treatment (V4), ensured a controlled and consistent supply of water directly to the root zone. This approach minimized the risks associated with both water deficit and waterlogging, conditions to which blueberry plants are highly sensitive. The regulation of soil moisture through drip irrigation maintained optimal conditions for nutrient uptake and physiological processes.

The combined application of mulching and irrigation in V4 resulted in a synergistic effect, leading to improved plant growth, enhanced soil conditions, and ultimately higher yield compared to single-factor treatments. These findings highlight the importance of integrated water and soil management strategies in optimizing blueberry production.

3.4 Graphical Representation of Results

To facilitate the interpretation of experimental results, graphical representations were developed to illustrate the relationships between treatments, soil properties, and yield performance.

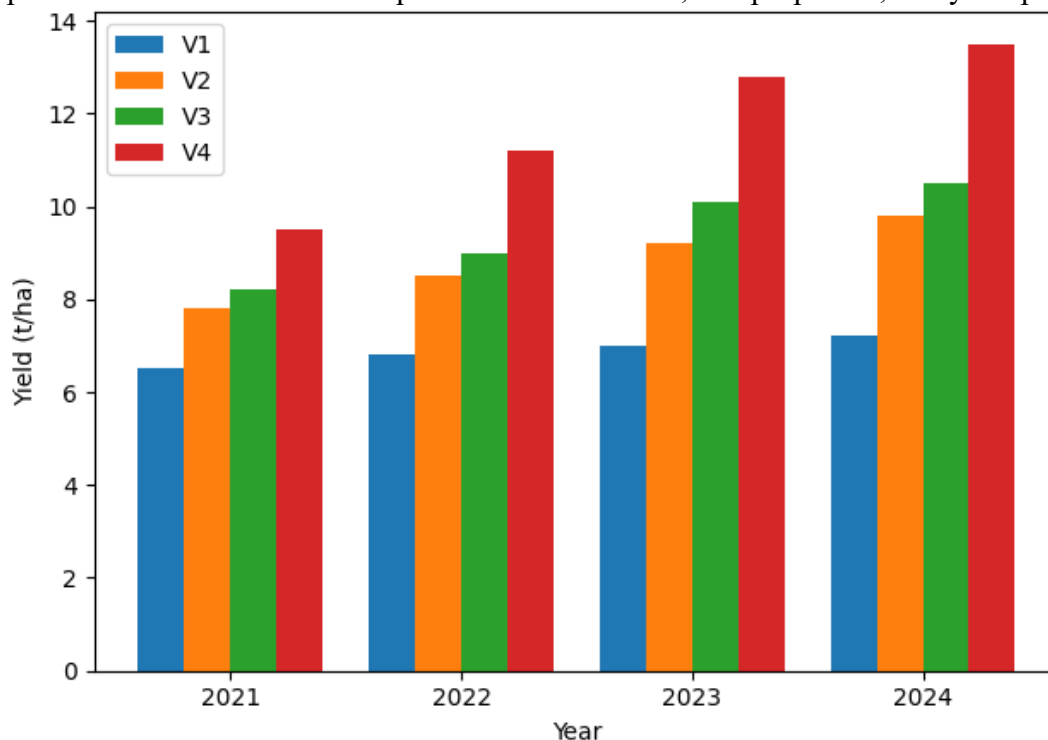
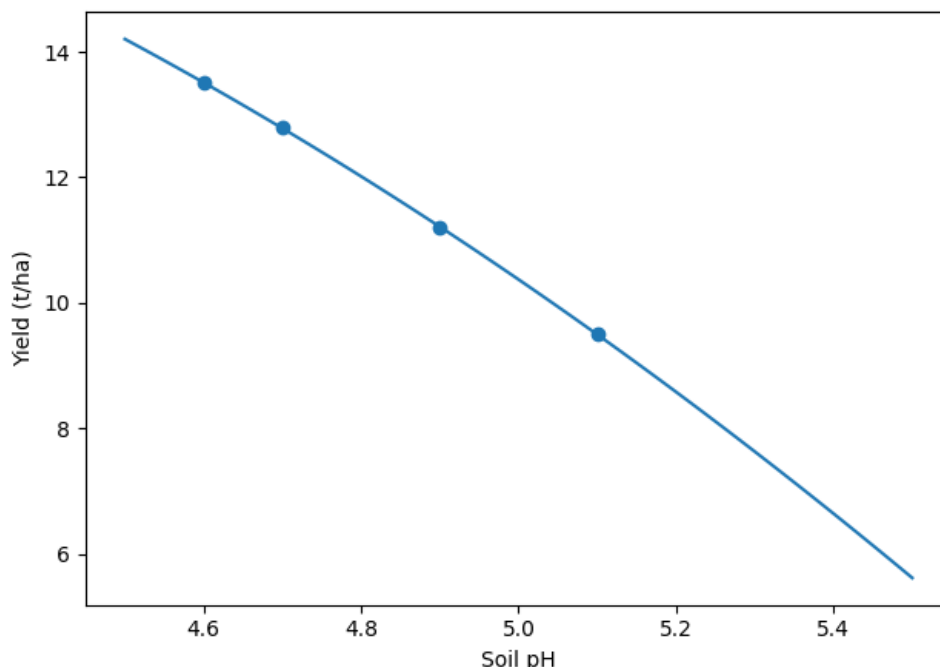


Figure 1. Yield dynamics under different treatments (2021–2024)

This figure presents a bar chart illustrating the variation in yield across treatments (V1–V4) over the four-year period. The graph clearly demonstrates a consistent increase in yield from the control treatment (V1) to the integrated treatment (V4), highlighting the effectiveness of combined agrotechnological practices.

**Figure 2. Relationship between soil pH and yield**

This figure shows a non-linear regression relationship between soil pH and blueberry yield. The curve indicates that maximum yield is achieved within the pH range of 4.5–5.2, while deviations from this optimal range result in a noticeable decline in productivity. This relationship confirms the critical role of soil acidity in regulating nutrient availability and plant performance.

4. Discussion

The results of the present study clearly demonstrate that soil acidity is a key determinant of blueberry productivity under humid subtropical conditions. The progressive increase in soil pH observed in the control treatment (V1) led to suboptimal conditions for plant growth, confirming that even slight deviations from the optimal pH range can negatively affect nutrient availability and uptake [2, 17, 18]. This finding is consistent with previous studies, which have shown that elevated soil pH reduces the availability of essential micronutrients such as iron and manganese, leading to impaired physiological processes and reduced yield [7, 13, 14].

The application of soil acidification (V2) significantly improved growing conditions by maintaining pH values closer to the optimal range. However, the results also indicate that pH regulation alone is not sufficient to achieve maximum productivity, as yield increases in this treatment remained lower compared to the integrated approach [8, 19].

Organic mulching (V3) contributed to improved soil physical properties, including enhanced moisture retention, reduced evaporation, and better soil aeration. These effects are particularly important in regions with high precipitation, where fluctuations in soil moisture and temporary waterlogging can negatively impact root function [18]. In addition, increased microbial activity under mulched conditions likely enhanced nutrient cycling and availability, further supporting plant growth [16, 18].

The integrated treatment (V4) demonstrated the highest effectiveness, highlighting the importance of combining multiple agrotechnological practices. The simultaneous regulation of soil pH, improvement of soil structure through mulching, and stabilization of soil moisture via drip

irrigation created optimal conditions for root development and nutrient uptake. The observed synergistic effect resulted in significantly higher yield compared to individual treatments [9, 15].

These findings are in agreement with previous research emphasizing the importance of soil management and organic amendments in blueberry cultivation. However, the present study extends existing knowledge by providing a comprehensive evaluation of the combined effects of key agronomic factors under specific regional conditions. The results underline the necessity of adopting integrated management strategies rather than relying on single-factor interventions.

5. Conclusion

The results of this study confirm that the optimization of agrotechnological practices plays a decisive role in improving blueberry productivity under the soil-climatic conditions of Western Georgia.

The findings indicate that maintaining soil pH within the optimal range of 4.5–5.2 is essential for ensuring adequate nutrient availability and plant growth. In addition, the application of organic mulching significantly enhances soil moisture retention, improves soil structure, and supports biological activity in the root zone. The use of drip irrigation further contributes to stabilizing soil moisture conditions, preventing both water deficit and excess moisture stress.

The integrated application of these practices resulted in a substantial increase in yield, reaching up to 41% compared to conventional management. This demonstrates that the combined effect of soil acidity regulation, mulching, and irrigation is significantly more effective than individual treatments.

From a practical perspective, the integrated system (V4) can be recommended as an efficient and sustainable approach for blueberry cultivation in humid subtropical regions. The adoption of such practices will contribute to increased productivity, improved fruit quality, and better resource use efficiency.

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