Scientific Papers. Series B, Horticulture. Vol. LXX, No. 1, 2026
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

EVALUATION OF AGRONOMIC PERFORMANCE OF ARONIA SHRUBS UNDER THE IMPACT OF DIGITAL TECHNOLOGY INTEGRATION IN BISTRITA AREA

Anca Maria CHIOREAN[1], Zsolt JAKAB- ILYEFALVI[1], Georgeta Maria GUZU[1], Claudiu MOLDOVAN[1], Adrian ASĂNICĂ[2]

[1]Fruit Research & Development Station Bistrita, 3 Drumul Dumitrei Nou Street, Bistrita, Romania
[2]University of Agronomic Sciences and Veterinary Medicine of Bucharest, Faculty of Horticulture, 59 Mărăşti Blvd, District 1, Bucharest, Romania

Corresponding author email: ancasofron09@gmail.com

Abstract

This study evaluates the integration of digital technologies and their direct impact on the agronomic performance of Aronia shrubs, a crop increasingly valued for its nutraceutical properties. The real-time data analytics facilitated early detection of hydric stress, preventing productivity losses common in conventional management while maintaining an optimal fruit nutritional composition. The management of technological factors not only improves the physiological vigour of Aronia plants but also ensures their economic sustainability within the plantation. This optimization highlights a significant improvement in resource-use efficiency, crucial for adapting to climate variability. By quantifying the correlation between sensor-derived metrics and agronomic performance, the study validates digital tools as essential for risk mitigation. This research provides a model for transitioning from traditional aronia berry cultivation to a data-driven, high-performance horticultural system, offering a framework for producers aiming to maximize both environmental responsibility and commercial profitability in modern berry crops.

Key words: *Aronia melanocarpa, precision agriculture, IoT sensors, agronomic yield, digital workflows.*

INTRODUCTION

Precision agriculture is the fundamental element of the digital shift in modern horticulture, moving from basic field management to site-specific treatments based on real-time data analytics (Gebbers & Adamchuk, 2010). This development reflects a broader industrial revolution within the horticultural sector, characterized by the substitution of empirical intuition with data-driven management to optimize operational performance (Zambon et al., 2019). In the context of a global transition toward sustainable and nutrition-oriented fruiting shrub growth, the cultivation of *Aronia melanocarpa* has gained remarkable popularity among Romanian producers, even in Bistrita County. Due to its extraordinary profile of bioactive compounds, including antioxidants, polyphenols, and vitamins, aronia berries have transitioned into a robust and economically competitive alternative to conventional fruit species (Konecka & Jablonska-Rys, 2021). The increasing market demand for these health-promoting properties has consolidated the crop position as a high-value functional food source (Sidor & Gramza-Michałowska, 2019).

This expansion is supported by the shrub's natural resistance to low temperatures and pests, characteristics that align perfectly with the specific pedoclimatic conditions of the Transylvanian plateau.

The agronomic performance of these plantations no longer depends solely on natural factors, but increasingly on the farmers' ability to integrate digital technologies (Segarra et al., 2020). The modernization of the fruit growing sector is undergoing a critical transformation, from intuition-based management to one grounded in data-driven precision (Mulla, 2013; Bacco et al., 2019).

While small farms maintain conventional methods, an increasing number of medium and large farms in established fruit-growing basins have begun adopting Smart Farming solutions such as IoT monitoring systems for water resource management; satellite remote sensing for evaluating vegetation indices; and digital weather stations capable of issuing frost alerts and droughts, a phenomenon with a major

impact on the local microclimate (Balafoutis et al., 2017; Ferrández-Pastor et al., 2018).
The integration of these technologies represents not only a competitive advantage but a necessity to optimize yield per unit area and ensure consistent fruit quality under conditions of increasing climatic variability (Chira et al., 2020). The present study`s aim is to perform a comparative evaluation of the 2024 and 2025 growing seasons and how these digital tools influence the agronomic performance of aronia crop in the Bistrița area, providing a perspective on technological efficiency in modern horticulture.

MATERIALS AND METHODS

The research was conducted in an aronia plantation located in Bistrita-Nasaud County, latitude 47°08′20″N longitude 24°30′01″E. The study was carried out on plot T26/2L at the Fruit Research and Development Station Bistrița. The region is characterized by a moderate continental climate, with an average annual temperature of 9.91°C. This represents an increase of nearly 1.6°C above the historical annual average recorded in the last 25 years. Additionally, the mean annual precipitation stands at 650 mm. The experimental shrubs plot covers in total of 1.024 ha, with the aronia crop situated on a 0.18 ha sub-plot, representing 18.08% of the total area (Figure 1).



Figure 1. The experimental plot of shrubs from FRDS Bistrita

The biological material consisted of four chokeberry cultivars: 'Nero', 'Melrom', 'Viking', and 'Galicjanka'. The first two were established in 2020, while the remaining two were added in 2022 to complete the collection using 2-year-old potted plants. Randomized block design with three replicates was used, with plant spacing of 4 m x 1.5 m (1,667 plants/ha), each cultivar included 63 plants. Data interpretation was based on a comparative assessment of plant and fruit biometric parameters (canopy volume, total yield, and plant height) integrated with fruit measurements, to evaluate performance over the study period.
Environmental monitoring was performed using a nMetos 80 SM autonomous mini weather station (Pessl Instruments, Austria). The device recorded soil parameters (moisture and temperature at 40 cm) and microclimate data (air temperature, relative humidity, dew point, vapor pressure deficit VPD) in 15-minute increments. Real-time data telemetry was achieved through NB-IoT connectivity, with all parameters stored and processed via the Field Climate cloud.

RESULTS AND DISCUSSIONS

The data collected by the nMetos 80 SM station revealed significant inter-annual climatic variability in the Bistrita area regarding meteorological parameters that has been monitored during the first nine months of 2024 and 2025. While both years align with the global warming trend, the analysis highlights a transition from an extreme thermal regime (2024) to a precipitation regime characterized by severe instability, featuring extreme drought followed by hydric excess (2025) (Figure 2).

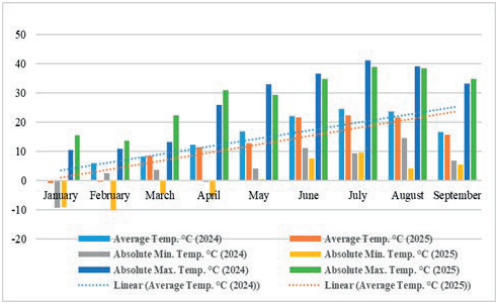


Figure 2. Monthly average of air parameters in 2024-2025 season

The year 2024 was marked by critical thermal stress in July, reaching an absolute maximum temperature of 41.2°C. In contrast, 2025 exhibited early thermal aggression. Although the monthly averages were relatively similar, the thermal amplitude in April 2025 was remarkable; an absolute maximum of 30.8°C

(typical of a summer day) was followed by a severe frost of -5.5°C.

This rapid alternation in 2025 indicates a high physiological risk for crops. The early onset of vegetation induced by high temperatures in March and early April was abruptly interrupted by frost; a phenomenon that was much milder in 2024 (-0.64°C).

The most significant difference between the two years lies in the rainfall distribution. Although the cumulative total in 2025 through September (647.4 mm) is higher than that of 2024 (552.6 mm), water-use efficiency was likely lower in 2025 due to non-uniform distribution. Critical deficit (June) recorded in 2024 provided optimal hydration with 107.8 mm. In 2025, the same period recorded a historical minimum of only 5.6 mm, triggering extreme pedological drought during the critical development phase of aronia berries. August 2025, brought a massive influx of 167.4 mm, compared with only 40.6 mm in 2024. This volume, while high, often stems from convective events (storms), which can cause erosion without fully compensating for the drought stress accumulated in June (Figure 3).

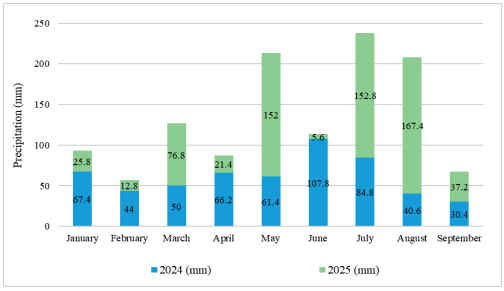


Figure 3. Monthly average of rainfall in 2024-2025 season

The data comparison reveals that 2024 was a year dominated by extreme summer thermal stress, whereas 2025 was defined by hydric instability and spring temperature shocks. For agricultural management, the data suggests that in 2025, irrigation systems were vital in June, whereas in 2024, the primary need was heat protection during the July peaks. These fluctuations underscore the necessity of adopting resilience strategies based on real-time monitoring of Vapor Pressure Deficit (VPD) and soil moisture.

The monitoring period (2024-2025) based on soil and air sensor data, revealed significant inter-annual variations in atmospheric moisture. In 2024, the mean relative humidity during the growing season (May-September) remained below 60%, with a minimum of 56.11% recorded in May. This correlated with a high VPD who reached a maximum of 1.64 kPa in July 2024 (Table 1).

In contrast, the 2025 season exhibited higher atmospheric humidity, reaching a maximum monthly average of 78.00% in May. Consequently, the VPD values in 2025 were substantially lower, with the lowest recorded mean of 0.43 kPa in May and a seasonal peak of only 1.30 kPa in June.

Soil water tension, measured via Watermark sensors (kPa), showed divergent trends between the two years. The 2024 season was characterized by progressive, severe drying of the soil profile. Values increased from 66.88 kPa in May to a seasonal maximum of 178.86 kPa in August, indicating extreme matric suction. Conversely, the 2025 season started with near-saturation levels in March (0.01 kPa), while the soil tension increased during the summer months, reaching a maximum of 84.76 kPa in July.

Table 1. Digital footprint of climate resilience of aronia plants

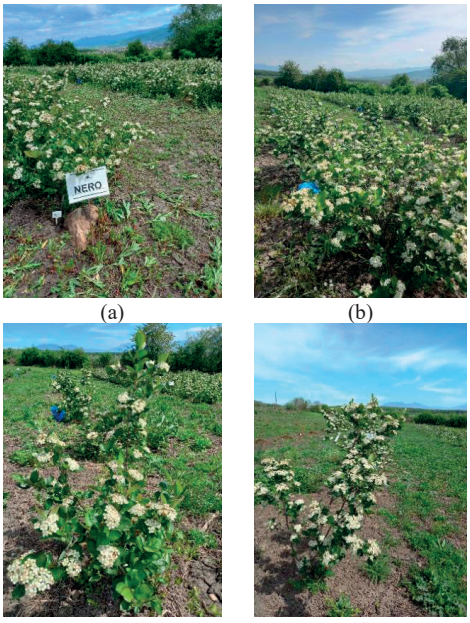
Parameter	2024	2025	Sensor Utility
Maximum soil tension (kPa)	178.86 Critical	84.76 Optimal	Irrigation needs/Soil moisture
Minimum air humidity (%)	56%	78%	Air moisture stress
Maximum VPD	1.64 kPa	1.30 kPa	Transpiration Control
2024 vs 2025	Critical stress	Favorable Growth	Irrigation necessity

Growth indicators for 2025 reveal distinct adaptive responses to improved environmental conditions (reduced water stress). All cultivars increased in height. 'Nero' showed the highest growth rate (+22%, reaching 111 cm), while 'Melrom' remained the tallest (113 cm).

'Viking' surpassed 100 cm, whereas 'Galicjanka' maintained a compact habit (75 cm).

In terms of canopy volume, 'Melrom' (0.795 m^3) and 'Nero' (0.775 m^3) exhibited the highest soil coverage and branching density. In contrast, 'Galicjanka' experienced a slight volume reduction following pruning intended to

stimulate compaction, while 'Viking' recorded the lowest volume in the plot (0.103 m^3). 'Nero' and 'Melrom' dominated with >20 shoots/plant. 'Galicjanka' remained stable (10 shoots), while 'Viking' improved but stayed below average (8 shoots) (Figure 4).



(a) (b)

(c) (d)

Figure 4. The four aronia cultivars' bush shape: (a) 'Nero'; (b) 'Melrom'; (c) Galicjaka; (d) 'Viking'

The distinct shift in pedoclimatic conditions between the two years (2024-2025) directly dictated the vegetative performance and adaptability of the cultivars (Table 2).

Table 2. Vegetative growth dynamics by cultivar

Cultivar	**Height dynamics**	**Volume dynamics**	**Branching status (2025)**
'Nero'	Sharp increase (+20 cm)	Stable/ Increasing	Very high (>20)
'Melrom'	Consistently high	Maximum (0.795 m^3)	Very high (>20)
'Viking'	Moderate growth	Low (0.103 m^3)	Medium (8)
'Galicjanka'	Consistently low	Stable/ Increasing	Medium (10)
Top cultivar vigor	Moderate growth	Max (>20 shoots)	Performance tracking

The correlation between biometric data, yield performance, and environmental monitoring confirms that atmospheric and soil moisture levels, alongside extreme weather events, were the primary drivers of growth and fruit quality throughout the study. In 2024, the cultivars faced a highly restrictive environment defined by low relative humidity, high VPD (Vapor Pressure Deficit, kPa) and extreme soil suction, while emergency manual water tank applications were used to mitigate the drought in the absence of a permanent irrigation system, a severe hail event in 2024 significantly compromised season output.

This mechanical damage, combined with environmental stress, resulted in minimal yields of approximately 1 kg for 'Nero' and 'Melrom' and only 0.370 kg and 0.230 kg for the 'Viking' and 'Galicjanka' cultivars. Furthermore, the surviving fruits in 2024 were visibly dehydrated and compromised in quality as the plants struggled to maintain turgor pressure under high atmospheric demand (Figure 5).



Figure 5. Impact of hail (2024) on fruit quality

The favorable conditions in 2025 marked by higher humidity, lower VPD, and near-saturated soil, triggered a substantial recovery. This environmental shift, coupled with the absence of extreme weather, allowed for optimal fruit hydration and quality in 2025 (Figure 6).



Figure 6. Aronia fruits in 2025 season

'Melrom' and 'Nero' demonstrated exceptional phenotypic plasticity, capitalising on the improved moisture levels to reach canopy volumes and a dominant productivity of 4.49 t/ha (56.62 kg) and 3.33 t/ha (42.31 kg), respectively. In contrast, 'Galicjanka' and 'Viking' maintained stable, compact habits with significantly lower 2025 yields, averaging 0.61 t/ha.

Evaluating the agronomic performance of aronia crops requires a rigorous comparative analysis of biometric and physico-chemical characteristics across multiple vegetation cycles. In this context, the present study introduces comparative data obtained during the 2024 and 2025 seasons for four representative varieties: 'Nero', 'Melrom', 'Viking', and 'Galicjanka'. The analysed parameters, such as fruit diameter, average weight, and soluble solids content (SSC), highlight not only the productive potential of each genotype but also their adaptability to annual climatic variations, providing essential indicators for optimising harvest timing and production quality. The following tables present the evolution of these indicators, providing a baseline for evaluating the productivity and sensory quality of each cultivar (Table 3).

Table 3. Morphological and quality characteristics of aronia fruits in 2024 vs. 2025

Cultivars	Year	Fruit weight (g)	Weight of 100 fruits (g)	Fruit Ø (mm)	SSC °Brix
Nero	2024	0.60	51.00	6.40	**27.00**
	2025	**0.90**	**85.00**	**10.07**	20.15
Melrom	2024	0.75	54.00	6.72	**26.50**
	2025	**0.95**	**90.00**	**10.14**	21.10
Viking	2024	0.85	69.50	7.83	**26.50**
	2025	**0.86**	**80.00**	**10.14**	21.10
Galicjanka	2024	0.85	60.00	7.25	**26.50**
	2025	0.85	**80.00**	**10.11**	21.12

The 2024-2025 comparative study of aronia cultivars reveals a significant morphological shift, with 2025 characterised by a "size explosion" where all varieties exceeded the 10 mm diameter threshold. 'Nero' exhibited the most dramatic evolution, increasing its mean diameter from 6.4 mm to 10.07 mm and its average weight by 50% (0.60 g to 0.90 g). While 'Melrom' emerged as the 2025 leader in mass (0.95 g/fruit and 90 g/100 fruits), the 'Viking' cultivar maintained a consistent mass (0.85 g to 0.86 g) despite a significant increase in diameter, indicating a reduction in fruit density during the 2025 season. A clear inverse correlation was identified between fruit volume and quality, as the average Soluble Solids Content (SSC) decreased from 26.6° Brix in 2024 to 20.8° Brix in 2025, indicating a dilution effect likely caused by higher hydration. Ultimately, the substantial increase in the mass of 100 fruits reaching up to 90 g in 2025 compared to the 51- 69.5 g range in 2024 confirms that 2025 was a superior year for gross biomass yield, whereas 2024 favored high-concentration processing. This inter-annual variability underscores the strong influence of environmental factors on aronia productivity and fruit chemical composition.

The integration of soil and air sensors proved essential in quantifying how the transition from the restrictive, hail-damaged 2024 season to a favorable 2025 environment not only drove a 22% growth surge but also restored commercial viability, shifting from the dehydrated, minimal yields of the first year to the high-quality production of the second.

These results highlight that integrating soil and air sensors via a weather station is a critical tool for precision agricultural management, particularly in the absence of automated irrigation systems. The sensors provided the necessary data to quantify this stress, while the manual watering reduced the drought's impact; the high VPD still forced plants to prioritize survival over expansion. The integration of these sensors allows for a direct correlation between environmental dynamics and biometric output, proving that even with manual interventions, shrub vigor remains a measurable indicator of environmental resource efficiency and the limitations of non-automated water management.

CONCLUSIONS

The integration of these digital tools allowed for a precise environmental monitoring of the aronia experimental plot regarding drought and provided the needed technological management through precise irrigation. The sensors proved essential for real-time stress detection, providing a robust technological framework for optimizing horticultural management in the Bistrița region.

The study highlights a climatic evolution from extreme heat in 2024 (41.2°C) to severe hydric

instability in 2025, where June precipitation recorded a historical minimum of 5.6 mm. Digital sensors were vital for monitoring soil tension, which reached a critical 178.86 kPa in 2024, and VPD levels that peaked at 1.64 kPa.

'Melrom' and 'Nero' proved to be the most resilient cultivars, achieving dominant 2025 yields of 4.49t/ha and 3.33t/ha respectively, while showing superior growth with over 20 shoots per plant. In contrast, 'Viking' and 'Galicjanka' showed slower adaptability, averaging yields of only 0.61t/ha.

This study demonstrates the efficiency of real-time data acquisition in identifying critical water stress thresholds and validates the role of sensor-based monitoring as a strategic tool for optimizing irrigation management and crop resilience under fluctuating climatic conditions.

ACKNOWLEDGEMENTS

This research work was carried out with the support of the Ministry of Agriculture and Rural Development, Project ADER 6.1.3/2023 and the Fruit Research and Development Station (FRDS) Bistrita.

REFERENCES

Bacco, M., Berton, A., Ferro, E., Gennaro, C., & Gotta, A. (2019). Smart farming: Opportunities, challenges and technology enablers. 2019 IEEE 5th World Forum on Internet of Things (WF-IoT), 537-542.

Balafoutis, A., Beck, B., Fountas, S., Vangeyte, J., & Walcher, J. (2017). Precision Agriculture Technologies Positively Contributing to Sustainability of Energy, *Water and Land Resources. Sustainability*, 9(7), 1239.

Chira, A., Chira, L., & Delian, E. (2020). The current state and perspectives of Romanian fruit growing in the context of climate change. *Scientific Papers. Series B. Horticulture, LXIV*(1), 45-52.

Ferrández-Pastor, F. J., García-Chamizo, J. M., Nieto-Hidalgo, M., & Mora-Pascual, J. (2018). Precision agriculture design, developed using IoT, Big Data and cloud computing. *Applied Sciences*, 8(8), 1369

Gebbers, R., & Adamchuk, V. I. (2010). *Precision agriculture. Science*, 327(5967), 828-831. https://doi.org/10.1126/science.1183899

Konecka, K., & Jablonska-Rys, E. (2021). Aronia melanocarpa (Michx.) Elliott – A review of its cultivation, chemical composition, and health-promoting properties. *Journal of Fruit and Ornamental Plant Research*, 29(1), 5-22.

Mulla, D. J. (2013). Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps. *Biosystems Engineering*, 114(4), 358-371.

Sidor, A., & Gramza-Michałowska, A. (2019). Black chokeberry (Aronia melanocarpa L.) and its products as a rich source of bioactive compounds: Reasons for a wider use. *Foods*, 8(10), 501.

Segarra, J., Buchaillot, M. L., Araus, J. L., & Kefauver, S. C. (2020). Remote sensing for precision agriculture: Sentinel-2 improved multispectral methods for greenhouse and open field cultivars. *Plant Methods*, 16(1), 1-15.

Zambon, I., Cecchini, M., Egidi, G., Saporito, M. G., & Colantoni, A. (2019). Revolution 4.0: Industry vs. Agriculture in a Future Development for SMEs. *Processes*, 7(6), 36.