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Harnessing digital and omics technologies for precision fertilization of cranberries in Quebec: A pathway to sustainable agriculture

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Abstract

Cranberry cultivation in Quebec faces significant challenges in nutrient management due to the introduction of new varieties with unknown nutritional needs. Traditional fertilization practices often lead to over-fertilization, escalating both economic costs and environmental degradation. This review discusses how digital and omics technologies can revolutionize cranberry cultivation by optimizing Nitrogen Use Efficiency (NUE) and ensuring precise nutrient management. The integration of genomics, proteomics, and metabolomics insights with real-time monitoring systems offers a sustainable pathway to enhance productivity while reducing the environmental impact.

Keywords: Nitrogen Use Efficiency (NUE), digital technologies, Omics technologies, genomics, proteomics, metabolomics

Introduction

Precision agriculture represents a revolutionary shift in cranberry cultivation, particularly for high-value varieties such as Crimson Queen, DeMoranville, and Mullica Queen, predominantly grown in Quebec, Canada. These varieties have distinct nutrient and water requirements that traditional farming methods have struggled to address, often resulting in inefficient fertilizer use, environmental degradation, and suboptimal yields. Precision agriculture leverages cutting-edge digital technologies, including IoT sensors, drones, GIS mapping, and data analytics, alongside omics approaches such as genomics and metabolomics, to create a more nuanced understanding of crop needs. By integrating real-time data with predictive modeling, this paradigm enables farmers to apply nutrients and water more precisely, minimizing waste and environmental impact while maximizing crop health and productivity. As a result, precision agriculture holds the potential to enhance sustainability and profitability in cranberry farming by aligning agronomic practices with the specific requirements of each variety and their unique growing conditions.



The cranberry cultivation challenge in Quebec

Quebec's cranberry industry is grappling with two critical issues

- **Environmental impact:** Overuse of fertilizers, especially nitrogen and phosphorus, has led to soil degradation and water pollution, notably phosphorus runoff.
- **Economic inefficiency:** High fertilizer costs without proportional yield increases strain profitability.

Nutrient recommendations in Quebec typically range from

- **Nitrogen (N):** 22-56 kg/ha, primarily for vegetative growth.
- **Phosphorus (P):** 11-22 kg/ha, focused on root development.

Treatment	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)	Organic manure (t/ha)	Objective
T ₁	40	15	70	8	Standard fertilization
T ₂	30	15	70	8	Reduced nitrogen
T ₃	25	10	60	10	Higher organic manure
T ₄	35	12	85	8	Increased potassium
T ₅	40	11	70	9	Reduced phosphorus
T ₆ (Control)	0	0	0	10	Organic manure only

These treatments aim to evaluate NUE, environmental impact, and cost efficiency.

Plant and soil nutrient analysis

Nutrient uptake will be measured using established methods:

- **Nitrogen:** Modified Kjeldahl method.
- **Phosphorus:** Molybdophosphoric blue color method.
- **Potassium:** Wet digestion.

Soil samples will be analyzed for pH, organic carbon, and available NPK content using techniques like the Olsen method and flame photometry.

Digital and omics technologies: A new horizon in cranberry cultivation

Real-time monitoring with digital tools

- **Drones and sensors:** Monitor soil moisture, nutrient levels, and plant health in real-time.
- **Predictive analytics:** Use historical and real-time data to forecast nutrient requirements, enabling timely adjustments to fertilizer applications.

Omics technologies for molecular-level insights

- **Genomics:** Identify cranberry varieties with superior NUE traits, facilitating the development of low-input, high-yield varieties.
- **Proteomics and metabolomics:** Investigate nutrient metabolism pathways, offering insights into nitrogen interaction with other nutrients and enhancing fertilizer formulation.

Nitrogen Use Efficiency (NUE): A key metric for success

NUE quantifies the efficiency of nitrogen input conversion into crop yield, calculated as:

$$\text{NUE} = \frac{\text{Crop Yield (Kg/ha)}}{\text{N applied (Kg/ha)}}$$

Improving NUE can simultaneously increase productivity and reduce environmental impact. Factors such as soil type,

- **Potassium (K):** 56-90 kg/ha, enhancing fruit development and plant resilience.

However, these blanket recommendations often fail to consider site-specific variability, necessitating a shift towards precision fertilization.

Methodology: Optimizing fertilization through digital and omics integration

Proposed treatment designs

A comprehensive experimental design using a Randomized Complete Block Design (RCBD) is recommended to mitigate environmental variability and ensure reliable comparisons. The following treatments (T) are proposed:

climatic conditions, and fertilization timing are critical in NUE optimization.

Expected outcomes and benefits

1. **Enhanced crop yield:** Improved NUE will lead to higher yields without increasing nitrogen input.
2. **Cost reduction:** Efficient nutrient use will lower fertilizer expenses, enhancing profitability.
3. **Sustainability:** Reduced nitrogen runoff and minimized environmental footprint will promote long-term ecological balance.

Conclusion: The future of sustainable cranberry farming

The integration of digital tools and omics technologies in cranberry cultivation is a groundbreaking step towards sustainable agriculture. By enabling precise, data-driven nutrient management, these innovations promise to enhance productivity, reduce costs, and protect the environment, making Quebec a leader in sustainable cranberry farming.

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