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RETRO-INNOVATION IN BIODYNAMIC AGRICULTURE: BRIDGING TRADITIONAL WISDOM AND SMART TECHNOLOGIES FOR SUSTAINABLE FARMING

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ABSTRACT

Integrating retro-innovation and smart technologies in biodynamic agriculture offers a promising pathway to sustainable farming. Retro-innovation combines traditional wisdom with modern advancements, while biodynamic agriculture offers a holistic approach to cultivation. Smart technologies, including IoT sensors, AI, drones, and blockchain, enhance precision and efficiency in farming practices. However, implementing these technologies in biodynamic agriculture presents challenges, including philosophical conflicts, infrastructure limitations, and cultural resistance. Despite these obstacles, the synthesis of traditional methods and modern technology through retro-innovation shows promise in creating resilient, sustainable agricultural systems. This integration has the potential to address contemporary challenges such as climate change and resource scarcity while preserving valuable traditional practices. Successful implementation requires interdisciplinary collaboration, policy support, and education to bridge the gap between traditional wisdom and technological innovation in agriculture.

Keywords: Retro-Innovation, Biodynamic Agriculture, Smart Farming Technologies, Traditional Farming Practices, Agricultural Sustainability.

1. INTRODUCTION

Innovation is the use of new ideas, products, services, or methods where they have not been utilized before. It involves introducing new or significantly improved products (goods or services) to the market or implementing new or improved processes within an enterprise (EUROSTAT Glossary EC). Innovation activities include all scientific, technological, organizational, financial, and

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commercial steps that lead, or are intended to lead, to the implementation of innovations (Rezk et al., 2015).

Agricultural innovation is defined as the process whereby individuals or organizations bring existing or new products, processes, and forms of organization into social and economic use to increase effectiveness, competitiveness, resilience to shocks, or environmental sustainability, thereby contributing to food and nutritional security, economic development, and sustainable natural resource management (Tropical Agriculture Platform, 2016; Owino, 2024). Successful agricultural innovation relies on domestic resources, expertise, collaboration, and strategic engagement to generate, evaluate, adapt knowledge, scale technologies, and drive social change, ensuring long-term improvements in agricultural systems (Tropical Agriculture Platform, 2016). Agricultural innovation, through advanced technologies, sustainable practices, and supportive policies, addresses global challenges while promoting resilient, sustainable farming systems.

Retro-innovation is defined by the active consideration of a time in the past, which provides inspiration for alternative solutions to contemporary problems (Zagata et al., 2020). It is essentially based on a combination of the old (tradition) and new (modernity) practices. This approach involves reminiscence and the revival of long-forgotten methods, which are then purposefully selected and adapted to meet current needs. Integration plays a key role, blending old practices with modern resources and contexts to create viable solutions. Retro-innovation is the purposeful revival of historic practices, implying hybridizing them with new ideas to ground them in modernity (Meunier, 2024). The success of retro-innovation depends on the learning process, which includes reviving historical practices and merging them with present-day technologies and requirements. Chunduri (2013) categorizes retro-innovation into three types: replicating past products for nostalgia, fulfilling emotional needs tied to the past, and addressing old needs with new methods. His research highlights the broader relevance of retro-innovation across industries, emphasizing technology's role in bridging past and present. León-Bravo et al. (2019) also consider technology inseparable from retro-innovation, as it facilitates the preservation and adaptation of historical methods while pursuing sustainable development. Retro-innovation focuses on recovering traditional processes, strengthening production control while aligning with environmental conservation and food safety goals. Policy support is essential for retro-innovation, creating frameworks for research funding, subsidies, and regulatory incentives to adopt sustainable practices. In agriculture, retro-innovation often integrates traditional knowledge and practices with contemporary methods. For example, Chilean dryland peasant wineries combine historical grape varieties and agroecological strategies to enhance climate resilience (Henríquez BJ, Cid-Aguayo et al., 2023).

Retro-innovation in agriculture blends traditional knowledge with modern methods, emphasizing intergenerational knowledge transfer. It enhances socioecological resilience, preserves cultural identity, and fosters collaboration across generations, applying traditional knowledge in innovative, sustainable ways. Retro-innovation's application extends beyond traditional systems. Educational institutions can promote retro-innovation through curricula integration and workshops, fostering collaboration between farmers, researchers, and technology developers. Technological adaptations of historical practices, such as modernized horse-drawn farming equipment designed with contemporary engineering tools, illustrate how retro-innovation can merge with digital and CAD-based technologies. These developments support eco-conscious farming while reducing reliance on industrial machinery. By bridging the past and the present, retro-innovation enables communities to rediscover and apply traditional knowledge in innovative ways. It provides tools for sustainable development, fostering socioecological resilience while preserving cultural identity and encouraging intergenerational collaboration.

Biodynamic agriculture, developed in 1924 by Rudolf Steiner, offers a pioneering solution to modern agriculture through its holistic approach to cultivation. It is distinguished from other agricultural practices through its holistic approach to cultivation, emphasizing sustainability and ecological balance (Singh et al., 2024). Over the past 100 years, biodynamic agriculture has developed worldwide in the context of increasing industrialization, without industrializing itself, and is still considered today as a radically alternative way of farming (Paull & Hennig, 2020; Turinek, 2020; Rigolot and Quantin, 2022; Rigolot and Roquebert, 2024). Biodynamic agriculture incorporates general organic practices alongside specific practices such as biodynamic preparations and secular rhythms. It views the farm as an "individual organism," emphasizing autonomy. Despite its effectiveness, biodynamic agriculture faces challenges in its recognition. Confusion with organic farming, limited product availability, and lack of widespread information are obstacles that limit its acceptance. However, as consumers are increasingly interested in healthy and sustainable foods, biodynamic farming is expected to gain greater acceptance in the future.

Biodynamic farming has interesting effects on soil quality, improving its physical and chemical properties (Sabahy et al., 2024) and increasing biodiversity (Oroian et al., 2022). Although data on food quality are limited, biodynamic farming appears to offer slightly higher nutritional value compared to conventional farming, but without a significant difference compared to organic farming (Santoni et al., 2022). Exploring retro-innovation, such as combining traditional lunar calendars with AI, could bridge biodynamic practices and modern technology effectively. However, further field applications are needed to evaluate biodynamic farming under different environmental and production conditions. This will help to understand its broader potential for improving food security, local economies, and cultural conditions, as well as determine its positive aspects and improvements in nutritional quality and sustainability in order to determine its positive

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aspects and improvements in nutritional quality and sustainability. Although it offers environmental benefits, more analysis is needed on its impact.

The notion of retro-innovation has been conceptualized as an active rediscovery of marginalized and often forgotten “knowledge and expertise that combines elements and practices from the past (…) and the present and configures these elements for new and future purposes” (Zagata et al., 2020, p. 163).

2. METHODS

This research employs a qualitative systematic review combined with multiple case study analysis in three phases. The first phase involved a systematic literature review using databases such as Web of Science, Scopus, Google Scholar, and Science Direct (2013–2024). Key search terms included "biodynamic agriculture," "retro-innovation," and "smart agriculture technologies." The initial search yielded a set number of papers, later refined through inclusion criteria.The second phase focused on content analysis through thematic examination, categorizing findings into retro-innovation applications, smart technology integration, biodynamic agriculture principles, and implementation challenges.The third phase involved case study selection and analysis of real-world implementations using a cross-sectional approach to identify common patterns and unique features. Cases were selected based on relevance, geographic diversity, scale, and documentation quality, providing key insights into the integration of traditional and modern agricultural practices. Data collection included primary and secondary sources, while comparative analysis, validation, and synthesis helped identify best practices, challenges, and future recommendations

Smart Farming Technologies are advancing in conventional and organic farming, yet biodynamic agriculture adopts them cautiously due to its holistic principles. However, they offer potential benefits, including IoT-based sensors for monitoring soil moisture, temperature, and humidity; automated irrigation systems for precision water management; smart weather stations for microclimate monitoring; Artificial Intelligence (AI) and machine learning (ML) for predictive analytics and decision support; remote sensing; drones for crop health assessment and pest detection; Global Positioning Systems (GPS) and Geographic Information Systems (GIS) for soil analysis and farm planning; and blockchain for traceability, ensuring supply chain transparency.

Smart farming technologies in biodynamic agriculture encompass various innovative tools that enhance precision and sustainability. For instance, IoT sensors could align with biodynamic principles by incorporating lunar cycle data into irrigation schedules, ensuring ecological harmony. IoT sensors are used to monitor soil moisture, temperature, and humidity, providing real-time data to optimize crop growth. IoT-based irrigation is transforming farming by enabling real-time monitoring of soil and crop conditions, optimizing water use, and improving yields. In Agriculture

4.0, IoT and data analytics enhance efficiency, allowing farmers to manage crops remotely. The convergence of IoT tools with agricultural technologies is driving a new era of nature-positive farming, where productivity is balanced with environmental stewardship (Chaudhari & Pathak, 2024). Automated irrigation systems ensure precise water management, while smart weather stations track microclimate, astronomical, and meteorological conditions to aid in planning. The modern wine industry embraces sustainability, adopting biodynamic farming and automated irrigation systems to optimize water use, conserve resources, and enhance eco-friendly practices for better efficiency (Van Truong & Khanh, 2023). IoT-enabled Smart Weather Stations combine traditional monitoring with Internet of Things technology for precise weather prediction. While they face challenges in power management, data transmission, sensor accuracy, and cost-effectiveness, their future development focuses on AI integration for improved forecasting and advanced IoT technologies like edge computing and blockchain. Advancements enhance systems, benefiting multiple sectors, including agriculture (Ganesan et al., 2024). Artificial Intelligence (AI) and machine learning (ML) technologies are transforming agriculture by leveraging big data, cloud storage, and advanced analytics to enhance data collection, processing, and decision-making analysis. These integrated systems provide valuable insights that improve decision-making and enable the implementation of sustainable agricultural practices (Muniasamy, 2020). Specifically, AI and ML contribute to advancements in soil and water management, yield prediction, disease and weed detection, supply chain optimization, livestock management, and species breeding and recognition, revolutionizing the agricultural landscape (Kumar et al., 2022). Remote sensing and drone technologies gather large-scale data, such as land cover, vegetation health, and water resource distribution, providing farmers with crucial insights into crop health and environmental conditions. By integrating micro-level sensor data with macro-level information, big data platforms improve accuracy and support agricultural practices. Remote sensing monitors climate changes and weather patterns, while drones offer real-time field assessments, optimizing crop management and aiding long-term agricultural planning with integrated meteorological data (Song et al., 2025). A combination of Global Positioning Systems (GPS) and Geographic Information Systems (GIS) is used for geo-mapping. Automatic steering systems, acquisition units, and sensing devices can be mounted on farm machines or placed in fields. These technologies allow autonomous operation. Variable rate technologies and communication modules enhance precision. They also improve efficiency in agricultural operations (Chedea et al., 2021). Companies are using blockchain for traceability of food products to respond quickly to food safety issues and reduce food fraud. Blockchain can provide end-to-end traceability of the agricultural supply chain by recording every stage of production, processing, and distribution. It ensures transparency and authenticity, allowing consumers to verify the origin and quality of agricultural products (Bandara et al., 2024).

3. RESULTS

3.1 Applications of retro innovation in biodynamic agriculture

Biodynamic production modes are sustainable agricultural practices that emphasize ecological and holistic approaches to farming. These methods integrate ethical and sustainable farming techniques, focusing on the interconnectedness of soil, plants, animals, and humans within a self-sustaining ecosystem. Biodynamic farming is versatile, capable of operating across various production systems, ranging from extensive (low input and family-based) to super-intensive (high input, large-scale operations). However, extensive systems, which often involve traditional or organic practices, dominate in biodynamic farming. The core goal of biodynamic methods is sustainability, aiming to enhance soil health, biodiversity, and ecological balance. These methods combine traditional knowledge with modern ecological insights, making them adaptable to different agricultural systems while maintaining a strong focus on sustainability.

Research on the long-term impacts of retro-innovation on food security and local economies would offer valuable insights. Biodynamic farming is a well-established system with defined principles, while retro-innovation is more of a concept involving the re-adoption of traditional methods for modern applications. Biodynamic practices are inherently holistic and sustainable, often aligning with retro-innovative approaches that prioritize ecological balance and resilience. Both biodynamic production and retro-innovation offer rich opportunities for further study, particularly in areas such as developing responsible strategies to incorporate these practices into mainstream agriculture, evaluating their socio-economic and environmental impacts, and investigating their role in promoting intergenerational knowledge transfer and community resilience. By exploring these approaches, researchers can contribute to sustainable agricultural transitions and resilience against climate and socio-economic challenges.

3.2 Retro innovation in smart agriculture

Retro Innovation in Smart Agriculture There are alternative agricultural and food system concepts that are less associated with ‘high-tech’ and are instead considered ‘retro-innovation’ (Stuiver, 2006). Retro-innovation in smart agriculture involves repurposing older technologies for new purposes and combining different artifacts to create innovative solutions (Zagata et al., 2020). For example, within the product life cycle of wheat product innovation, retro-innovation (combining past and present methods) is identified as a strategy for cultivating old wheat varieties. This approach is being adopted to enhance the health benefits of baked products (Cagliano et al., 2016). These wheat varieties provide more suitable nutrients, contribute to biodiversity conservation, and simultaneously promote sustained local microeconomic growth (De Boni et al., 2019).

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3.3 Case studies

Case studies illustrate the transformative potential of retro-innovation in biodynamic agriculture. The case study by Svensson et al. (2023) shows that in Norway, Farm D practices retro-innovative biodynamic agriculture, merging traditional methods with modern ecology. Converted in the 1970s, it diversified production with cereals, vegetables, livestock, and pastures, promoting self-sufficiency. The farm is managed by a six-member cooperative. Extensive grazing areas and bee-friendly flowers enhance biodiversity. By reviving historical agricultural practices while meeting biodynamic standards, Farm D adapts past techniques to modern sustainability challenges, creating a balanced, resilient food system rooted in ecological harmony. Biodynamic Farm D combines historical methods with sustainability, transferring knowledge through education, promoting biodiversity, and offering a replicable framework for sustainable agriculture.

Bertolino's (2021) case study demonstrates how the recovery of wastelands into sustainable areas fosters green entrepreneurship and environmental sustainability. The transformation of raw lands into farms resists external policies, giving marginal areas new significance. The revival of Italian food culture and biodynamic farming has brought ancient grains like rye back. Farmers embrace retro-innovation, merging past wisdom with modern science, prioritizing local food chains, ensuring fair pricing, soil conservation, sustainability, and Earth-friendly agricultural practices with technological advancements.

Another case study, SEKEM, founded by Ibrahim and Helmy Abouleish, transformed desert land in Egypt into fertile farmland through biodynamic farming practices, promoting sustainable agriculture and community development. This initiative turned 70 acres of barren land into productive soil, contributing to community growth. SEKEM collaborates with over 3,000 farmers, applying biodynamic methods to 4,600 acres (Abouleish & Kirchgessner, 2005). The organization’s holistic model integrates agriculture, culture, and economy, aligning with Egypt’s Vision 2030 for sustainable development (SEKEM Association, 2021). SEKEM’s approach demonstrates the potential of biodynamic farming to drive environmental, social, and economic change.

4. DISCUSSION

The integration of smart technologies into biodynamic farming through retro-innovation offers a promising path toward sustainable agriculture. However, several challenges must be addressed. Biodynamic farming emphasizes spiritual and ethical principles, such as lunar cycles and natural inputs, which may conflict with the mechanistic approach of smart technologies like IoT and AI. This misalignment often leads to resistance from practitioners who view technology as undermining biodynamic principles. Additionally, many biodynamic farms are in remote areas

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with poor internet connectivity, limiting the use of IoT systems reliant on real-time data transmission. The high upfront cost of smart technologies, including sensors, drones, and AI systems, can be prohibitive for small-scale biodynamic farms with limited financial resources. Managing large volumes of data from IoT devices can also overwhelm farmers lacking technical expertise, making integration challenging. Moreover, smart technologies often demand significant energy, conflicting with biodynamic sustainability goals. Data centers and computing systems contribute to carbon emissions, while the production and disposal of electronic devices generate e-waste, contradicting biodynamic principles of environmental stewardship. A lack of awareness about the benefits and applications of smart technologies further hinders adoption. Training and education are crucial but difficult to implement. Many biodynamic communities value tradition and may perceive smart technologies as a threat to their cultural identity. Overcoming resistance requires effective communication and demonstrating how technology can complement, rather than replace, traditional methods. Additionally, biodynamic certification standards may not provide clear guidelines for advanced technologies, creating uncertainty for farmers and technology providers. Concerns about data privacy and cybersecurity further complicate adoption. Integrating smart technologies into biodynamic farming requires retro-innovation—adapting modern tools to fit traditional methods while maintaining their essence. Customization, such as incorporating lunar cycles into AI systems, is complex and resource intensive. To address these challenges, farmers and technology providers must collaborate to develop secure, culturally sensitive solutions aligned with biodynamic principles. Clear certification guidelines and targeted training programs can bridge the gap between tradition and innovation, ensuring the sustainable and secure adoption of smart technologies

5. CONCLUSION

The integration of smart technologies into biodynamic farming through retro-innovation represents a transformative approach to sustainable agriculture. By blending traditional knowledge with modern tools such as IoT, AI, drones, and blockchain, this approach enhances precision, efficiency, and ecological balance while preserving cultural heritage and fostering socio-economic resilience. However, successful implementation requires addressing philosophical, cultural, and technical challenges through interdisciplinary collaboration, policy support, and education.

Retro-innovation offers a unique opportunity to revitalize biodynamic farming, making it more resilient to contemporary challenges such as climate change and resource scarcity. By fostering a synergistic relationship between the past and the present, this approach not only strengthens the sustainability of agricultural systems but also ensures the preservation of traditional practices for future generations. As research and innovation in this field continue to evolve, the integration of smart technologies into biodynamic farming through retro-innovation will play a pivotal role in shaping a more sustainable and equitable food system.

In conclusion, a practical roadmap for adopting smart technologies in biodynamic farming is necessary to ensure gradual, manageable integration. For example, starting with low-cost IoT sensors for soil monitoring, expanding to AI for decision-making, and offering training programs can help farmers transition while maintaining ecological harmony. By introducing phased implementation, farmers can begin with simple, cost-effective tools and progressively scale their use of advanced technologies. This approach ensures that the adoption of smart systems aligns with sustainability goals.

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