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A Systematic Review of Management Science Integration in Farm Decision Tools: Advancing Theory for Agricultural Problem-Solving

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Abstract
This systematic review examines the integration of management science into farm management literature, focusing on its role in addressing contemporary agricultural challenges. By synthesizing recent studies, the review explores how tools such as optimization, decision analysis, systems modeling, and precision agriculture platforms enhance decision-making under conditions of complexity and uncertainty. Key findings highlight the transformative impact of digital tools like Variable Rate Application (VRA), Electro Optical System Data Analytics (EOSDA) Crop Monitoring, and Folio3 AgTech Software on resource allocation, risk management, and supply chain optimization, contributing to improved efficiency, profitability, and sustainability. However, significant gaps persist, including limited adoption among smallholder farmers, fragmented data systems, and insufficient theoretical frameworks to integrate interdisciplinary insights. The review identifies opportunities for advancing theory through supervised control loops and cyber-physical systems, emphasizing the need for unified models that bridge agronomy, data science, and behavioral economics. Practical implications include enhanced decision-support systems and the necessity for policy interventions to promote accessibility and digital literacy. This study calls for interdisciplinary collaboration and user-centered design to fully realize the potential of management science in fostering resilient, sustainable, and equitable agricultural systems.

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1. Introduction

Farm management is increasingly recognised as a cornerstone of agricultural sustainability, productivity, and resilience in the face of 21st-century challenges. Habib (2024) highlighted, the traditional farming landscape has been reshaped by a series of concurrent pressures, ranging from climatic unpredictability to economic instability, technological disruption, and heightened societal expectations around food safety and environmental stewardship. Modern farmers navigate this complex environment with limited resources and heightened uncertainty, which calls for new paradigms in managing agricultural enterprises. The challenges confronting agriculture are multifaceted and interconnected. Climate change, for instance, has fundamentally altered historical weather patterns, leading to more frequent and severe droughts, floods, and temperature extremes. These changes disrupt crop phenology and livestock health and undermine the predictability of seasonal farming operations (Habib, 2024). Water availability has become increasingly erratic, pushing farmers to adopt more efficient irrigation and water-saving technologies (Habib, 2024). Pests and diseases are also rising, exacerbated by shifting climatic zones and intensifying both prevalence and resistance to conventional controls (Sergieieva, 2024). Economic pressures compound these environmental risks. Farmers now face rising production costs, including increases in fuel, fertilisers, machinery maintenance, and labour (Duong, Brewer, Luck & Zander, 2019) [15]. Small and medium-sized farms are especially vulnerable to these financial strains because they often lack the economies of scale and capital reserves needed to invest in innovative solutions (Dhillon & Moncur, 2023; Wilk, Andersson & Warburton, 2012) [14, 44]. Respect for labour laws, environmental regulations, and food safety standards is essential to modern farm management. Better documentation, verification, and monitoring systems are required; the specifications add complexity (Bunei, Barclay & Kotey, 2023) [7]. These dynamics have exposed the shortcomings of conventional, intuition-based farm management practices. More organised, evidence-based systems that can facilitate adaptive decision-making and long-term strategic planning are desperately needed as agriculture grows more data-rich and risky. Management science has a lot of promise in this regard.

Management science offers various analytical techniques and tools, including simulation, systems modelling, optimisation, and decision analysis, and can improve decision-making in complex and uncertain situations. These tools have been used for a long time in industrial engineering, logistics, and operations research, and there is growing interest in applying them to agricultural settings (van Mourik *et al.*, 2021) [43]. Data-driven planning models, real-time decision-support systems, and precision agriculture technologies have all been made possible by the integration of management science into farm management. Management science concepts can be operationalised in daily farming through technologies like satellite monitoring, Internet of Things (IoT) sensors, and software platforms like Folio3 Agtech and Electro-Optical System Data Analytics (EOSDA) Crop Monitoring (Fuentes-Peñailillo, Gutter, Vega & Silva, 2024; Habib, 2024; Navulur, Sastry & Giri Prasad, 2017; Sergieieva, 2024) [18, 34]. These platforms help farmers make timely and well-informed decisions by giving them detailed information about crop health, soil conditions, equipment performance, and weather forecasts.

Varying Rate Technology (VRT) and predictive analytics, for example, enable farmers to customise input to the unique requirements of various field zones, increasing yield results while reducing environmental impact (Sergieieva, 2024). These days, decision support systems are used to simulate different planting or harvesting scenarios under varied market or climate conditions, manage irrigation schedules, and keep an eye on pest and disease risks. Farmers' approaches to long-term planning, risk management, and resource allocation are changing as a result of these capabilities. Nevertheless, the successful integration of management science into farm management is not without challenges. There are still disparities in digital literacy, infrastructure, and institutional support, and technological adoption is still uneven, especially among smallholder farmers. Additionally, many tools are created without consulting end users, leading to solutions that are either too complicated or not sufficiently tailored to local contexts (Collini *et al.*, 2022) [11]. Notwithstanding these obstacles, an increasing amount of data indicates that management science can transform agricultural problem-solving through increased sustainability, resilience to external shocks, and improved efficiency.

The goal of this systematic review is to compile the most recent research on the integration of management science into farm management in order to evaluate its benefits, drawbacks, and prospects. In keeping with the recent acceleration of digital transformation and technological adoption in agriculture, the review focuses exclusively on recent literature. The focus is on application-based research, conceptual frameworks, and empirical studies using tools like precision agriculture platforms, optimisation models, and decision support systems. We found theoretical and methodological gaps, discovered patterns and trends in the literature, and assessed the usefulness of management science applications in agricultural settings. The review examined how these applications support or contradict current farm management paradigms.

To achieve the above objectives, the review is guided by the following questions:

1. What management science tools have been applied in farm management literature since 2015?
2. How have these tools contributed to solving agricultural problems such as efficiency, profitability, and sustainability?
3. What theoretical and practical gaps exist in the current literature on integrating management science into agriculture?
4. What models or frameworks have been proposed or applied?
5. What are the key barriers and opportunities for advancing theory and practice in this field?

2. Literature Review and Theoretical Review

Farm management encompasses a complex decision-making process that balances economic, environmental, and operational dimensions to optimise agricultural productivity. Defined as the strategic orchestration of land, labour, technology, and finance, farm management today goes far beyond the confines of crop scheduling and input procurement (World Bank, 2018). It covers long-term planning, resource sustainability, compliance management, and real-time monitoring. Management science offers an analysis tool to study and to improve agricultural decisions and it is founded upon the applied mathematics, system theory and operations research. It has been established that there are four overarching concepts namely optimisation, simulation, decision analysis and systems modelling that are especially applicable in farm management.

Optimisation refers to the employing of math procedures to distribute limited resources, including labour, fertiliser and water, so as to maximize production or reduce expenses. This is usually done by the usage of technologies such as VRA that involved the precision application of geospatial nutrient mapping of fertilisers. Sergieieva (2024) points out that such an approach is highly effective at minimizing cases of over-application and promotes greener practices in farming. Through simulation, planners and farmers can be able to predict the impacts of different variables under different situations. As an example, EOSDA Crop Monitoring combines real-time satellite data and past climate records to predict irrigation and create disease risk modelling (Sergieieva, 2024). These simulations help mitigate uncertainty by enabling "what-if" scenario planning. Decision analysis helps in evaluating multiple alternatives under uncertainty. It supports structured decision-making processes where trade-offs between profit, environmental impact, and risk must be explicitly analysed. In complex farming systems, decisions often involve balancing short-term operational goals with long-term sustainability targets, a task that benefits from multi-criteria analysis frameworks.

Systems modelling further represents farm operations as dynamic systems with feedback loops. According to van Mourik *et al*. (2021) [43], these models allow for integration across biological, economic, and environmental subsystems. Their research advocates for supervised control loops in agricultural production systems, highlighting how continuous monitoring and control can improve the stability and efficiency of farming operations. Many of these concepts are embedded in software platforms like Folio3, which uses real-time dashboards and field analytics to monitor animal performance, automate reporting, and support compliance (Kaur *et al*., 2023; Morrone, Dimauro, Gambella & Cappai, 2022) [24, 32]. Similarly, EOSDA integrates predictive models to provide soil moisture indices, evapotranspiration rates, and vegetation health metrics all essential for high-resolution decision-making (Sergieieva, 2024).

Theoretical Gaps in Integrating Management Science with Farm Management

Despite these technological advancements, the theoretical integration of management science into farm management remains underdeveloped. Much of the existing work (Barnes *et al*., 2019; Bronson & Knezevic, 2016; Budaev, Lada, Simonova, Skobelev & Travin, 2019; Capalbo, Antle & Seavert, 2017; Carolan, 2018; Eastwood, Ayre, Nettle & Rue, 2019) [2, 3, 6, 16, 7] are application-oriented, with limited exploration of how these tools transform managerial cognition, knowledge flow, or institutional behaviour within agricultural systems. One key gap lies in the disconnect between agronomic expertise and analytical optimisation tools. Although farmers increasingly rely on digital solutions, little theoretical work explores how these tools reshape the underlying decision paradigms in farming. For instance, how do farmers interpret data-driven insights when they conflict with traditional knowledge? What decision heuristics emerge when using predictive analytics versus experiential learning? Van Mourik *et al*. (2021) [43] draw attention to the absence of frameworks that consider the interaction between the human decision-maker and the control systems they operate. Their review advocates for a cyber-physical perspective that acknowledges farmers as users and co-developers of decision systems. However, the literature on agricultural management hasn't given this strategy much thought. Another drawback is the disregard for institutional and behavioural elements that influence the adoption of management science tools. Although EOSDA and Folio3 are extremely technical tools, their efficacy is frequently limited by socioeconomic disparities, infrastructure accessibility, and farmer digital literacy (Habib, 2024).

An equally pressing issue is the technical competence gap among practitioners. Many tools rely on understanding data visualisation, algorithmic modelling, or software programming, all skills not commonly held by the average farmer. Without adequate training, the risk of misinterpretation of data or improper tool usage increases, potentially leading to counterproductive outcomes. Choruma *et al*. (2024) argue that extension services must evolve from traditional agricultural support to digital coaching and systems literacy. However, these services are often underfunded and inconsistently available, particularly in regions that most need them. There is also a mismatch between the speed at which technology advances and the rate at which educational institutions adapt their curricula to prepare the next generation of farmers and agronomists.

Furthermore, the emergent characteristics and feedback mechanisms that are inherent in real-world farming are ignored by current models, which treat farm systems as static or linear. This is especially problematic in light of market volatility and climate change, where resilience and adaptability are more crucial than static optimisation. Lastly, there is still disciplinary fragmentation in the literature. Agronomists, data scientists, systems engineers, and agricultural economists frequently operate in silos, producing theoretical models that are either overly general or too specific. Integrative theories that can span these fields and provide a comprehensive understanding of contemporary farm management are desperately needed.

The rationale for this systematic review is grounded in the need to synthesise a highly fragmented body of literature and generate a coherent narrative around the integration of management science in farm management. While there is considerable evidence of practical applications, there remains a lack of consolidated understanding regarding these approaches' effectiveness, limitations, and transformative potential. This review answered critical questions: Can management science tools improve farm-level decision-making and sustainability? Are they accessible and usable for a diverse range of farming systems? What conceptual models guide their development and deployment? By addressing these questions, the review identified both best practices and blind spots in the existing literature. With the rapid advancement of technology in agricultural decision-making from artificial intelligence to satellite imagery, the literature must shift from descriptive research to theory-building. By bridging the gap between conceptual clarity and empirical practice, this systematic review aims to develop new frameworks that can guide research and implementation. This review provides a foundation for interdisciplinary integration. As Habib (2024) accurately points out, a single discipline cannot address agriculture's complex issues. Management science cannot be divorced of broader agroecological, socioeconomic, and institutional context to facilitate systemic and farm level change.

3. Methodology

Systematic Review Protocol

In order to be methodologically open, reproducible, and comprehensively synthesize evidence available, the proposed study uses a systematic review methodology, consistent with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. The systematic review is limited to the issue of the intersection between the farm management literature and the management science. It aims to establish possible trends regarding the tool use, theoretical correctness, and applicability of the tools in problem-solving in the agricultural context. The sources of data consisted of the recent literature, which comprised academic sources, technical reports, conceptual overviews, and practical cases that exist within the boundaries of the review.

4. Management Science Applications in Farm Management

Resource Allocation

The ability to use resources precisely is one of the key benefits of using management science techniques in agriculture. Site-specific management is made possible by technologies like Variable Rate Application (VRA), which customises fertiliser or water application by fusing field-level observations with satellite data. By guaranteeing that inputs are only used where necessary, VRA increases productivity and lowers environmental externalities, claims Sergieieva (2024). Nie, Wu, Li, Li, and Hou (2024) describe in detail how contemporary instruments employ digital soil mapping and remote sensing data to direct precision fertilisation. These techniques lower expenses and nutrient leaching by ensuring that nutrient application in spatially heterogeneous fields corresponds with crop demands. Another field that makes extensive use of optimisation models is irrigation planning. To assist farmers in choosing the best irrigation schedules, EOSDA Crop Monitoring takes into account soil moisture indices and evapotranspiration rates (Mohamed-Naziq, Sathyamoorthy, Dheebakaran, Pazhanivelan & Vadivel, 2024) [30]. Effective water use can determine economic survival in areas with limited water resources, which is especially important.

Risk Management

In a world with a changing climate, predictive systems are becoming more and more crucial to preserving agricultural productivity. Predictive modelling tools that anticipate disease outbreaks, pest invasions, and crop failure risks are one way that management science contributes. EOSDA's satellite-based risk detection algorithms exemplify the integration of simulation and predictive analytics for disease risk assessment. These tools analyse climatic trends, vegetation indices, and historical disease data to alert farmers before economic damage becomes irreversible (Sergieieva, 2024). Similarly, van Mourik *et al*. (2021) [43] describe the potential of systems control models to adapt to risk dynamically by monitoring external variables and triggering real-time adjustments. To lessen susceptibility to environmental changes, temperature or humidity thresholds, for example, can automatically initiate crop protection measures or modify irrigation schedules.

Supply Chain Optimisation

Supply chain coordination is also useful when more than farm gate is involved in management science. To enhance the quality of the products, the accessibility of markets and an accelerated transportation process, blockchain, traceability software, and logistics optimisation tools are also finding extraneous usage. The researchers note that by introducing traceability systems into agri-food logistics, transparency and accountability increase (Hasan, Habib & Mohamed 2023) [22]. Using blockchain technology it is possible to track the provenance of produce, field to shelf making quality control and regulatory compliance easy. The use of optimisation algorithms to track real-time inventory and demands also allows agribusinesses to minimise wastage, minimise the costs of transportation, and react quickly to changes happening in the market. Such technologies are very applicable in fresh produce supply chains where the perishable nature of the items supplied need immediate logistical decisions due to the changing consumer demand. When based on the digital twins and the simulation models, the farm manager can forecast the demand and harvest it accordingly, distributing delivery transport resource to shorten delivery length. Case studies reviewed prove the effectiveness of the platforms like Folio3 and EOSDA and the associative power of tools like VRA to change the state of affairs. In future, data, modelling and decision science will collaborate in ensuring sustainability, efficacy and resilience of agriculture. These products demonstrate the cooperation of the management theory and agricultural science.

5. Key Findings

Patterns and Trends in Management Science Integration

The systematic review reveals a consistent and expanding pattern in integrating management science tools into contemporary farm management. One of the most salient trends is the growing reliance on digital tools and data-driven decision-support systems, particularly those associated with automation, precision agriculture, and predictive analytics. The shift from intuition-based to evidence-based agricultural decision-making significantly departs from traditional farming practices. Sadiku, Ashaolu, and Musa (2020) note that modern farm management is increasingly shaped by technologies that capture, process, and analyse large datasets. These include satellite imagery, weather data, and in-field sensor readings data streams that are now being harnessed through platforms such as Folio3 AgTech and EOSDA Crop Monitoring. These systems enable farmers to optimise their input use, forecast risks, and make timely interventions based on real-time conditions rather than experience.

Automated irrigation platforms, disease prediction model, compliance-tracking software and variable rate application (VRA) are the most common tools that are integrated. Dhanaraju, Chenniappan, Ramalingam, Pazhanivelan and Kaliaperumal (2022) [13] argue that these technologies are redefining how work is undertaken in almost every step of the agricultural value chain by enabling remote field monitoring, crop stress identification, and input scheduling using centralised platforms. Systems based on the control theory, and especially those using supervised feedback loop, become popular in crop and livestock management (Bisson, Casenave, Boudsocq, & Daufresne, 2019) [4]. They are types of systems that constantly measure significant parameters such as temperature, humidity and moisture in soils and after gathering the data, these systems automatically adapt the work. This belongs to the larger communication to autonomous management of farms whereby progressively more abilities are evasively relinquished to algorithms and AI procedures. All these trends will indicate a significant digital revolution in farming. The practice of farm management has turned into a sector that is extremely computer-driven, big-data dependent and decisions are made in real-time and in large measure of consulting with the help of analytic tools, leaving the world of physical work and instinctive management long behind.

Impact on Agricultural Problem-Solving

The integration of management science in farm management is already generating substantial outcomes in terms of efficiency, profitability, and sustainability.

1. Efficiency

The operational efficiency is one of the main spheres affected. The optimisation models in such platforms as EOSDA and Folio3 help to perform the planning economically and simplify the process, minimizing the wastes of input. As an example, precision fertilisation using satellites allows the availability of nutrients to meet the demands of crops and decrease under consumption of fertiliser (Levin, 2024) [27]. On the same note, an evapotranspiration modelling method of irrigation scheduling saves water in drought prone regions without destabilizing the crop production process. Garyaeva, Garyaev and Parfenov (2023) [19] claim that automation has the potential to minimise labour redundancies and promote task coordination. By means of combining machinery sensors with scheduling software, farm administrators are able to increase the rate of accuracy in harvestings, minimizing time gaps as well as enhancing the durability of equipment.

2. Profitability

The improvement in resource allocation, cutting down of losses and better forecasting of the market have led to reported increases in profitability. Preductive analytics allows planning crop selection and better scheduling of harvest due to market demand and weather It allows the various planning and better scheduling of crop selection and harvest according to the market demand and weather (Habib, 2024). Early-warning systems also result directly into yields and revenue by decreasing the loss to crop pest and disease. EOSDA's vegetation health indices and disease risk modelling allow farmers to act pre-emptively, avoiding costly interventions later in the season (Dasari *et al*., 2024) [12]. This type of decision support leads to cost minimisation and yield optimisation, which are key to enhancing profitability in an increasingly competitive agricultural market.

3. Sustainability

Sustainability is a third major domain of impact. Modern management science tools are aligned with environmentally conscious practices, as they often reduce the overapplication of inputs like nitrogen, phosphorus, and water. VRA systems exemplify this by enabling precise fertiliser placement, thus minimising leaching and runoff into water bodies (King, Pletnyakov, Taylor, Ekanayake and Werner, 2022). Moreover, traceability systems supported by blockchain (as noted by Habib, 2024) foster supply chain transparency and food safety, ensuring compliance with environmental and health regulations. These systems build consumer trust and enhance accountability throughout the value chain.

Disciplinary and Methodological Diversity in the Literature

The literature covered in the review spans multiple disciplines agronomy, environmental engineering, data science, and agricultural economics, each contributing valuable insights but often operating in isolation. This fragmentation of discipline is posing difficulties to methodological standardisation and the integration of theory. Agronomic research, e.g., might focus on yield results, data science studies might emphasise the accuracy of a model, and an economic evaluation might focus on how cost-efficient the evaluation is. Nevertheless, there are relatively few studies that take the initiative of considering such perspectives into holistic evaluation of the roles played by management science in the field of agriculture. Espig, Finlay-Smits, Meenken, Wheeler and Sharifi (2020) [17] promote the interdisciplinary approaches that connect the systems modelling with the farm management goals. They argue that the true value of the management science lies in its ability to connect the environmental measurements with the decision-making frameworks or biological processes with the economic outcomes. The diversity of methods is also evident in the variety of the tools employed, both such basic as machine learning and regression analysis, as well as more complex tools as control loops or rule-based algorithms. Such richness makes the process of comparison and replication more attempting, despite also indicating the dynamism of the field. It is difficult to define which instruments are most effective in this or that farming system or in this or that conditions, as many studies do not follow the same standards of reporting. It needs a deeper theoretical interest to understand how the management science is transforming farm level activities as well as greater agrarian situation.

6. Advancing Theory for Agricultural Problem-Solving Theoretical Contributions of Management Science to Farm Management

Management science contributes a formal, structured methodology to agricultural decision-making, enabling practitioners to transition from intuition-based judgment to analytical, evidence-based practices. Such contributions are particularly important in regimes that are typified by uncertainty, limited resources and variable climatic situations that are increasingly becoming typical of contemporary farming. The decision-making procedure is formalised using systems modelling, optimisation and decision analysis, which is one of the major theoretical contributions to management science. These practices allow adaptable responsiveness, uniformity, and predictability. According to He, Yang, and Qiu (2024) [23], control theory and systems thinkings play a fundamental role in addressing dynamic aspects of the relationships that have existed between input variables, biological processes and output performance of agricultural systems. In particular, closed-loop client control, offering on-the-fly tracking, feedback, and corrections, has gained increased and increased prominence. These control mechanisms bring the concepts of systems engineering and cybernetics in to farming in order to provide a consistent and efficient performance by farms with time.

Moreover, the theoretical robustness is added by the predictive modelling which is facilitated by the simulation and historic data analysis procedures by transforming empirical trends into the generalised guideline on how to make decisions in the future. Samples of these platforms include those like EOSDA Crop Monitoring that use predictive analytics to guide the timing of input, risk of disease mitigation, and irrigation strategies (Sim, Tang, Zhou & Zhu, 2021). Such platforms illustrate how the theoretical concepts of the operations research and control engineering have been operationalized to be able to apply them to real-life farming activities.

The other theoretical contribution is a transition to systems thinking. Rather than treating decisions as isolated actions, management science promotes an all-encompassing approach that sees farms as integrated systems with biological, economic, technological, and social subsystems. This systems perspective enables the modelling of cascading effects, including how fertiliser decisions affect crop yield, soil health, water quality, and regulatory compliance. The decision-support feature of software platforms like Folio3 highlights a conceptual shift from reactive to proactive management, where strategic foresight is embedded in everyday farm decisions (Capalbo, Seavert, Antle, Way & Houston, 2018) [8]. These platforms are excellent illustrations of the transition to digitalised, knowledge-intensive agriculture and are consistent with the theoretical frameworks of embedded decision logic and real-time analytics.

Proposed Frameworks or Models for Integration

The most significant theoretical frameworks proposed in the reviewed literature are supervised control loops and cyber-physical management systems. These frameworks work by combining three essential elements: action (algorithmic or user-directed intervention), prediction (model-based forecasting), and observation (data collection). The use of supervised control systems in livestock and crop operations to concurrently manage resource use, environmental factors, and production risks is thoroughly examined by Monteiro, Santos, and Gonçalves (2021) [31]. Decision variables (such as the rate at which pesticides are applied or the volume of irrigation) are continuously modified in supervised control systems in response to input from sensors and models. By minimising resource overuse and reacting instantly to departures from ideal conditions, the looped feedback structure guarantees dynamic adaptation. This illustrates the fundamental ideas of control theory, especially as they relate to industrial systems, and shows how they can be applied to the agricultural sector.

By connecting digital and physical components via a network of sensors, actuators, and computer algorithms, cyber-physical management systems (CPMS) expand on this idea. These systems gather information from the farm environment (such as soil moisture and livestock health indicators), process it using analytical engines, and trigger reactions like turning on irrigation pumps or modifying feeding schedules. As Oymatov *et al*. (2023) [37] explain, platforms like EOSDA embody the operational side of these theoretical models, translating raw environmental data into actionable insights that maintain system equilibrium. Both frameworks underscore a closed-loop logic, where continuous measurement, forecasting, and correction allow farms to maintain optimal states across multiple performance indicators. Their theoretical sophistication lies in treating the farm not as a set of disjointed tasks but as a multi-objective control problem, requiring simultaneous attention to productivity, cost, compliance, and sustainability.

Furthermore, these models align with emerging concepts of digital twins in agriculture virtual representations of real farms that simulate and test interventions before physical implementation. The integration of satellite-based monitoring (EOSDA), dashboard-driven control (Folio3), and predictive analytics exemplifies a trend toward model-driven, virtual-first farm management systems (Kotam, Vinayak, Suhas & Rohini, 2024) [26].

Implications for Addressing Complex Agricultural Challenges

The theoretical models described above are not merely abstract; they have real implications for managing complex agricultural challenges. Traditional management techniques find it more difficult to remain sustainable or efficient as resource depletion, climate variability, and regulatory scrutiny rise. By incorporating resilience, adaptability, and foresight into decision-making processes, integrated, model-based systems with a management science foundation present a viable remedy. First, integrated modelling systems have a major positive impact on climate risk management. Based on historical climate data and current weather monitoring, predictive analytics allow farms to plan planting, harvesting, and irrigation in advance of heatwaves, floods, or droughts (Satheswaran, Akshaya, Abirami, Durga-Nandhini & Sarathi, 2023) [39]. This predictive ability improves adaptive capacity and lessens susceptibility to weather shocks. Second, these models enhance traceability and compliance, two facets of agricultural regulation that are becoming more and more significant. Farms can quickly produce the data needed for certifications, sustainability reporting, and regulatory inspections by integrating documentation, reporting, and auditing features into decision-support platforms such as Folio3 (Giagnocavo, Bienvenido, Li & Yang, 2017) [23]. In value chains focused on exports, buyers demand transparency throughout the production process, which is especially pertinent.

Third, multi-dimensional trade-offs are addressed through theoretical integration. An action that boosts yield, for instance, may degrade the quality of the soil or increase labour intensity. Farm managers can systematically, instead of subjectively, balance these trade-offs using multi-objective optimisation, a fundamental management science technique. This supports long-term planning over reactive problem-solving, shifting the paradigm from "fixing what's broken" to "preventing problems through foresight." Importantly, these models are scalable. While high-capital operations benefit from advanced IoT and satellite-linked systems, the same theoretical principles of closed-loop feedback, predictive optimisation, and multi-criteria analysis can be applied in simpler, context-specific ways in smallholder settings. Translating theoretical frameworks into cost-effective, user-friendly tools that reflect local realities is challenging.

Role of Interdisciplinary Approaches

The development and application of these theoretical contributions are deeply interdisciplinary, requiring collaboration across agronomy, systems engineering, data science, behavioural economics, and environmental science. Agricultural problems are rarely one-dimensional and embedded within ecological, economic, and social systems. As such, theoretical models that ignore this complexity are unlikely to be effective in real-world applications. Thorén (2021) [42] underscores the importance of interdisciplinary integration, advocating for models that accommodate technical precision and user practicality. Evapotranspiration, for example, can be used by a system to optimise irrigation schedules. It might not be feasible in reality if it ignores the farmer's financial constraints, labour availability, and regulatory environment. Multidisciplinary cooperation also makes it easier to design modular systems, in which different parts (like economic planners, risk analysis tools, and climate models) can be created separately and then combined to form a single ecosystem for decision-support. This encourages inclusivity and contextual relevance by enabling flexible adoption across various farming systems.

7. Practical Implications

Applications for Farmers and Agribusiness Stakeholders

Integrating management science enables farmers to make decisions proactively rather than reactively, spotting problems before they become serious and distributing resources more effectively. Cost-saving techniques made possible by VRA systems, such as site-specific fertiliser or irrigation delivery, directly benefit farmers. Systems for traceability, especially those that use blockchain technology, add value by making it easier to access markets and comply with certification requirements. Hasan *et al*. (2023) [22] highlight that these systems support end-to-end transparency across agri-food supply chains, from farm to consumer. Farmers and agribusinesses can document production practices, input histories, and handling conditions, enabling them to meet stringent regulatory and market-driven standards, especially in export-oriented sectors. For agribusiness stakeholders, management science tools streamline logistics, procurement, and compliance operations. For example, EOSDA's suite of monitoring tools allows processors and distributors to evaluate supplier performance remotely and consistently. This reduces overhead costs associated with manual inspections and fosters stronger, data-backed relationships between producers and supply chain partners (Sergieieva, 2024).

Opportunities for Technology and Data-Driven Farm Management

The convergence of AI, IoT, and satellite imaging has opened unprecedented opportunities for customised, adaptive farming solutions. These technologies push the limits of management science applications by enabling dynamic models that respond instantly to biological, environmental, and market cues. To help farmers make accurate sub-field decisions, EOSDA Crop Monitoring, for instance, uses satellite-derived indices to track vegetation health, evapotranspiration, and disease risk (Oymatov *et al*., 2023) [37]. AI-powered platforms such as Folio3 AgTech offer predictive diagnostics and real-time alerts to help identify anomalies in equipment performance, livestock health, or pest activity before they result in a significant financial loss (Michelena, Fontenla-Romero & Calvo-Rolle, 2024). Such advances do not only revolutionize operations but the benefit of being strategic. The data-rich systems enable farms and agribusinesses to make forecasts, assess risk exposure, and make resilience plans with regard to climate uncertainty and plan possible outcomes in long run scenarios and investment decisions. Finally, scalable, yet inexpensive possibilities of management science incorporation into open-source tools and cloud computing bases arise. Due to the increasing access levels, especially utilized by the mobile technologies, even farmers with low resources may start using simplified decision-support systems that are adapted to the local conditions.

8. Challenges and Barriers

Obstacles to Integrating Management Science in Farm Management

Although the advantages of using management science in agriculture are evident, various structural and practical obstacles prevent it to become the most common used area on the larger scale, not to mention among small and medium-sized farmers. Among them is the high barrier to entry. Such advanced digital farming technologies as predictive analytics systems, virtual reality analytics, and automated irrigation systems are also examples of sophisticated technologies in the sector; they typically involve an upfront cost associated with buying hardware, software subscriptions, and back-end data infrastructure (King *et al*., 2022). Such expenses may be too expensive to smallholder farmers who may not access government credit and subsidies. EOSDA Crop Monitoring, as an example, applies satellite-based analytics comprehensively; nonetheless, in order to apply it massively, it requires delivering connectivity infrastructure and trained individuals (Oymatov *et al*., 2023) [37].

The second big deterrent will be heterogeneity of data systems between platforms. Farmers struggle to combine the knowledge of various devices or software since several of these tools are designed by different companies and do not interact with each other. This restricts the integrated application of information in the planning and decision-making. As such, take the instance where satellite data fail to merge conveniently with in-field sensors or economic prophesying apparatus; there may exist redundancy or gaps in cognizance. According to Manning (2024), this lack of cohesion of the system is among the main obstacles to the adoption of farms as a whole. The other major barrier is the absence of digital literacy particularly among aged farmers and farmers in rural localities. Many farmers have no idea how mobile apps, cloud-based dashboards and geospatial visualisation tools work. Even when technology is made available, it can become useless due to a lack of specialised training and user-friendly interfaces. Oymatov *et al*. (2023) [37] acknowledge that the potential of advanced platforms like EOSDA often remains underutilised due to poor digital adoption and weak user engagement strategies.

Technological, Cultural, and Economic Constraints

The adoption of management science tools is frequently hampered by behavioural limitations and cultural resistance, in addition to financial and infrastructure problems. Certain farming communities distrust automated systems, especially those that deprive farmers of their decision-making authority. Tools that control hardware or generate suggestions without human input may be perceived as intrusive or untrustworthy. Additionally, the technological complexity of some tools acts as a disincentive. Farmers may choose to use traditional techniques and firsthand knowledge rather than figuring out complex data models or multi-parameter dashboards. Nadschläger, Nikander, and Auer (2019) [33] assert that for technologies like Folio3 AgTech Software to be effective, they must not only deliver precise information but also do so in a manner that is appropriate for the context in which farmers make decisions. When people think that a system is too complicated or hard to use, adoption rates fall.

Connectivity and power infrastructure remain critical barriers in rural settings, especially in low- and middle-income regions. Unstable internet access, limited network coverage, and unreliable electricity supply limit the potential of cloud-based platforms, real-time analytics, and remote monitoring systems (Njoka, Thimo & Agarwal, 2023) [36]. Without the foundational infrastructure, even well-designed tools cannot be effectively deployed. Economically, the benefits of precision farming tools may be unevenly distributed. Large commercial farms often have the resources to adopt and maintain these systems, while smaller farms struggle to justify the investment due to economies of scale. This creates a digital agricultural divide, where efficiency gains and sustainability benefits are confined to well-capitalised producers.

9. Recommendations and Conclusion

Call to Action for Researchers, Practitioners, and Policymakers

In the future, researchers will undoubtedly need to close the gap between theory and practice. One example is creating interdisciplinary frameworks that integrate agronomy, systems science, data analytics, behavioural economics, and policy studies. More emphasis should be placed on user-centred design and participatory research when developing tools that represent farmer priorities and real-world circumstances. Adopting management science tools for practitioners entails more than just adopting new technology; it also entails committing to organisational transformation and capacity-building. Software developers must prioritize usability and local relevance in their designs, and farmers and farm managers require specialised training and assistance to incorporate these tools into their everyday operations. Policymakers need to acknowledge their part in making precision agriculture accessible to all. Levelling the playing field and guaranteeing that the advantages of modern farm management are widely distributed, particularly among smallholder farmers and underserved areas, requires subsidies, infrastructure investments, and extension reforms. This review concludes by urging a coordinated, cooperative effort to fully realise the potential of management science in agriculture as a paradigm shift for sustainable development, problem-solving, and equitable growth in global food systems, rather than as a collection of discrete tools.

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