

Review

An Integrated Approach to Sustainable Development in Agronomy

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Abstract: Sustainable development in agronomy implies an integrated approach that incorporates economic, legal and sociological aspects in the implementation of modern agricultural practices. The aim of this paper is to identify and analyse the systemic conditions and limitations for enhancing sustainability in the agricultural sector by linking diverse but interdependent factors. The study is grounded in a critical review of existing scientific and expert sources, covering the economic viability of sustainable technologies, the role of regulatory frameworks and public policy instruments, and the influence of social values and behavioural patterns on innovation adoption. The findings indicate that sustainability in agronomy cannot be ensured solely through technological innovation or ecological optimisation but requires the alignment of economic incentives, legal support mechanisms and social engagement. Emphasis is placed on the need for interdisciplinary coordination that enables the development of practical models connecting theoretical foundations with field-level implementation. This integrative perspective is essential for creating resilient and equitable agri-food systems capable of responding to environmental pressures, market dynamics and social expectations in a coherent and long-term manner.

Keywords: *Sustainable agronomy; economic instruments; regulatory framework; social acceptance; interdisciplinary integration.*

1. Introduction

Contemporary agricultural systems are faced with the challenge of increasing productivity while using resources more efficiently, preserving the environment and enhancing the quality of life in rural areas. Sustainability has therefore emerged as a key development priority, grounded in balancing economic growth, social equity and the protection of natural resources [1,2]. It encompasses economic, environmental and social dimensions through a holistic approach aimed at ensuring long-term stability and prosperity. At the same time, rising systemic risks – including climate change, digital transformation, regulatory pressures and evolving societal expectations – call for coordinated and sustained responses. The limited effectiveness of existing institutional and economic mechanisms further underscores the need for new theoretical frameworks that integrate environmental, social and governance dimensions [3].

In a sustainability-oriented framework, economic policies are essential for steering activities towards long-term development goals by shaping investment flows, resource distribution and market dynamics, while accounting for environmental and social impacts [4]. Their relevance is particularly evident in strategies that align economic growth with social equity and environmental protection. Evidence from diverse national contexts suggests that integrated policy approaches can foster green economy development, reduce inequalities and preserve natural resources [5], underscoring the need for coherent institutional and governance systems.

Dosadašnja istraživanja uglavnom su bila fokusirana na agronomske i ekološke aspekte Core sustainability aspects such as soil health, biodiversity and production efficiency remain vital [6]. Yet, without economic support, legal frameworks and social acceptance, technical innovations alone prove insufficient [7]. Effective implementation requires governance mechanisms that integrate strategic planning with local conditions and institutional capacities [8]. Agriculture 4.0 illustrates both the potential and challenges of digital transformation, underscoring the need for infrastructure and policy alignment. Digitalisation must be socially and regulatorily embedded to enhance long-term resilience and sustainability in the sector [9].

Profitability, incentive availability and market stability are crucial economic factors for adopting sustainable practices [10]. Legal frameworks—through regulations, standards and international agreements—significantly influence agricultural practice [11], while sociological perspectives underscore the roles of institutional trust, cultural norms and community participation [12]. Some authors highlight technology and digitalisation as key drivers, whereas others stress the need for participatory approaches and social inclusion to ensure fairer resource distribution [13]. These diverse views point to the importance of an integrated approach that transcends disciplinary boundaries. This paper therefore examines sustainable development in agronomy by linking economic, legal and sociological dimensions, focusing on the systemic conditions needed to implement sustainable practices and develop an interdisciplinary governance framework for the sector.

2. Theoretical framework of sustainable agronomy

In the face of climate change, limited resource availability and growing social inequalities, sustainable agronomy has become a key pillar of agricultural transformation. Its scope goes beyond technical yield improvement and includes sustainable management of land, water and energy, biodiversity protection, strengthening rural economies and preserving quality of life. Within this broader theoretical framework, the concept of sustainalism is increasingly recognised as an integrated approach to sustainability that connects ecological, social and economic dimensions by balancing growth, equity and resource conservation. As a contemporary theoretical model, sustainalism highlights six core principles of global sustainability: justice, peace, access to energy and infrastructure, sustainable lifestyles and education [3], providing a foundation for a new paradigm of agriculture based on resilience, inclusion and long-term stability.

The concept of sustainalism, increasingly present in contemporary theoretical frameworks, represents an integrated model of sustainable development that connects ecological, social and economic dimensions with the aim of achieving a balance between growth, equity and resource conservation. This approach is based on six key principles of global sustainability: justice, peace, access to energy and infrastructure, sustainable lifestyles and education [3], thereby shaping a new paradigm of agricultural policy focused on resilience and long-term stability

2.1. The concept of sustainability in agronomy

Sustainable development, as outlined in the 2030 Agenda and the Sustainable Development Goals (SDGs), is grounded in four interdependent pillars: economic prosperity, social inclusion, environmental protection, and effective and transparent governance [14]. This comprehensive approach calls for deep structural changes that transcend sector-specific policies and promote the integration of development goals within planetary boundaries. The World in 2050 initiative highlights that sustainability can only be achieved through the simultaneous advancement of all dimensions, supported by coordinated institutional and societal transformation. Accordingly, sustainability is increasingly understood not as a purely technical objective, but as a transformative process requiring systemic and inclusive change

In the context of agronomy, sustainability entails a redefinition of agricultural objectives towards achieving a balance between productivity, resource preservation and social welfare [15]. Sustainable agronomy provides a framework for integrating local knowledge, innovation and systems thinking [16], shifting away from linear “production–consumption” models towards circular and restorative approaches. It aligns with the principles of the circular economy,

agroecological practices and strategies that promote resilience and multifunctionality within agricultural systems.

Sustainable agronomy goes beyond technical optimisation and encompasses the value-based, political and social dimensions that influence the choice of practices and investment decisions [6]. While agroecology and sustainable agriculture are closely related concepts, they differ in focus: agroecology relies on ecological principles and local knowledge, whereas sustainable agriculture provides a broader institutional framework for addressing global challenges [15].

Sustainable agronomy requires integrating multiple disciplines, stakeholders and methods. Developing indicators across local, regional and global levels is vital for shaping strategies that ensure long-term sector sustainability. Effective implementation depends on models that bridge theory and practice.

2.2. Economic dimensions of sustainable agroecology

Implementing sustainability in agriculture relies on combining agroecological and agroeconomic models. While the former focuses on local, eco-friendly practices, the latter emphasises market viability and profitability. Their integration supports the development of resilient and inclusive agri-food systems.

Agricultural subsidies are among the most widely used tools of agricultural policy, but their multilayered role and often misaligned objectives frequently hinder efficiency, equity and sustainability. While they can enhance food availability, reduce import dependency and stabilise farm incomes, subsidies also tend to generate fiscal pressures and ecological side effects, such as excessive fertiliser use and market distortions [17]. Weak targeting, delivery delays and neglect of local conditions further reduce their effectiveness, highlighting the need for more precisely designed and better coordinated support measures.

In addition to fiscal support, sustainable agroecology requires a strategic approach that links agricultural production with other sectors of the economy. In developing countries, high agricultural productivity contributes positively to economic growth and employment, particularly when the sector is diversified and integrated with industry and services [18]. Empirical studies confirm that an increase in the agricultural labour force, higher value added, and trade openness support GDP growth. In this context, production diversification, agribusiness development, and strengthening local supply chains are essential for enhancing rural resilience and overall system sustainability.

Contemporary models of sustainable agroecology require not only economically rational incentives but also the development of precise tools for evaluating policy impacts. Multiscale methodological frameworks enable the definition of criteria and indicators across various levels, from agroecosystems to regional policies, focusing on productivity, stability, resilience, reliability and adaptability [19]. This approach allows for a comprehensive analysis of policy outcomes and the assessment of trade-offs and interrelations between the objectives of different stakeholders.

Although numerous studies highlight a positive correlation between GDP growth and agricultural value added, contemporary analytical approaches emphasise that this does not necessarily imply causation. Institutional context, development level, and external factors can significantly influence outcomes, requiring cautious interpretation of findings [20]. Consequently, there is growing emphasis on the need for a systemic approach that links agriculture with industry, services, and regional development [21]. Recognising agriculture as a driver of rural transformation is essential for designing sustainable development policies at multiple levels.

2.3. Legal framework and institutional mechanisms

Legal frameworks derived from technical harmonisation within the European Union can significantly enhance agricultural sustainability by supporting both product standardisation and occupational safety. In Poland, the application of compliance regulations in the agricultural machinery sector has reduced accident rates and improved safety conditions on family farms [22]. At the international level, food quality and safety standards play a crucial role in contemporary regulatory systems, particularly in global trade and bilateral agreements. Analysis of public

communication during the Transatlantic Trade and Investment Partnership (TTIP) negotiations, an initiative to align EU and US regulatory and trade standards, showed that media coverage failed to clarify legal and technical food safety issues for consumers [23]. These findings underscore the importance of legal mechanisms such as conformity assessments and risk analysis, as well as the need for transparent, coordinated institutional communication to foster trust in food policy and regulation.

The harmonisation and implementation of international and private food standards, such as GlobalGAP, BRC and IFS, contribute to both producer competitiveness and the sustainability of food systems. These standards facilitate market access, enable traceability and strengthen consumer trust. However, their adoption varies significantly across countries, with institutional capacity, market size and pre-existing trade relations with the countries of origin of the standards (e.g. Germany and the United Kingdom) playing a key role in the certification process [24]. This highlights the risk that, while formally open, these systems may in practice favour existing trade flows and hinder access for new entrants from developing countries.

The role of legislation in promoting sustainable agriculture lies in supporting practices that preserve resources and reduce negative externalities, such as limiting pesticide use, protecting soil quality, and promoting biodiversity. The adoption of comprehensive legal frameworks, accompanied by effective oversight mechanisms and advisory support, is essential for aligning agricultural practices with sustainable development goals [11]. At the global level, documents such as the FAO's framework for agricultural legislation and The World in 2050 initiative highlight the need for regulatory approaches that integrate economic, social and environmental objectives [14]. Institutional mechanisms, including national food safety agencies, standardisation bodies and inspection services, are responsible for ensuring consistent implementation of regulations, while maintaining the flexibility necessary for innovation and adaptation to local conditions.

3. Social change and governance in sustainable agronomy

Sustainable agronomy entails changes that extend beyond technological innovations and economic incentives, requiring a deeper understanding of social dynamics and the role of actors in the transformation process [12,25]. The way in which communities accept and adapt sustainable practices is shaped by norms, trust, identities and decision-making patterns [26], while managing these changes calls for participatory models and the integration of diverse perspectives [27]. The focus is on social capacities for collective action and institutional readiness to enable a just and inclusive transition towards more sustainable systems [3].

3.1. Sociological perspectives and adoption factors

The adoption of sustainable agricultural practices depends not only on technical or economic factors, but also on social context, value systems and institutional support. Studies show that farmers' decisions are shaped by community norms, identities and the social role of the "good farmer" [26]. Innovations are often embraced through collective processes, trust-based networks and local interactions, underscoring the role of social dynamics in enabling sustainable transitions [12].

Recent research underscores the complexity of agroecological transitions, emphasising the need for multidimensional approaches that integrate social, political, and market-related factors. The socio-economic aspects of agroecology are closely tied to land access, institutional support, political commitment, and active participation of local communities. Effective implementation requires participatory methods, on-the-ground engagement, and the inclusion of diverse stakeholders to bridge the gap between short-term economic interests and long-term sustainability objectives. Local knowledge, consumer involvement, market incentives, and enabling political frameworks all play a crucial role in promoting more balanced and resilient agri-food systems [25].

Farmer attitudes and behaviours are gaining prominence in research on sustainable agriculture. Four key approaches to behavioural change have been identified: innovation, stakeholder empowerment, knowledge co-creation, and systems thinking [27]. Evidence shows that social, economic and environmental factors interact to shape farmers' willingness to adopt change, while

cultural and regional contexts contribute to varied responses. This underscores the importance of locally tailored interventions informed by a nuanced understanding of social dynamics.

Decision-making in sustainable agriculture is shaped by adaptive and dynamic processes that unfold over time and in response to changing environments. Flexibility, responsiveness and anticipation are key components of on-farm decision-making models [28]. Understanding adaptation as a sequential process provides deeper insight into farmers' behaviour, particularly in the face of climate risks and complex uncertainty. Accordingly, farm decision-making models shed further light on how farmer behaviour evolves under such conditions.

3.2. Economic, sociological and ethical aspects of implementing sustainable solutions

The implementation of sustainable practices in agronomy is influenced not only by their technical efficiency or regulatory compliance, but also by a range of economic, social and ethical factors that shape stakeholders' readiness to adopt change. From an economic standpoint, profitability, the availability of incentives and exposure to market risks are critical considerations [10]. Farmers' decisions are guided not only by environmental and legal obligations but also by anticipated costs, return on investment and long-term viability [5].

Social aspects encompass local dynamics, roles, and the status of communities where changes are implemented, with the adoption of innovations depending on social norms, trust in institutions, and community participation in decision-making [12, 26]. Table 1 outlines key ethical considerations and recommendations to be taken into account when designing and implementing sustainable innovations in agronomy, with an emphasis on participatory mechanisms based on knowledge exchange and the strengthening of local capacities.

Tabela1. Ethical aspects of introducing sustainable agrotechnological solutions [5,9,21-23,25,29-32].

Ethical principle	Challenges	Recommendations (with sources)
Informed consent	Insufficient understanding of research goals and participant rights	Provide clear and accessible information based on ethical body guidelines [29]
Privacy and confidentiality	Handling of sensitive data on practices and participants' lives	Implement data protection measures throughout the research process [30]
Power relations	Unequal position between researchers and local actors	Involve communities in all stages of research and decision-making [31]
Economic risk	Potential financial consequences for participants	Transparently communicate possible costs and benefits [5]
Vulnerable groups	Exclusion of youth, women, and minorities	Ensure inclusive mechanisms for protection and participation [21]
Technological pressure	Imposing digital solutions without prior community preparation	Introduce gradually through education and institutional support [9]
Access to information	Unequal access to knowledge and data among actors	Develop local information systems and advisory networks [23]
Gender and generational sensitivity	Exclusion of women and young people from decision-making	Implement targeted inclusion measures in development projects [25]
Corporate influence	Risk of dominance by large actors in standardisation and policymaking	Strengthen participation of smallholders in consultation processes [32]
Legislative coherence and legal certainty	Lack of transparency or overly complex regulations; misalignment between local and international legal frameworks	Provide clear, applicable, and locally understandable regulations; involve producers and experts in consultations [22,23]

From an ethical standpoint, research and innovation in the agricultural sector should be grounded in principles of fairness, voluntariness, and the protection of vulnerable groups. Key considerations include informed consent, privacy, power dynamics, and the equitable distribution of benefits and risks, as well as an understanding of the social norms that shape farmers' behaviour. The adoption of sustainable practices does not depend solely on their technical efficiency or economic viability, but also on the broader social context, value systems, and institutional support. Sociological analyses indicate that actors' decisions are shaped by symbolic meanings, perceptions of what constitutes a "good farmer", and local community norms [26], while the implementation of innovations often occurs through collective processes and networks of interaction [12]. The successful application of sustainable solutions is not determined by isolated interventions, but by their integration into a broader system of governance, which must be understood as a comprehensive framework connecting various stakeholders, sectors, and policies across ethical, social, and institutional dimensions.

3.3. Towards an integrated model of sustainability governance in agronomy

Sustainability governance in agronomy requires a systemic approach that incorporates ecological, economic, social, and governance dimensions [3,14]. Faced with challenges such as climate change, resource degradation, and growing inequalities, fragmented responses are no longer sufficient. Coherent institutional frameworks and cross-sectoral policy coordination are needed [4] to connect local knowledge, scientific evidence, and regulatory mechanisms in order to strengthen the resilience and stability of agri-food systems [25].

Agroecological transitions cannot be limited to technical solutions; they require participatory governance models involving communities, expert institutions, and policymakers [12,26]. Trust, social capital, and collective action are critical for successfully translating sustainable approaches into practice. Within this framework, theoretical models such as sustainalism [3] provide a conceptual foundation for aligning sectoral goals, highlighting equity, social inclusion, and balance as core principles of sustainability. Innovation, in this sense, is understood not only as technological advancement but also as a socially embedded process [8].

N At the local level, the effectiveness of integrated models depends on their adaptability to agroecological and socio-cultural specificities. Research indicates that flexible decision-making mechanisms and stakeholder dialogue contribute to broader acceptance and greater effectiveness of sustainable practices [27]. The future of food systems relies on models that integrate all dimensions of sustainability, with strategies such as agroecological, organic and precision agriculture playing a vital role in resource conservation, food security and public health [33].

Transitioning towards such a model requires coordination across multiple levels, from the formulation of national policies to the empowerment of local actors, along with continuous evaluation and alignment of measures with sustainable development goals.

4. Conclusion

Sustainable agronomy is increasingly recognised as a comprehensive strategic framework that extends beyond yield enhancement and process optimisation. It integrates economic, social, legal and ethical dimensions in the transformation of agri-food systems. The reviewed models show that the successful implementation of sustainable practices depends on a combination of factors, including regulatory clarity, institutional support, local community engagement and accessible economic incentives. Digitalisation and innovation hold considerable potential to enhance sectoral efficiency and resilience, provided they are aligned with societal values and principles of equity. Multidisciplinary perspectives offer deeper insights into the complex interplay of actors, norms and institutional structures that influence decision-making in agriculture.

Effective sustainability governance in agronomy requires connecting strategic planning with local knowledge and social context. Moving away from fragmented policies towards integrated management models that involve all stakeholders and balance short-term goals with long-term system stability is essential. Sustainable agronomy should therefore be seen not only as an objective, but as a continuous process that demands learning, adaptation and collective engagement in

building more resilient and fair development pathways. Long-term success depends on the capacity of agricultural systems to generate not only economic value, but also social cohesion and ecological balance. This integration represents the core potential of sustainable agronomy as a key enabler of a responsible transition towards a more sustainable future.

Conflicts of Interest: The authors declares no conflict of interest.

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