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From Productivism to Integrated Agriculture: Historical Trajectories of Paradigms, Sustainability Tensions, Digitalization, and Policy Agendas for Agricultural System Transition

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A R T I C L E I N F O

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A B S T R A C T

This article asserts that the transition towards integrated agriculture is a historical consequence and a policy necessity to address ecological-social crises while maintaining food productivity. This study uses a narrative–integrative qualitative literature review (QLR) of publications from 2020–2026 to (i) map the historical trajectory of agricultural paradigms, (ii) analyze contemporary tensions between productivism, sustainability/agroecology, and digitalization/precisi on, and (iii) formulate a conceptual framework and policy implications for integrated agriculture. The main findings indicate that paradigm shifts move from productivist modernization to a more systemic corrective agenda: sustainable intensification, agroecology, and digitalization, each offering different mechanisms and risks. Empirical-conceptual evidence supports integrated agriculture (e.g., crop–livestock integration, rice–fish, agroforestry, and bioenergy integration) as a system redesign strategy that can increase diversification, nutrient cycling efficiency, and resilience. However, its benefits are contextual and involve trade-offs, requiring appropriate design and institutional support. Policy recommendations are prioritized on orchestrating cross-sector governance, financing and incentives to reduce adoption risks, strengthening system-design-based extension services, and data governance so that digitalization supports sustainability inclusively. The article concludes with a targeted research agenda to strengthen impact evidence, examine trade-offs, and clarify the institutional prerequisites for transition

INTRODUCTION

The development of agriculture is one of the main foundations in the journey of human civilization, which continues to undergo transformation along with social, economic, and technological changes. From the Neolithic revolution to today's digital era, agriculture not only functions as a food provider but also as an important pillar in economic development and global social stability. In the modern context, the agricultural sector faces increasingly complex pressures, such as world population growth, environmental degradation, and increasingly unpredictable climate change. Therefore, the study of the paradigm and history of agricultural development becomes very important for understanding the dynamics of transformation towards a more adaptive and sustainable agricultural system [1], [2]..

The urgency of this research becomes even stronger as conventional farming systems that are oriented towards high productivity begin to show various negative impacts, such as declining soil quality, environmental pollution, and socio-economic disparities among farmers. The agricultural model based on the Green Revolution, which for several decades has been considered a solution for global food security, is now criticized for its dependence on external inputs and its impact on ecosystem sustainability. This has driven the emergence of a new paradigm that emphasizes the balance between productivity and environmental sustainability [3].

Although there has been much research discussing the development of agriculture from a technological or economic perspective, there still exists a research gap in integrating historical aspects and the evolution of agricultural paradigms comprehensively toward the concept of integrated agriculture. Most studies tend to be partial, for example only discussing sustainable agriculture, digitalization, or agroecology separately without considering their historical connections. In fact, understanding the evolution of agricultural paradigms comprehensively is very important for designing a more holistic future agricultural system [4], [5].

In addition, there is a conceptual gap in linking the transformation of agricultural paradigms with the context of globalization, climate change, and the development of digital technology simultaneously. Many studies have not explicitly examined how the integration of these factors shapes new directions in modern agricultural systems, particularly towards an integrated agricultural model that combines ecological, social, and technological aspects. Therefore, a more integrative approach is needed to systematically understand these changes [6], [7]. Based on this gap, this study raises several main research questions, namely: (1) how the history of agricultural development shapes the modern agricultural paradigm; (2) how the evolution of agricultural paradigms from subsistence to sustainable and digital agriculture occurs; and (3) how the integration of various paradigms can form a concept of integrated agriculture that is adaptive to global challenges. These questions serve as the basis for analyzing the relationship between history, paradigms, and the transformation of agricultural systems comprehensively.

The main purpose of writing this article is to conduct an in-depth analysis of the historical evolution and paradigms of agriculture, as well as to identify the direction of transformation towards sustainable integrated agriculture. Specifically, this article aims to: (1) examine the historical development of agriculture from a multidimensional perspective; (2) analyze the shift in agricultural paradigms in a global context; and (3) formulate a conceptual framework for integrated agriculture as a solution to various challenges in the modern agricultural sector. Thus, this research is expected to provide both theoretical and practical contributions to the development of sustainable agricultural policies [8], [9].

Furthermore, this article also has strategic significance in supporting the sustainable development agenda, particularly related to food security, poverty alleviation, and climate change mitigation. In the context of Indonesia and other developing countries, the transformation towards integrated agriculture becomes very important to increase productivity while maintaining the sustainability of natural resources. Therefore, this study is not only academically relevant but also has significant policy implications in designing future agricultural systems that are inclusive, resilient, and sustainable [10], [11], [12].

LITERATURE REVIEW

History of Agricultural Development

The history of agriculture can be traced back to the Neolithic revolution around 10,000 years ago, when humans began transitioning from a nomadic lifestyle of hunting and gathering to a settled life of farming. This change is considered an important milestone in human civilization because it allowed the formation of permanent communities, land ownership, and the emergence of more complex social systems. Crops such as wheat, barley, rice, and corn became an important part of early domestication. In addition, humans also began domesticating animals to help with food production and transportation. The development of agriculture during this period had a significant impact on social structure because it created a food surplus that enabled the division of labor. From this point, great civilizations in Mesopotamia, Egypt, and East Asia developed. The early history of this agriculture shows that the economic and social transformation of humans is inseparable from the ability to manage and develop agricultural systems systematically [13], [14].

In ancient civilizations such as Mesopotamia, agriculture played a key role in sustaining the life of the world's first cities. Complex irrigation systems were built to channel water from the Euphrates and Tigris rivers to farmlands, enabling large-scale food production. In Egypt, the Nile River became the main source of soil fertility through annual floods that provided fertile silt for agricultural land. These agricultural systems supported the development of great kingdoms with hierarchical social structures and strong bureaucracies. Meanwhile, in East Asia, rice paddy farming began to develop with efficient irrigation techniques. Simple technological advances such as plows, wheels, and crop storage systems also strengthened the basis of ancient agriculture. This history shows that the success of early civilizations was greatly influenced by

innovations in agriculture that ensured a sustainable food supply for their communities [15].

Agriculture in the classical era, such as during the times of Greece and Rome, showed advancements in production and distribution techniques of agricultural products. The Romans developed large plantation systems or latifundia managed by slaves and producing commodities for both local markets and export. Irrigation technology, water channels, and farming tools increasingly developed, thereby improving production efficiency. In addition, the Romans also built road systems that facilitated the distribution of harvests to various regions of the empire. Agriculture, besides serving as a source of food, also became the foundation of the economy and the military. On the other hand, the Greek people emphasized small-scale agriculture with a focus on grapes, olives, and grains, which became important commodities in trade. During this period, agriculture was not only an economic activity but also a part of the culture and identity of society. This demonstrates the central role of agriculture in supporting the greatness of classical civilization [16].

Entering the Middle Ages in Europe, the agricultural system underwent changes with the development of feudalism. Farmland was managed by the nobility and the church, while peasants worked as laborers in exchange for protection. This system created dependence between the peasants and the landowners. Nevertheless, innovations continued to develop, such as the use of windmills and water mills to grind wheat and the division of land with a three-field rotation system. This system allowed the land to remain fertile by planting different types of crops alternately. At the same time, agriculture in Asia developed rapidly with irrigated rice field systems that supported large population growth. The history of medieval agriculture shows how social, economic, and political structures shaped agricultural practices. This demonstrates that agriculture, besides being determined by technology, is also determined by the power system and the social order prevailing at that time [17].

The agricultural revolution in Europe in the 17th to 18th centuries became one of the major turning points in the history of agricultural development. The use of new technologies such as iron plows, seed planting tools, and the implementation of more advanced crop rotation significantly increased productivity. This shift contributed to population growth, urbanization, and the birth of the industrial revolution. With the food surplus generated, many rural workers migrated to cities to work in the industrial sector. The agricultural revolution also marked a shift from the feudal system toward agrarian capitalism, where land began to be seen as an economic asset that could be traded. Innovations in agriculture not only increased crop yields but also influenced social, economic, and political changes broadly. This period laid the foundation for the emergence of a new paradigm that prioritized productivity and efficiency in agricultural activities [18].

The Industrial Revolution of the 18th and 19th centuries drastically accelerated the transformation of agriculture. Mechanization through the use of tractors, harvesting machines, and soil processing equipment increased the scale of agricultural production. Agriculture was no longer entirely dependent on human and animal labor but began to rely on machine technology. In addition, the development of chemistry produced artificial fertilizers and synthetic pesticides that could significantly increase crop yields. However, the excessive use of chemical inputs also caused negative impacts on the soil and the environment.. During this period, agriculture became increasingly integrated with the market economy, where agricultural products were produced to meet the needs of industry and international trade. This transformation marked the birth of modern, more complex agriculture, while also creating new challenges related to ecosystem sustainability and the welfare of small farmers in facing the dominance of large agribusinesses [19], [20].

The 20th century was marked by the Green Revolution pioneered by scientists like Norman Borlaug. This program introduced high-yield varieties of rice, wheat, and corn that were able to drastically increase productivity. At the same time, the use of chemical fertilizers, modern irrigation, and pesticides was increasingly implemented. The Green Revolution succeeded in reducing hunger in various developing countries, particularly in Asia and Latin America. However, this success also brought negative impacts such as soil degradation, water pollution, and loss of biodiversity. In addition, dependence on external inputs caused small farmers to experience economic pressure. The history of the Green Revolution shows that agricultural progress does not always bring equal benefits, but also creates disparities. Nevertheless, the Green Revolution became an important milestone in the history of global agriculture because it demonstrated human capability to transform the world food system through technological innovation [21], [22].

In the second half of the 20th century, agriculture became increasingly influenced by the development of biotechnology. Genetic engineering facilitated the development of transgenic crops that are resistant to pests, diseases, and extreme climate conditions. This technology opened opportunities to improve food security in the face of climate change and rapid population growth. Controversies regarding the safety of food, ethics, and the environmental impact of transgenic crops remain global debates. On the other hand, biotechnology research has also contributed to the development of more environmentally friendly biofertilizers and biopesticides. The history of biotechnology development in agriculture shows a shift from a mass production paradigm toward a system that is more based on science and advanced technology. This transformation marks the beginning of a new era, where agriculture focuses not only on yields but also on genetic innovation and long-term sustainability [23].

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The history of agriculture is also inseparable from the influence of globalization. International trade has made agricultural products an important commodity in the global economy. Food-producing countries must adapt to international standards regarding quality, food safety, and environmental sustainability. Globalization opens opportunities for farmers to reach wider markets, but it also presents challenges in the form of intense competition with imported products. Furthermore, small farmers are often marginalized in a global system that favors large agribusiness companies. History shows that globalization has shaped the pattern of global food distribution, while also strengthening interdependence among countries. The role of agriculture in international trade demonstrates that its history is not only local, but also part of the dynamics of the global economy. Therefore, the history of agricultural development cannot be separated from the context of globalization, which extends its reach to the international level [26], [27].

In addition to economic and technological aspects, the history of agriculture also shows the important role of culture and tradition. Many communities have developed agricultural practices based on local wisdom, such as the subak system in Bali or terracing in the Philippines. These practices not only function as methods of cultivation but also as part of cultural identity. History records that traditional agriculture is often more environmentally friendly compared to modern industrial systems. However, modernization and globalization have marginalized many local practices. Nevertheless, there are now efforts to revive agriculture based on local wisdom as part of the sustainable agriculture movement. This shows that the history of agriculture is not only about technology and production but also about values, culture, and social heritage that shape human relationships with nature. Thus, agriculture has a holistic and multidimensional historical dimension [28].

The history of agriculture also shows a close relationship with climate and ecosystem changes. For thousands of years, humans have adapted to different climatic conditions, ranging from wet tropical areas to dry deserts. This adaptation gave rise to various agricultural systems, such as shifting cultivation, irrigated rice fields, and dryland farming. However, modern climate change has posed new challenges, where seasonal patterns are irregular and natural disasters occur more frequently. This requires agriculture to transform again with more climate-resilient systems. The history of agricultural adaptation to environmental conditions demonstrates human flexibility in managing natural resources. However, the current climate crisis shows that adaptation must be faster and more innovative to ensure the global food system remains secure.

Thus, the history of agriculture is the history of human adaptation to the ever-changing dynamics of nature [29], [30].

In the 21st century, the history of agriculture entered a new phase called sustainable agriculture. This concept arises from the awareness that excessive exploitation of land, water, and biodiversity endangers the continuity of human life. Various approaches such as agroecology, organic farming, and local food systems are being redeveloped. This movement tries to balance productivity with environmental sustainability. The history of modern agriculture shows that dependence on chemical inputs and the global food industry cannot be maintained forever. Therefore, sustainable agriculture becomes part of the evolution of history that prioritizes long-term sustainability. This development reflects human efforts to correct past mistakes and design a food system that is fairer, healthier, and more environmentally friendly. Sustainable agriculture becomes an important milestone in history that connects the past to the future [31], [32].

The history of agriculture is also closely related to political developments and policies. Agricultural policies implemented by governments, both at the local and global levels, have a significant influence on the direction of its history. For example, fertilizer and improved seed subsidy policies in many developing countries encouraged the adoption of the green revolution. On the other hand, international trade regulations affect the competitiveness of local agricultural products. History also shows that political conflicts are often related to the struggle for agricultural resources, such as fertile land and water access. Thus, the history of agriculture is not only a technical issue but is also full of political dimensions. In the future, this history will continue to be influenced by global policies related to food, climate, and trade. This demonstrates that agriculture is always at the intersection of technology, politics, and economics, which influence each other dynamically [33].

The history of agricultural development reflects the long journey of humanity in adapting to natural, social, economic, and technological challenges. From the domestication of simple crops to modern digital agriculture, this history demonstrates humans' ability to continuously innovate. However, every advancement also brings consequences, both in the form of environmental damage and social inequality. Therefore, understanding the history of agriculture is very important for designing a more sustainable future. This history is not merely a record of the past, but also a mirror that provides valuable lessons for present and future generations. By studying the history of agriculture, the direction of integrated agricultural development can be organized to be not only productive but also equitable, environmentally friendly, and capable of withstanding global challenges. Ultimately, the history of agriculture is the history of human civilization itself [34], [35].

2. Evolution of Agricultural Paradigms

The agricultural paradigm is a framework of thinking that underlies how humans view, manage, and develop farming activities according to the demands of the times. Since the dawn of civilization, agriculture has experienced significant paradigm shifts, ranging from traditional subsistence-based systems to entering the modern agricultural era that emphasizes efficiency and productivity. This paradigm shift is influenced not only by internal factors such as technology and knowledge, but also by external factors such as global food needs, climate change, and the socio-economic dynamics of society. In its development, the agricultural paradigm is not merely a matter of production techniques, but also concerns the relationship between humans and nature. Therefore, the evolution of the agricultural paradigm can be understood as a reflection of changes in values, ideologies, and priorities in managing natural resources for the sustainability of human life across generations [36].

In the early period, the agricultural paradigm was still oriented towards fulfilling the basic needs of households. This system is called subsistence farming, where farmers only plant crops to meet the food needs of their families without considering excess production. This paradigm operated alongside minimal technology and limited knowledge about soil, water, and other natural resource management. Subsistence farming practices were also highly dependent on natural conditions, so when crop failures occurred, communities faced food crises. Although simple, this paradigm emphasized harmony with the ecosystem, because external inputs such as chemical fertilizers, pesticides, and mechanization were not yet known. In this context, agriculture focused more on daily survival than on the accumulation of economic surplus. This early paradigm became an important foundation in the history of agriculture, before the introduction of innovations that brought drastic changes to the food production system [37], [38], [39].

Along with the development of civilization, the agricultural paradigm began to shift towards intensification. Society began to utilize simple technology, such as irrigation, soil cultivation with metal tools, and plant breeding through seed selection. This intensification paradigm aims to increase crop yields in order to meet the needs of the growing population. In addition, agriculture also began to produce a surplus that could be traded, leading to the emergence of an agriculture-based economic system. This paradigm gave rise to labor specialization, the division of social roles, and the development of agrarian civilization. However, at this stage, environmental sustainability began to be threatened due to increasingly intensive land exploitation. Even so, the value of balance was still fairly maintained because technology had not yet developed as far as the industrial revolution. Therefore, the traditional intensification paradigm still has a close relationship with local wisdom and community-based natural resource management practices [40].

The advent of the industrial revolution in the 18th century brought significant changes in the agricultural paradigm. Agriculture was no longer seen as a simple activity, but as a production sector that needed to be enhanced through mechanization, the use of chemical fertilizers, and pest control

technology. This modern agricultural paradigm emphasizes productivity, efficiency, and market orientation. Farmers began producing commodities not only for local needs but also to meet regional and international demand. However, this paradigm also gave rise to various problems, such as environmental degradation, dependence on chemical inputs, and loss of biodiversity. Therefore, although the industrial revolution successfully increased food production significantly, the modern agricultural paradigm carries ecological consequences that are still felt today. This evolution marks a shift from subsistence-based agriculture toward large-scale agribusiness systems with a global orientation [41], [42].

In the 20th century, the agricultural paradigm was increasingly influenced by the Green Revolution, which introduced high-yield varieties, chemical fertilizers, and synthetic pesticides. Its main goal was to increase crop yields to address global hunger, especially in developing countries. The Green Revolution indeed succeeded in boosting productivity and reducing hunger rates, but it also brought about new problems. Dependence on external inputs made farmers economically vulnerable, while environmental pollution and soil degradation became increasingly severe. This paradigm emphasized short-term efficiency without considering ecosystem sustainability. As a result, a new awareness emerged among scientists and policymakers that agriculture is not only about quantity, but also about quality, sustainability, and ecological balance. This evolution shows that the agricultural paradigm is never static, but always dynamically moving in line with the continuously developing challenges of the times [22], [43].

The modern agricultural paradigm, which focuses on mass production, has produced various social and cultural impacts. Traditional community-based agriculture is beginning to be replaced by large-scale industrial agricultural systems that prioritize production efficiency. This has led to the loss of local knowledge, weakening of rural social solidarity, and an increase in the economic gap between small farmers and large agribusiness companies. Thus, the evolution of the agricultural paradigm also affects the social structure of society. Whereas agriculture was previously synonymous with togetherness and local wisdom, the modern paradigm makes agriculture more commercial and integrated with the global market. This condition drives social transformation in rural areas, providing economic opportunities but also potentially causing structural injustice. Therefore, shifts in the agricultural paradigm are always followed by changes in societal values and lifestyles [44], [45].

Entering the era of globalization, the agricultural paradigm increasingly emphasizes integration with the international trade system. Agriculture is no longer just about providing local food, but also as part of the global supply chain. Agricultural products are required to meet standards of quality, food safety, and distribution efficiency. Small farmers must compete against multinational corporations with large capital and access to advanced technology. This paradigm shows that agriculture is moving further away from its traditional patterns, where environmental sustainability is often sacrificed to meet international market demands. However, globalization also opens up new

opportunities for farmers to expand market access and utilize digital technology to increase productivity. The evolution of this paradigm shows the presence of contradictions; in addition to presenting opportunities, it also poses significant challenges for ecological sustainability and social justice [46].

As environmental awareness increases, the agricultural paradigm is beginning to shift towards the principle of sustainability. Agriculture is no longer measured solely by productivity, but also by its impact on ecosystems. The concept of environmentally friendly agriculture is being developed by utilizing biological technology, organic fertilizers, integrated pest management, as well as soil and water conservation. This paradigm emphasizes the importance of maintaining a balance between human needs and the preservation of nature. Sustainable agriculture prioritizes crop diversification, the use of environmentally friendly technology, and the integration of livestock with crops. This evolution marks a fundamental change in the perspective on agriculture, from merely an economic means to a system that supports ecology. Thus, the sustainability paradigm becomes the answer to food crises, environmental damage, and the increasing global food demand that must be met without depleting natural resources [47], [48].

The evolution of agricultural paradigms is also greatly determined by advances in science and technology. Innovations in biotechnology, genetics, and information technology are leading agriculture towards a more advanced direction. For example, the cultivation of transgenic plants that are resistant to pests and diseases is one of the important steps in increasing productivity. Likewise, the utilization of digital technologies such as the Internet of Things (IoT), big data, and artificial intelligence (AI) allows for more precise land management. This paradigm is known as smart farming, which offers high efficiency and more resource-efficient usage. This change emphasizes that the evolution of agricultural paradigms always goes hand in hand with technological advances. However, the emerging challenge is how to ensure that the technology not only benefits certain parties but can also be accessed fairly by small and medium farmers [49], [50].

In addition to technological factors, the evolution of agricultural paradigms is also influenced by demographic factors. Rapid population growth forces agriculture to significantly increase food production. Meanwhile, rapid urbanization reduces the number of agricultural workers and limits the available land. This situation encourages the emergence of a new paradigm that prioritizes innovation, land efficiency, and high productivity. One solution is urban farming, vertical farming, and hydroponics, which can be applied in cities with limited land. This paradigm shows that agriculture is no longer limited to rural land, but can also be integrated into urban life. Thus, the evolution of the agricultural paradigm is not only about changes in production methods, but also about adaptation to demographic dynamics and changes in modern societal lifestyles [51], [52].

Global climate change also accelerates the evolution of agricultural paradigms. Uncertain seasons, rising temperatures, and more frequent natural disasters force farmers to change their farming methods. The agricultural paradigm now must incorporate factors of adaptation and mitigation to climate change. Water-saving irrigation systems, the selection of drought-resistant varieties, and crop diversification are part of the new strategy. This adaptive paradigm emphasizes flexibility, resilience, and the sustainability of the food system. Without a change in paradigm, agriculture will struggle to withstand increasingly complex climate challenges. This evolution shows that agriculture is not just an economic activity, but also a socio-ecological system that must constantly adapt to the dynamics of the global environment. Therefore, the modern agricultural paradigm must prioritize sustainability as well as long-term resilience to climate crises [53].

The evolution of agricultural paradigms also touches on political and public policy aspects. Governments in various countries play an important role in determining the direction of agriculture through regulations, subsidies, and research investments. National food policies often become the foundation for the emergence of new paradigms, such as food security-based agriculture, organic agriculture, or digital agriculture. For example, some countries have adopted zero hunger policies that emphasize the production of healthy food while also preserving environmental sustainability. This paradigm emphasizes the crucial synergy of farmers, government, private sector, and the public to build a sustainable food system. This evolution affirms that agriculture is not just a technical matter, but is also influenced by political, economic, and global policy factors. Thus, the agricultural paradigm is always multidimensional, encompassing social, economic, environmental, and political aspects simultaneously [52], [54].

Society also plays an important role in shaping the agricultural paradigm. Consumer awareness of healthy, organic, and environmentally friendly food encourages the emergence of a more ethical agricultural paradigm. Market demand for organic and non-GMO products shows that the consumption paradigm also helps determine the direction of agricultural production. Consumers now not only consider price and availability, but also assess the social and ecological impacts of the products they consume. As a result, the agricultural paradigm is increasingly directed to meet the demands of critical and environmentally conscious consumers. In other words, the evolution of the agricultural paradigm is influenced not only by farmers or the government, but also by global consumer preferences. This indicates that agriculture is an interconnected system, where small changes in consumption patterns can shift the overall direction of the agricultural paradigm [55].

The paradigm shift in agriculture also reflects the dynamics of the relationship between humans and nature. While in the early days of agriculture humans were still entirely dependent on nature, now humans strive to control and engineer the environment for the sake of production. However, over time, humans realized that excessive exploitation actually damages ecosystems and threatens food sustainability. Therefore, the latest agricultural paradigm

emphasizes the importance of harmony between humans and nature. Integrated agriculture that combines modern technology with ecological principles is considered the answer to this problem. This paradigm seeks to build a balance, where productivity is still achieved without sacrificing environmental sustainability. Thus, the evolution of the agricultural paradigm can be seen as a long journey towards a new awareness, that sustainability and ecological balance are the main foundations for the future of the world's food.

The evolution of agricultural paradigms reflects the long journey of humans in managing natural resources for survival. From subsistence, intensification, the green revolution, to smart and sustainable agriculture, each stage demonstrates efforts to adapt to the challenges of the times. This paradigm shift affirms that agriculture is not just a technical activity, but also a complex social, political, economic, and ecological process. Going forward, the agricultural paradigm is likely to continue evolving towards a more integrated, environmentally friendly, and digitally-based system. This indicates that the future of agriculture cannot be separated from the principles of sustainability, innovation, and social justice. By understanding the evolution of agricultural paradigms, we can design the direction of agricultural development more wisely, inclusively, and capable of addressing global challenges while preserving the sustainability of the Earth [54], [56].

METHODOLOGY

This methodology section briefly but rigorously explains how this article uses a narrative–integrative qualitative literature review (QLR) to build a conceptual-historical synthesis on the evolution of agricultural paradigms and the direction of integrated agriculture, without claiming the exhaustive coverage of a systematic literature review but still maintaining transparency of the process through scope limitation, selection trace, and search log [57], [58]. The search scope primarily focuses on publications from the 2020 to 2026 period to capture the latest developments related to sustainability, agroecology, agricultural system transformation, as well as digitalization/precision within the framework of paradigm shifts; pre-2020 sources may only be added selectively if they are canonical-historical and necessary to bridge development phases (for example, the green revolution) toward current debates. The prioritized databases are Scopus and the Web of Science Core Collection because both are curated citation indexes that support backward/forward citation chaining tracking and help maintain the consistency of source quality [59], [60].

Inclusion criteria are established so that the selected evidence is truly relevant to answering the research question (RQ) in the Introduction: (i) journal articles of type Article or Review; (ii) written in Indonesian or English; (iii) published in the period 2020 - 2026; (iv) explicitly discussing the history/trajectory of agricultural changes, paradigm shifts (e.g., productivism—sustainability—agroecology—digital), transformation of agricultural/food systems, or integration design (e.g., crop–livestock integration, input–residue circularity, biophysical-social synergy) as a response to ecological and social challenges. Exclusion criteria include: (a) purely technical articles (e.g., algorithms) without implications for paradigms or historical trajectories; (b) out-

of-scope studies (not related to agriculture/food systems) or those that cannot be linked to the RQ; and (c) sources that do not provide adequately verifiable arguments/findings. The selection procedure is carried out in stages: export results from Scopus and WoS → deduplication → screening titles/abstracts based on criteria → full-text assessment → citation chaining to capture anchor references and influential conceptual debates; all inclusion–exclusion decisions are recorded to reduce the risk of selection bias and reporting failures that often occur in traditional reviews if there is no explicit procedure [60], [61].

The synthesis was carried out through thematic analysis and integrative narrative: each full-text article that passed was extracted into a matrix (study context, concept/paradigm used, key assumptions, type of evidence, main findings/arguments, and policy implications), then coded to identify patterns of historical continuity–discontinuity and mechanisms of paradigm shifts; themes were then arranged into a line of argument explaining transitions between paradigms to produce a conceptual framework of "integrated agriculture" consistent with the research questions and article objectives [58]. To maintain rigor, this QLR applies a "fit-for-purpose" quality appraisal (not a score-based assessment like SR) by evaluating outlet credibility (reputable/indexed journals), clarity of objectives, coherence of arguments, methodological transparency (for empirical studies), and contextual relevance (especially for developing countries/Indonesia); Strong sources that contradict the dominant narrative are still maintained as negative/counter evidence so that the synthesis does not fall into confirmation bias [57], [61]. Validity/rigor is strengthened through (i) an audit trail and extraction matrix, (ii) retracing key claims to the primary sources, (iii) checking theme consistency against the RQ, and (iv) presenting scope limitations as a reasonable consequence of a narrative review oriented towards argument development, while thematic techniques are used to ensure that the interpretation process remains structured and traceable [59], [62].

RESULTS AND DISCUSSION

Sustainable Agriculture Paradigm

The paradigm of sustainable agriculture was born as a response to various negative impacts of the intensive farming model that relies heavily on external inputs such as chemical fertilizers, synthetic pesticides, and mechanical technology. This intensive model does indeed significantly increase food production, but on the other hand, it also causes soil degradation, water pollution, and loss of biodiversity. Therefore, sustainable agriculture is understood as an approach that seeks to balance human needs for food with environmental conservation and the continuity of future generations. This approach emphasizes environmentally friendly practices, resource use efficiency, as well as the strengthening of farmers' socio-economic institutions. The sustainable paradigm, in addition to being viewed as a production technique, also becomes a moral framework that emphasizes collective responsibility to maintain ecosystem sustainability [63].

Sustainable agriculture is also based on the principle of harmonious interaction between ecological, social, and economic aspects. The ecological aspect emphasizes the conservation of soil, water, and biodiversity as basic capital for long-term production. The social aspect underlines the importance of community involvement, fair distribution of agricultural yields, and protection of vulnerable groups such as small-scale farmers. Meanwhile, the economic aspect focuses on production efficiency that not only provides financial profit but also does not compromise the sustainability of natural resources. Thus, this paradigm creates a holistic approach that positions agriculture as an integral part of sustainable development, in line with the Sustainable Development Goals (SDGs), particularly concerning food security, poverty reduction, and environmental protection [8].

In practice, the sustainable agriculture paradigm is realized through various strategies, one of which is the implementation of organic farming, which reduces or eliminates the use of synthetic chemicals. In addition, agroforestry or the integration of crops with trees is also an important approach to maintain soil fertility and reduce the risk of erosion. Biology-based technologies, such as the use of biofertilizers and integrated pest management, are also part of the strategy to strengthen the resilience of agricultural ecosystems. Along with that, digital technology innovations in sustainable agriculture have also emerged, such as the Internet of Things (IoT) for land monitoring, big data for climate prediction, and blockchain for transparency in the food supply chain. The integration of these innovations strengthens the sustainable paradigm by combining local wisdom and modern technology to support adaptive and resilient agricultural practices [64], [65].

The sustainable agriculture paradigm also emphasizes the importance of circularity in the food system. This concept promotes the principles of a circular economy, where waste from one production process can become an input for another process. For example, organic waste from households can be processed into compost that enriches the soil again. The implementation of this system not only reduces dependence on external inputs but also helps lower carbon emissions. In addition, this paradigm requires a landscape-based approach, which not only focuses on agricultural land alone but also considers the connection with forests, rivers, and other buffer zones. In this way, agriculture does not stand alone but becomes part of a broader ecosystem, so its sustainability can be maintained holistically [66], [67].

In Indonesia, the sustainable agriculture paradigm is increasingly gaining attention, especially with the growing awareness of climate change issues and the vulnerability of farmers to ecological disasters. Government programs, such as the development of organic farming, integrated farming systems, and environmentally friendly villages, indicate a shift in orientation from merely pursuing production to moving towards more sustainable agricultural development. However, the implementation of this paradigm still faces challenges in the form of limited infrastructure, low digital literacy among farmers, and market dominance by chemically-based products. Therefore, strengthening farmers' capacities through education, training, and access to

environmentally friendly technologies becomes a key factor in realizing the success of the sustainable agriculture paradigm at both local and national levels [68], [69], [70].

The sustainable agriculture paradigm not only emphasizes increasing crop yields but also maintaining ecosystem balance. One of the key concepts is agroecology, which is an approach that emphasizes the integration of agriculture with ecological principles. Through the application of agroecology, agricultural systems are able to utilize natural interactions such as biological pest control, crop rotation, and soil conservation to reduce dependence on synthetic chemical inputs. Thus, this paradigm seeks to reduce the negative impacts of conventional agriculture such as water pollution, soil degradation, and biodiversity loss. The agroecology approach also prioritizes the local wisdom of farmers, so agricultural practices are not only ecologically relevant but also align with the culture and social conditions of the community. Therefore, this paradigm is believed to be one of the main solutions in creating a sustainable food system in the future [71].

In addition to agroecology, the sustainable agriculture paradigm also integrates modern technology, such as digital agricultural sensors, drones, and the Internet of Things (IoT). These technologies are used to monitor land conditions, soil moisture, and plant nutrient needs in real time. In this way, farmers can optimize the use of water, fertilizers, and pesticides in a more efficient and environmentally friendly manner. This concept is known as precision agriculture. The integration of technology with sustainable principles creates an agricultural system that is more adaptive to climate change while also increasing productivity. This shows that sustainable agriculture does not mean completely returning to traditional methods, but rather combining ecological practices with technological innovations. This synergy enables the creation of agricultural patterns that are oriented toward food security while maintaining ecosystem sustainability for future generations [72], [73].

The sustainable agriculture paradigm also emphasizes the importance of social justice and the welfare of farmers. In many cases, modern agricultural systems tend to favor large corporations while small farmers are often marginalized. Therefore, sustainable agriculture seeks to ensure the fair distribution of benefits, access to markets, and the protection of the rights of small farmers. One relevant approach is fair trade, where farmers receive a reasonable price for their produce. With this paradigm, sustainability is viewed not only in ecological terms but also includes social and economic aspects. This is important so that the agricultural system can not only survive in the long term but also improve the quality of life of the primary actors in the food supply chain, namely farmers [74], [75], [76].

The concept of sustainability in agriculture is also closely related to climate change mitigation. Agriculture is a sector that contributes significantly to carbon emissions, particularly from the use of chemical fertilizers, livestock, and land clearing. The sustainable agriculture paradigm seeks to reduce the carbon footprint through methods such as managing organic fertilizers, using renewable energy, and practicing carbon farming or agriculture that absorbs carbon by

increasing soil organic matter. In this way, agricultural systems not only function as food producers but also as part of the solution in facing the climate crisis. These efforts are also supported by research showing that soils with high organic matter content can store more carbon, thereby strengthening both ecological functions and long-term productivity [77].

The sustainable agriculture paradigm also emphasizes the importance of biodiversity. The diversity of plants, animals, and soil microorganisms plays a crucial role in maintaining the balance of agricultural ecosystems. For example, the presence of natural enemies of pests can reduce the need for pesticide use, while soil microbes help improve soil fertility and health. By maintaining diversity, agricultural systems become more resilient to shocks, whether due to pest attacks, diseases, or climate change. Therefore, sustainable agriculture strategies encourage polyculture cropping patterns, agroforestry, and the conservation of natural habitats around farmland. These practices provide dual benefits, namely increased agricultural yields as well as broader environmental protection [78], [79], [80]. In addition to biodiversity, this paradigm also highlights the importance of a circular economy in agricultural systems. This concept emphasizes the reuse of agricultural waste as new resources. For example, organic waste can be processed into compost, while biomass waste can be used as an alternative energy source. Thus, the production and consumption cycle in the agricultural sector becomes more efficient and generates minimal waste. Circular economy practices can also reduce farmers' production costs as they can reuse existing resources. This not only increases farmers' competitiveness in the market but also reduces the negative environmental impact of agriculture. This paradigm shows that sustainability in agriculture not only means preserving the environment but also optimizing economic efficiency [81], [82], [83].

One of the biggest challenges in realizing sustainable agriculture is the need for supportive public policies. Without regulations that encourage environmentally friendly practices and provide incentives for farmers, this paradigm is difficult to implement widely. The government plays an important role in providing access to green technology, subsidizing organic fertilizers, and supporting education programs for farmers about sustainable agricultural practices. In addition, trade policies must also be directed to protect local farmers from unfair competition in the global market. With a comprehensive policy framework, the sustainable agriculture paradigm can develop more quickly and have a significant impact on both national and global food security [84].

The sustainable agriculture paradigm also requires collaboration among various actors, ranging from farmers, academics, government, to the private sector. Academics can provide research and innovation to support environmentally friendly practices, while the private sector can invest capital in sustainable agricultural technologies. On the other hand, the government needs to create conducive regulations, and farmers as the main actors must receive training and guidance to be able to adopt these practices. This multi-stakeholder collaboration becomes a key element because the challenges in agriculture are not only technical but also social, economic, and political. With close cooperation,

the transition to sustainable agriculture can be carried out more inclusively and evenly across different layers of society [85], [86].

In addition to collaboration, education and outreach to farmers play a central role in building a sustainable paradigm. Many farmers in rural areas still rely on traditional methods or excessive use of chemical fertilizers due to limited knowledge. Effective outreach programs can help them understand the importance of environmentally friendly practices, how to manage land sustainably, and the long-term benefits of such systems. Education is not only limited to farmers but also to the younger generation through school curricula that incorporate sustainable agriculture concepts. In this way, future generations will have a greater awareness of the importance of maintaining a balance between food production and environmental sustainability [87].

The sustainable agriculture paradigm is a major transformation in the way humans view food production. It is no longer merely about pursuing quantity, but also quality, fairness, and ecosystem sustainability. This paradigm unites ecological, technological, social, economic, and policy aspects into a holistic whole. If applied consistently, this system can address global challenges such as food crises, climate change, and social injustices in the agricultural sector. Therefore, sustainable agriculture is not just a choice, but a necessity that must be prioritized to ensure the survival of current and future generations. This transformation requires a collective commitment as well as awareness that food is part of basic human rights that must be protected fairly and sustainably [88], [89], [90].

2. Agricultural System Transformation

The transformation of the agricultural system is a dynamic process that reflects changes in the patterns of food production, distribution, and consumption in response to continuously evolving global needs. These changes not only include technical factors but also social, economic, and environmental ones. As the world's population increases, agricultural systems are required to produce more food, of higher quality, and in an environmentally friendly manner. The development of technology, market globalization, and sustainability demands have shifted the way humans understand and conduct agricultural activities. If initially agriculture was more subsistence-based, now the transformation towards a modern agribusiness system with integration into the global supply chain is becoming increasingly dominant. This transformation also involves a change in the role of farmers, who were previously only small producers, to becoming part of important actors in the economic ecosystem. Therefore, agricultural transformation is not merely a matter of production, but also involves governance that is oriented towards the long term [91], [92], [93].

One of the main drivers of agricultural system transformation is the revolution in digital and biotechnology. Digital technology enables the implementation of precision agriculture through the use of sensors, drones, big data, and artificial intelligence. With this technology, farmers can monitor soil conditions, moisture, and plant health in real-time, making the use of agricultural inputs more efficient. Meanwhile, biotechnology has opened up opportunities for the creation of superior crop varieties that are resilient to climate change,

pests, and diseases. The application of technology-based systems not only increases productivity but also helps reduce negative environmental implications. This transformation brings agriculture into a new era, where data and information become important assets in decision-making. Therefore, the success of modern agricultural transformation heavily depends on the connectivity between technology, government policies, and farmers' ability to adopt innovations [94].

The transformation of agricultural systems is also closely related to the concept of sustainability, which emphasizes a balance between food production, environmental conservation, and community welfare. Today's agricultural systems are no longer solely oriented toward increasing yields, but also consider social and ecological impacts. Practices such as agroforestry, crop rotation, the use of organic fertilizers, and water conservation are beginning to be promoted as part of a sustainable approach. This becomes increasingly relevant as climate change poses serious challenges to global food availability. Efforts to transform toward more environmentally friendly systems also aim to reduce greenhouse gas emissions from the agricultural sector. Thus, sustainable agriculture is seen as an integral part of the food system transformation that must be carried out comprehensively to ensure long-term food security [69], [95].

Besides environmental aspects, the transformation of the agricultural system also drives changes in the social and economic structure of rural communities. Agricultural modernization demands an increase in farmers' capacity, both in terms of knowledge and skills. Education, training, and access to information become key factors for farmers to be able to adapt to technological and market developments. On the other hand, the role of women in agriculture is increasingly gaining attention, given their significant contribution to food production. This transformation also gives rise to new business models based on communities and cooperatives that can enhance farmers' bargaining power in the market. With broader involvement, agriculture is no longer seen as a traditional sector but as a driving force for inclusive rural development [96].

The transformation of the agricultural system is also influenced by the dynamics of the global market. Trade liberalization and connectivity between countries have expanded export opportunities for agricultural products. However, this also results in challenges such as price competition, international quality standards, and strict regulations. Small farmers often find themselves in an unfavorable position when facing a global market dominated by multinational companies. Therefore, policies are needed that can protect local farmers while also enabling them to compete in the international market. Agricultural transformation in the era of globalization must be able to integrate local needs with global standards, so that agricultural products are not only competitive but also meet sustainability aspects [97], [98].

The transformation of modern agriculture is also seen in the utilization of big data to support evidence-based decision-making. Data generated from land, weather, and market behavior sensors is collected and analyzed to predict plant growth patterns, harvest estimates, and commodity price fluctuations. This predictive analysis allows farmers to minimize the risk of losses due to crop

failure or market volatility. For example, machine learning algorithms can provide recommendations for the best planting times based on rainfall and temperature projections. Data not only serves as a record but also becomes an important instrument in smart agriculture strategies. The integration of big data with logistics systems also strengthens the agricultural supply chain, enabling the distribution of harvests to reach consumers more quickly and efficiently [99], [100], [101].

Another significant change is the development of a more integrated agricultural value chain. While farmers previously focused only on production, they are now also required to understand aspects of distribution, packaging, and marketing. This transformation encourages farmers to actively participate as business actors, not just raw material producers. Innovations in the value chain, such as agricultural e-commerce, digital distribution applications, and online marketing services, shorten the distance between farmers and consumers. This not only increases product selling prices but also improves farmers' bargaining power. A modern value chain can create a fairer agricultural ecosystem, where profits are no longer concentrated in intermediaries but are more proportionally shared along the distribution line [102], [103], [104].

The transformation of the agricultural system also emphasizes food security as a top priority. Food globalization presents challenges in the form of strict quality standards, whether in terms of safety, nutrition, or sustainability. For this reason, various technologies are applied, such as food quality sensors, blockchain for product origin transparency, and digital certifications that verify production standards. In this way, consumers can trace the product's journey from the field to the dining table. Ensured food safety not only increases consumer confidence but also opens access to global markets. This transformation ultimately strengthens the competitiveness of local agriculture in international markets, making the agricultural sector not only a support for domestic needs but also a high-value export commodity [105].

The agroecology approach has become an important part of the transformation of modern agriculture. Agroecology emphasizes the integration of ecological principles with agricultural practices to create a more sustainable production system. Examples include the use of cover crops, crop rotation, and commodity diversification to maintain ecosystem balance. This approach not only improves soil fertility but also reduces the need for external inputs such as chemical fertilizers and synthetic pesticides. Agroecology is seen as a solution that connects technological modernization with local wisdom, making it more suitable for the needs of rural communities. By combining scientific and traditional practices, agricultural systems can be more resilient to the challenges of climate change and global market pressures [106], [107], [108].

The transformation of the agricultural system also cannot be separated from the institutional approach. The government, non-governmental organizations, cooperatives, and the private sector play an important role in creating a supporting policy framework. Agricultural policy reforms based on environmentally friendly incentives, subsidies for organic fertilizers, as well as support for access to financing become the driving forces of change. In addition,

the institutionalization of farmer cooperatives is increasingly seen as relevant in consolidating the strength of small farmers. Through strong institutions, farmers are able to increase bargaining power, gain wider market access, and adopt technology more quickly. This institutional transformation shows that modern agriculture depends not only on technology but also on a solid social system [41], [48], [86].

Digitization also creates a new agricultural economy oriented towards innovation and entrepreneurship. The emergence of agricultural startups (agritech) is proof that this sector is increasingly being seen as a potential business field. Agritech applications provide services ranging from microfinancing, digital agronomy consulting, to harvest marketplaces. This business model provides opportunities for the younger generation to engage in the agricultural sector without having to rely on traditional patterns. With digital innovation, young farmers can access capital more easily, sell products directly, and connect with global markets. This transformation also opens up new jobs in non-traditional sectors, such as agricultural data analysts, application developers, and agricultural technology consultants [109].

The transformation of the agricultural system also focuses on resilience to global crises. The COVID-19 pandemic, for example, serves as a lesson that agricultural supply chains are very vulnerable to disruptions. Therefore, new strategies are developed to ensure the sustainability of food production even in emergency situations. Automation technology, vertical farming, and urban farming become solutions to reduce dependence on long distribution systems. In addition, the capacity to store agricultural products is also strengthened to ensure food remains available year-round. Thus, agricultural transformation is not only about efficiency and profit but also about national food security in facing unpredictable global crises [110], [111], [112].

This transformation also brings changes in agricultural education and research. Higher education curricula in the field of agriculture now place greater emphasis on digital skills, data analysis, and entrepreneurship. Universities collaborate with agritech companies to create applied research that can be directly implemented in the field. In addition, agricultural research centers are also encouraged to focus on green technology innovations, such as the development of seeds resistant to extreme climates and agricultural waste processing technology. By strengthening the synergy between academics, government, and the private sector, the transformation of the agricultural system can proceed more systematically. Education that adapts to the needs of the times prepares a new generation of farmers to face global challenges [113], [114], [115]. On the other hand, agricultural transformation faces challenges in the form of unequal access to technology. Not all farmers have the financial capacity or skills to adopt modern technology. This disparity can widen the gap between smallholder farmers and large agribusiness companies. Therefore, transformation strategies must be inclusive, providing training, equipment subsidies, and empowerment programs. The government and the private sector need to ensure that agricultural technology is not enjoyed by only a select few, but can be accessed by all layers of society. Without inclusive policies,

agricultural transformation risks reinforcing agribusiness monopolies, making the goal of creating food self-sufficiency difficult to achieve [116].

The transformation of the agricultural system is a multidimensional process involving technology, institutions, policies, and social change. The integration between modern and traditional aspects, digital and ecological approaches, local and global perspectives becomes the key to the success of this transformation. Future agriculture is no longer seen merely as a food provider, but also as a driver of economic development, a promoter of technological innovation, and a guardian of environmental sustainability. Therefore, transformation efforts must be designed comprehensively, involving all stakeholders, and based on a long-term vision. With this approach, the agricultural system can develop to be more adaptive, resilient, and highly competitive in facing global challenges [70], [117], [118].

3. The Historical Trajectory of Agricultural Paradigms and Their Main Drivers

Recent literature shows that the history of agricultural development can be understood as a series of paradigm shifts triggered by a combination of demographic pressures, changes in knowledge-technology regimes, market incentives, and increasingly evident ecological consequences (RQ1 and RQ2). Conceptually, "productivist modernization" (intensification of external inputs, specialization, and standardization) has indeed succeeded in increasing output, but it has also produced externalities that subsequently sparked "corrective waves" in the form of sustainable intensification, agroecology, and more recently digitalization/precision as new innovation pathways—each carrying different policy assumptions and risks [119], [120]. Two notable findings in the recent literature are: (i) the sustainability agenda is increasingly shifting from merely "input efficiency" to "system redesign" that restores ecological functions and natural capital; and (ii) the currents of transformation increasingly recognize that agriculture must be positioned as part of food systems and landscapes that affect biodiversity and ecosystem resilience (Wanger et al., 2020, doi:10.1038/s41559-020-1262-y; McGreevy et al., 2022, doi:10.1038/s41893-022-00933-5). In the context of Indonesia, literature that explicitly reflects the legacy of the Green Revolution emphasizes that historical production increases were followed by resource degradation impacts (e.g., soil fertility), thereby encouraging the search for integrated crop–livestock models as a post-Green Revolution circular economy strategy (Swastika et al., 2024, doi:10.1016/j.jafr.2024.101269). These findings directly answer RQ1 (history shapes the modern paradigm) and build the argumentative basis for RQ2 (how the paradigm evolves from subsistent/conventional to sustainable/digital through responses to ecological and governance crises).

4. Tensions of the Contemporary Paradigm

Literature synthesis reveals that the core debate today is no longer "whether increased productivity is necessary or not," but rather "how productivity is achieved and who bears its ecological-social costs" (RQ2). The sustainable intensification framework emphasizes increasing yields and efficiency on existing land while preventing land conversion, but many authors stress that the success of SI actually depends on reframing the research agenda

(cross-context priorities) and on adequate policy-institutional support so that SI does not stop at technical efficiency alone (Butler et al., 2020, doi:10.1038/s41893-020-0507-8). On the other hand, agroecology is positioned as a more "transformational" paradigm because it defines sustainability not merely in environmental parameters, but also in terms of knowledge relations, justice, and resource governance; the consolidated principles and elements of agroecology provide an analytical framework to identify both "incremental" and "transformational" pathways of change [119]. This tension becomes sharper when digitalization/precision is promoted as a solution for efficiency and resilience, yet policy literature suggests that digitalization can reproduce productivist biases—for example, because policy attention is stronger on efficiency and output rather than biodiversity, soil health, and other normative aspects—and is also constrained by fragmented legal/data governance issues [121], [122]. The political debate over precision technology also reveals two camps: supporters who see it as crucial for sustainability, and critics who consider the approach to be contrary to the vision of agroecology, particularly regarding corporate control, the direction of innovation, and dependence on data infrastructure [123]. These findings confirm the answer to RQ2: the evolution of the modern paradigm moves through a 'competition of frameworks' (productivism–SI–agroecology–digital), and its consequences demand a historical-institutional reading (not just technical) to understand why certain paradigms gain strength in particular periods.

5. Empirical and conceptual evidence for the integrated agriculture model

Empirical-conceptual evidence since 2020 has shown that "integrated agriculture" (integration across biophysical and managerial components) is a key mechanism to address the research gap that demands a historical-paradigmatic integration toward systemic solutions (RQ3). In crop–livestock integration (ICLS), cross-continental meta-analyses indicate that crop yields in ICLS are generally comparable to non-integrated systems (around −7% to +2%), but there are important trade-offs: dual-purpose crop systems on average reduce yields by about 20%, confirming that "integration" does not automatically excel without component design and local agroecological suitability [124]. Other reviews emphasize the benefits of ICLS in terms of output diversification, nutrient cycle efficiency, and contributions to food security, but also note adoption barriers (investment, skills, market competition), indicating that organizational/institutional support is needed for wider adoption—a finding relevant to the context of lower-middle-income countries [125]. In more complex integrations (crop–livestock–bioenergy), life cycle analysis at the national/regional scale in China shows mitigation co-benefits across various impact categories (ranging approximately 1.8%–94.8%), but still leaves environmental risks (such as dominant freshwater eutrophication; and the need to consider trade-offs when bioenergy expansion occurs in critical areas) [126]. For crop–livestock–forestry integration (ICLF/CLF), the literature assesses that this system is capable of "reconciling" soil health, production, and climate mitigation through a combination of biomass diversification, improvement of soil functions, and contribution to the carbon balance—however, the results are

highly contextual, depending on spatial-temporal design and management objectives [127], [128], [129]. In Asia, rice–fish integration practices show clear ecological mechanisms (improvement of water quality, dynamics of aquatic biota), as well as variations in institutional access that affect social outcomes and sustainability; this reinforces the argument that integrated agriculture is a "package" of biophysical + institutional components [130], [131]. For Indonesia, evidence at the practical level also shows that rice–fish coculture can improve sustainability performance by reducing costs, increasing yield diversification, and strengthening social-institutional aspects in communities [132]. Explicitly, the overall findings in this dimension answer RQ3: cross-component integration (biophysical–economic–institutional) is the conceptual foundation of 'integrated farming,' but its benefits arise through proper design, not merely the summation of components.

Table 1. Comparison of Integrated Agriculture Models

Integrated Agriculture Model	**Regional / Study**	**Main Component**	**Reported Benefits**	***Main Trade-off/Risk***	**Citation**
Integrated Crop–Livestock Systems (ICLS)	Cross-continental meta-analysis; various commodities	Crop and livestock rotation/collocation; ground cover grazing; nutrient cycling	Crop yields are generally proportional to non-integrated systems; opportunities for land efficiency and diversification; indication of a "sweet spot" under certain conditions	Dual-purpose crops lower average yields; yields are greatly influenced by soil/climate/management context	[124]
Integrated Crop–Livestock–Forestry (ICLF/CLF)	Review Cerrado Brasil	Plants, livestock, and trees (agrosilvopastoral)	Potential for improving soil health, productivity, and climate mitigation; positioned as a nature-based solution	Design complexity; investment/knowledge requirements; benefits depend on purpose & configuration	[128], [129]
Rice–fish co-culture	Asia (practice typology; study of	Rice and fish; water management; relatively low	Contribution to nutrition, ecosystem services, and	Variations in institutional access to fish; the need for water	[130], [131]

Integrated Agriculture Model	Regional / Study	Main Component	Reported Benefits	*Main Trade-off/Risk*	Citation
(rice–fish)	Hani terraces)	synthetic input (variation)	adaptability; improvement of water quality/ecological indicators in certain cases	management; not always recorded in national statistics	
Integrated crop–livestock–bioenergy	Tiongkok (analisis dampak siklus hidup)	Plants, livestock, and the use of bioenergy/residues	Environmental impact mitigation in many categories; substitution of fossil energy & chemical fertilizers as a mechanism	Freshwater eutrophication remains dominant; potential trade-offs in critical areas during bioenergy expansion	[126]

6. Policy and Institutional Factors Shaping the Transition

The literature emphasizes that paradigm transitions (including towards integrated agriculture) cannot be understood merely as technology adoption, but rather as institutional change and governance (RQ3). In the realm of agroecology, land governance studies highlight that access, ownership, and contestation of land are fundamental variables that determine whether agroecology can be scaled fairly; without reform or regulations sensitive to inequality, the 'scaling' agenda risks replicating exclusion [133]. At the food policy level, research shows the risk of a "sustainable food policy without sustainable agriculture" when policy design is more focused on consumption/urban downstream, while agroecological producer actors do not have an adequate position in governance and policy co-production; this indicates the need to integrate producers and farmer organizations into the design of transition policies [134]. For digital agriculture, the legal-policy prerequisites that determine the direction of sustainability impact include data ownership regimes, cross-regulation coordination which is currently fragmented, as well as the recognition that policies often prioritize resource efficiency over other sustainability principles [121], [122]. From a food system perspective, cross-country indicator findings show that "governance" and "resilience" are leverage points because of their high interconnection with other indicators (diets, environment, livelihoods), so isolated policy changes risk being ineffective in shifting the system; the implication is that integrated agricultural strategies need to be framed as cross-sectoral policy packages (food–environment–disaster resilience–welfare) [135]. Thus, this policy-institutional dimension reinforces the answer to RQ3:

integrated agriculture requires the orchestration of policies (incentives, extension services, financing, data protection, land governance) so that biophysical integration can become a systemic transition, not just a project-level innovation.

7. Advanced Research Gap and Debated Issues

Although there is much evidence supporting the argument of integrated agriculture as a path toward sustainability, the literature also highlights areas that are still debated (relevant to the research gap). First, evidence on the impact of climate (mitigation and especially the quantification of emissions/sequestration) on agroecology practices and integration is still uneven; a review of cases of small systems in low- to middle-income countries shows strong indications that agroecology can support adaptation and often does not sacrifice yields, but information on mitigation (e.g., GHG emissions, carbon sequestration) is still limited in the available publications [136]. Secondly, crop–livestock integration studies confirm that average crop yields can be comparable, but contextual variability is high (soil type, type of integration, commodities) so simple policy generalizations ("integration definitely increases yields") are not valid; this demands a more precise research agenda on "conditions for success" and trade-off design [124]. Thirdly, digitalization/precision presents a normative controversy: for proponents, it is a means of efficiency for sustainability, while for critics it risks deepening data dependency and reinforcing the corporatization of innovation—a issue that directly links to the question of who controls the direction of the transition [121], [123]. Fourth, specifically in the Indonesian context, integrative studies state that the low adoption of ICLS is not only a technical issue, but also a matter of knowledge-skill capacity, dissemination, and policy support (credit, price incentives, demonstration) that are still inadequate; this emphasizes the 'institutional' gap in the transition towards integrated agriculture [137].

8. Implications for Practice and Policy

The most consistent practical implication of this synthesis is that 'integrated agriculture' should be understood as a system architecture—reengineering the relationships between components (crops, livestock, trees/water, residues/energy) supported by governance—rather than merely adding production units. From a practical perspective, integration design needs to focus on proven mechanisms: (i) closing nutrient loops and enhancing soil functions through biomass/root diversification and residue recycling; (ii) managing water and habitats to restore ecosystem services (especially in rice–fish systems); and (iii) consciously configuring components to minimize trade-offs (for example, caution in dual-purpose crop systems that may reduce yields, or in bioenergy expansion that can create water quality trade-offs) [124], [126], [130]. From a policy perspective, the literature recommends a package of instruments: financing and adoption risk reduction (credit/incentives), outreach and demonstrations based on learning-by-doing, strengthening farmer organizations and local markets that absorb output diversification, as well as land governance and data governance reforms to ensure that the benefits of the transition are not concentrated among powerful actors [121], [125], [133]. At the food system level, the most strategic policy entry points are governance-resilience indicators (civil

society participation, right to food, government effectiveness, price volatility, and disaster vulnerability) because they have broad cross-theme linkages; this means that integrated agricultural policies will be more effective if packaged within multi-sectoral and multi-scale food system transformation strategies [135].

9. Validity and Limitations of Evidence and Their Implications for the Level of Confidence

Because these findings are built through narrative–integrative QLR, the highest level of confidence emerges in patterns that are repeated across methods and contexts (for example, consistency of benefits from integration through diversification and nutrient cycling; as well as broad recognition of the role of governance) and is lower in claims that are highly contextual or dependent on model assumptions (e.g., specific mitigation impacts, or economic outcomes in certain regions) [124], [135]. The literature also highlights limitations of evidence for some outcomes (e.g., GHG emissions and sequestration in agroecology/LMIC studies), so conclusions about "climate superiority" need to be positioned as plausible but condition-dependent and require more measured follow-up research [136]. Furthermore, QLR has the potential to leave publication bias or study selection bias if the search is not recorded and re-evaluated; therefore, the consistency of arguments in this section should be supported by explicit efforts to include counter-evidence on debated themes (e.g., productivism vs agroecology, or the risks of digitalization) so that the resulting conclusions truly address RQ1–RQ3 in a balanced manner [121], [123].

CONCLUSIONS AND RECOMMENDATIONS

In short, this article concludes that the shift in agricultural paradigms is a historical process driven by demographic pressures, technological innovations, and socio-ecological consequences—and that 'integrated agriculture' is most sensibly understood as a system redesign strategy that integrates biophysical and institutional components to address sustainability challenges. In line with the aim of examining historical developments, the synthesis shows a trajectory from traditional diversification practices toward productivism/intensification, then moving toward sustainability-based corrections due to increasingly recognized externalities (soil degradation, biodiversity loss, climate risks). In line with the objective of analyzing paradigm shifts, the evidence confirms the existence of a contemporary tension between productivism (output/efficiency orientation) and the transformational paradigm (agroecology and sustainable intensification), while digitalization/precision offers new efficiency pathways but raises issues of governance and access inequality. In line with the goal of formulating an integrated agricultural conceptual framework, findings show that integration models (e.g., crop–livestock, rice–fish, crop–livestock–bioenergy, and agroforestry) can create co-benefits (income diversification, nutrient cycling, system resilience), but are always accompanied by contextual trade-offs, requiring proper design and institutional support.

Based on these findings, policy recommendations are prioritized as a package of actions that directly address barriers to the transition towards integrated agriculture and bridge paradigm tensions with operationalizable instruments. First, in governance and institutional arrangements, the government needs to develop a cross-sectoral framework (food–environment–climate resilience–trade) with governance–resilience indicators as leverage points to avoid partial interventions; this includes strengthening the participation of farmer organizations in policy formulation and improving land governance so that the transition does not create new exclusions.. Second, regarding financing and incentives, policies need to shift incentives from merely inputs towards ecosystem service outcomes and adoption risk reduction (e.g., risk-sharing, low-interest loans, weather-based insurance, blended finance for investments in housing/biogas/micro-irrigation), targeting the "success conditions" of integration and learning from adoption barriers already identified in crop–livestock integration. Third, regarding extension services and knowledge development, the focus needs to shift from single technology transfer to system design assistance (combination of components, crop–livestock calendars, residue management, and water management) through farmer field schools, demonstration plots, and farmer innovation networks. Fourth, in data governance for digitalization (so that digital supports sustainability, rather than reinforcing productivism bias), rules on data rights, interoperability standards, and mechanisms for privacy protection as well as fair access for small farmers are needed; without these, digital policies risk widening gaps and hindering integration with agroecology/sustainability principles.

Future research agendas need to be prioritized to close the evidence gaps that most determine the effectiveness of policy and integrated agriculture design, while also deepening the answers to RQ1–RQ3. The six most urgent research topics are: (1) Under what biophysical and socio-economic conditions does crop–livestock integration enhance resilience without reducing yields—suggested approaches include multi-location longitudinal studies and mixed-methods (panel surveys, farm economic analysis, ethnography of farmer decisions) to explain the heterogeneity of findings; (2) What are the net impacts of greenhouse gas emissions, water quality, and soil health from various integrated agriculture designs in Indonesia? In this case, LCA and field measurements and nutrient/carbon flow modeling are recommended, considering that mitigation gaps remain significant in certain literature. (3) How does institutional design (land rights, the role of cooperatives, value chain partnerships) affect the equitable distribution of transition benefits? In this case, a political economy study and participatory action research with farmer organizations are recommended to test fair "scale" pathways. (4) How can digital/precision be integrated with agroecology and integrated farming without reinforcing data dependency and productivity bias? In this case, an analysis of data governance policy-law and design-based research on digital services supporting ecosystem services is recommended. (5) Which incentive instruments are the most effective and efficient to accelerate the adoption of integrated farming? In this case, quasi-experimental impact evaluation (e.g., difference-in-differences on

credit/incentive programs) and policy scenario modeling are recommended. (6) What are the consequences of integrated agricultural transformation on food system resilience (prices, nutrition, volatility) and how do governance–resilience indicators function as leverage points? In this regard, system modeling and cross-scale indicator analysis are recommended to connect the farm level with the food system.

The limitations of this study need to be emphasized so that the application of findings across contexts is done cautiously. First, because this article uses a narrative–integrative qualitative literature review, its main strength lies in the construction of arguments and the mapping of concepts across themes, but it is not intended for the estimation of 'definitive' quantitative effects as in a systematic review; consequently, the strongest conclusions are consistent patterns across studies, whereas specific numbers/benefits should be treated as context-dependent. Second, evidence on some outcomes (particularly measurable climate mitigation or water quality trade-offs in certain models) is still uneven, so claims of 'superiority for climate' should be placed as strong hypotheses that require more rigorous local testing. Third, cross-regional generalizations in Indonesia must consider the heterogeneity of agroecology, market structures, and institutional capacity; therefore, policy recommendations should be implemented as adaptive packages based on repeated learning loops and periodic evaluations, rather than as a single blueprint.

Implications for stakeholders and next steps for uptake can be formulated as follows. For policymakers, the findings that link and indicate the need to 'lock in sustainability' in transition policy design include combining economic incentives with institutional mandates (land governance, cross-sector coordination, and data governance), while also using governance–resilience indicators as an evaluation compass. For farmer organizations/cooperatives, priority steps are to strengthen capacity in market design and negotiation for diversified products (e.g., rice–fish, livestock integration), build standards of practice, and advocate policies so that adoption does not add risk burdens for smallholders. For researchers, the research agenda demands cross-disciplinary collaboration: political economy history to understand the trajectory of paradigms; ecology and soil science to map integration mechanisms; and policy-data science to design fair digital governance. For donors and development partners, the most valuable support is medium-term transition financing, the formation of learning alliances (government–researchers–farmers–private sector), and funding for impact evaluation/monitoring that opens space for policy correction. Ultimately, the main contribution of this article is to integrate historical readings of paradigms, analysis of contemporary tensions, and evidence of integration mechanisms towards integrated agriculture into a conceptual framework relevant for designing transition policies in developing countries, including Indonesia. By emphasizing that integrated agriculture is not merely a technology package but a systemic change requiring governance, financing, extension services, and data governance simultaneously, this article offers an argumentative basis to reorganize policy priorities so that productivity and sustainability are not narrowly pitted against each other. The transition

towards integrated agriculture requires coordinated action across actors and scales, with a commitment to openly test trade-offs, build inclusive institutions, and position long-term resilience of the food system as a shared goal.

FURTHER STUDY

This research still has limitations so that further research is needed on the topic From Productivism to Integrated Agriculture: Historical Trajectories of Paradigms, Sustainability Tensions, Digitalization, and Policy Agendas for Agricultural System Transition in order to perfect this research and increase insight for readers and writers.

REFERENCES

A. Ambarnis, "Corak Kehidupan Masyarakat Dunia Pada Masa Transisi Revolusi Neolitik dalam Perspektif Ekologis Berdasarkan Kajian Buku Clive Ponting," J. Pendidik. dan Konseling, vol. 4, no. 6, pp. 12636–12642, 2022, [Online]. Available: https://journal.universitaspahlawan.ac.id/index.php/jpdk/article/download/10572/8071/32014

Agtecher, "Sejarah Pertanian: Dari Revolusi Neolitikum hingga Pertanian AI," Agtecher. [Online]. Available: https://agtecher.com/id/blog/history-of-agriculture/

C. Kremen, "Ecological intensification and diversification approaches to maintain biodiversity, ecosystem services and food production in a changing world," Emerg. Top. Life Sci., vol. 4, no. 2, pp. 229–240, Sep. 2020, doi: 10.1042/ETLS20190205.

D. Putra and A. Santosa, "Implementasi Internet of Things (IoT) dalam Pertanian Modern di Indonesia," J. Teknol. Pertan., vol. 11, no. 1, pp. 55–68, 2022.

H. Basri et al., Pendidikan untuk Peradabab: Membangun Generasi Emas Indonesia, 1st ed. Padang: Aikomedia Press, 2025. [Online]. Available: https://www.researchgate.net/profile/Syarif-Hidayat-21/publication/393981631_PENDIDIKAN_UNTUK_PERADABAN_MEMBANGUN_GENERASI_EMAS_INDONESIA/links/6882c79f253dcb78df87a958/PENDIDIKAN-UNTUK-PERADABAN-MEMBANGUN-GENERASI-EMAS-INDONESIA.pdf

H. de Foresta, A. Kusworo, G. Michon, and W. A. Djatmiko, "Ketika Kebun Berupa Hutan: Agroforest Khas Indonesia - Sebuah Sumbangan Masyarakat," Bogor, 2000. [Online]. Available: https://www.cifor-icraf.org/publications/region/sea/publications/softcopy/BK0055-04.pdf

J. Blesh et al., "Against the odds: Network and institutional pathways enabling agricultural diversification," One Earth, vol. 6, no. 5, pp. 479–491, May 2023, doi: 10.1016/j.oneear.2023.03.004.

J. Pretty et al., "Assessment of the growth in social groups for sustainable agriculture and land management," Glob. Sustain., vol. 3, p. e23, Aug. 2020, doi: 10.1017/sus.2020.19.

J. Pretty, T. G. Benton, Z. P. Bharucha, L. V Dicks, and C. B. Flora, "Global Assessment of Agricultural Sustainability: Patterns of Global Agricultural Development," Sustain. Sci., vol. 15, no. 5, pp. 1225–1237, 2020.

J. Zhang and D. Chen, "Drone Technology for Precision Agriculture: Recent Advances and Future Trends," Remote Sens., vol. 13, no. 16, p. 3202, 2021.

K. Fischer, G. Vico, H. Röcklinsberg, H. Liljenström, and R. Bommarco, "Progress towards sustainable agriculture hampered by siloed scientific discourses," Nat. Sustain., vol. 8, no. 1, pp. 66–74, Dec. 2024, doi: 10.1038/s41893-024-01474-9.

L. I. Purba et al., Pertanian, Tanah, dan Perubahan Sosial. Penerbit Yayasan Kita Menulis, 2025. [Online]. Available: https://www.researchgate.net/publication/399514353_Pertanian_Tanah_dan_Perubahan_Sosial

M. A. Altieri and C. I. Nicholls, "Agroecology and the emergence of a post-COVID agriculture," Agric. Human Values, vol. 37, no. 3, pp. 525–526, 2020.

M. A. Altieri and C. I. Nicholls, "Agroecology and the Redesign of Agricultural Systems for Sustainability," Agronomy, vol. 10, no. 3, p. 216, 2020.

M. Hasan, M. Dinar, S. Rijal, Rahmatullah, Inanna, and N. Arisah, Sejarah Pemikiran Ekonomi, 1st ed. bandung: Media Sains Indonesia, 2020. [Online]. Available: https://eprints.unm.ac.id/28744/1/Buku Digital - Sejarah Pemikiran Ekonomi.pdf

M. Kernecker et al., "Transition zones across agricultural field boundaries for integrated landscape research and management of biodiversity and yields," Ecol. Solut. Evid., vol. 3, no. 1, Jan. 2022, doi: 10.1002/2688-8319.12122.

P. N. Nelson, "Sustainable Soil Management in Tropical Agriculture," in Sustainable Soil Management: Beyond Food Production, 1st ed., S. Jayaraman, R. C. Dalal, and R. Lal, Eds., Cambridge Scholars Publishing, 2023, ch. 8, pp. 1–350.

R. Lal, "Farming systems to return land for nature: It's all about soil health and re-carbonization of the terrestrial biosphere," Farming Syst., vol. 1, no. 1, p. 100002, 2023, doi: https://doi.org/10.1016/j.farsys.2023.100002.

R. Lal, C. Monger, L. Nave, and P. Smith, "The role of soil in regulation of climate," Philos. Trans. R. Soc. B, vol. 376, no. 1834, Sep. 2021, doi: 10.1098/rstb.2021.0084.

S. A. Novitri, "Sejarah Revolusi Hijau dan Dampaknya Hingga Saat Ini," JurnalAgro. Accessed: Apr. 16, 2026. [Online]. Available: https://jurnalagro.com/sejarah-revolusi-hijau-dan-dampaknya-hingga-saat-ini/

W. Sumantri and D. W. Firdaus, "Kebijakan Agraria pada Masa Orde Baru: Implikasi Program Revolusi Hijau terhadap Petani Indonesia," Bihari J. Pendidik. Sej. dan Ilmu Sej., vol. 7, no. 1, pp. 17–24, 2024, [Online]. Available: https://jurnal.unsil.ac.id/index.php/bihari/article/download/17074/4406