

Implementation of Smart-Eco Bioproduction in Supporting Healthy Food Programs in Sleman Regency

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ABSTRACT

The concept of Smart-Eco Bioproduction (SEB) developed by the Faculty of Agriculture, Universitas Gadjah Mada. It integrates three key aspects environment, economy, and society, which are integrated into the food supply system. SEB aims to produce safe and healthy food products supported by healthy plant cultivation. This study focuses on the social aspects of SEB implementation and the challenges of providing healthy food in Sleman Regency. Using a qualitative research design with a critical constructivism approach. The research involved farmers, agricultural service employees, and extension workers as informants. Findings indicate that SEB implementation engages various institutions, including the agricultural service, farmer groups, certification bodies, universities, and marketing partners. SEB is generally interpreted as eco-friendly farming practices that avoid chemical inputs and emphasize sustainability. However, several challenges remain, such as limited digital marketing capacity, inadequate irrigation systems, and high dependence on farmer group leaders. Moreover, while SEB is understood as a sustainable farming model, its role within the broader framework of healthy food provision requires clearer positioning. To strengthen SEB, farmers need capacity building in both technical and managerial aspects, alongside greater cross-sectoral collaboration. Therefore, strengthening partnerships and institutional support is also essential to ensure the sustainability of SEB in Sleman.

Keywords: agricultural institutions, healthy food, smart-eco bioproduction (SEB)

INTRODUCTION

The Fourth Industrial Revolution has driven transformation across various sectors, including agriculture. At the same time, increasingly complex global challenges, such as climate change, population growth, urbanization, and land-use change, have intensified the need for food systems that are productive, sustainable, and environmentally responsible (Siahaan, 2022; Pinuji, 2020). Growing public awareness of healthy lifestyles has also increased demand for food produced with minimal chemical residues and pesticide use (Fajarani et al., 2021). These developments have encouraged a shift from conventional agriculture toward production systems that integrate environmental sustainability, economic viability, and technological innovation.

Conventional agriculture, which relies heavily on synthetic chemical inputs, may contribute to declining soil quality, water pollution, and risks to human health (Prihandarini, 2023). Sustainable agriculture therefore offers an alternative approach that seeks to maintain ecosystem functions while meeting current food needs without compromising the ability of future generations to meet their own needs (Dewi et al., 2024). Within this broader sustainability agenda, the Faculty of Agriculture, Universitas Gadjah Mada, has developed the SEB concept as an ecology-based smart agricultural approach that integrates environmental, economic, and social dimensions within a sustainable production system (Wastutiningsih et al., 2022). SEB also emphasizes efficient resource use and the reduction of negative environmental impacts while incorporating technological innovation into agricultural management (Tarigan, 2020).

Conceptually, however, SEB should be distinguished from conventional organic farming. Organic farming primarily emphasizes environmentally responsible production practices, including reducing or eliminating synthetic chemical inputs and maintaining ecological processes. SEB has a broader scope because it combines

these ecological principles with economic viability, social and institutional capacity, and the use of smart and precision technologies. Digital monitoring systems, soil sensors, the Internet of Things (IoT), and data-based decision-making can therefore serve as enabling components of more advanced SEB implementation (Rachmawati, 2020). Accordingly, the adoption of organic farming practices alone does not necessarily indicate full SEB implementation. Rather, organic agriculture can provide an important ecological foundation for a broader transition toward an integrated SEB system.

Sleman Regency is one of the major food-producing areas in the Special Region of Yogyakarta, with rice production reaching 116,951 tons in 2022 (Badan Pusat Statistik Provinsi DI Yogyakarta, 2022). The local government has demonstrated its commitment to sustainable and healthy food production through Sleman Regent Regulation No. 62 of 2023 concerning the Development of Area-Based Organic Agriculture. The regulation promotes organic agriculture as a means of supporting sustainable agricultural development, increasing the economic value of agricultural products, and improving quality of life. In the context of SEB, these organic agriculture initiatives can be viewed as an important entry point for strengthening its ecological and institutional dimensions. However, the transition toward a fully integrated SEB system also requires the development of technological capabilities, particularly digital and precision agriculture tools. Where IoT-based monitoring, sensors, and other digital precision technologies remain limited or absent, this technological gap represents an important bottleneck in the transition from organic agriculture toward full SEB implementation.

The implementation of SEB is therefore influenced not only by technical and economic factors but also by social and institutional conditions. Many farmers in Indonesia are relatively old, have limited formal education, and face difficulties in adopting technology-based agricultural innovations (Juniarti et al., 2022). Agricultural extension systems also face challenges in adapting to emerging technologies and new agricultural practices (Saputro, 2021). Furthermore, stakeholder coordination, limited understanding of the SEB concept, institutional capacity, and policy support may affect how SEB principles are translated into field-level practices (Wastutiningsih et al., 2022). These conditions suggest that technological limitations should not be viewed solely as a matter of access to equipment, but also as an institutional challenge involving farmers' capacity, extension support, knowledge transfer, and coordination among relevant actors.

Against this background, this study examines the implementation of SEB in supporting healthy food programs in Sleman Regency, with particular attention to its social and institutional dimensions. Specifically, the study analyzes the extent to which existing agricultural practices reflect SEB principles and identifies the challenges and constraints affecting their implementation. Rather than assuming that organic farming represents full SEB implementation, this study considers it part of an ongoing transition toward a more integrated system and examines the ecological, institutional, and technological gaps that may constrain this transition. The findings are expected to provide a basis for strengthening strategies toward more comprehensive and sustainable SEB implementation.

RESEARCH METHOD

This study employed a qualitative descriptive approach to examine the implementation of SEB in supporting healthy food programs in Sleman Regency, Special Region of Yogyakarta. The study was conducted in Kapanewon Ngaglik, Ngemplak, and Prambanan, which were purposively selected to represent farmer groups engaged in SEB-related agricultural practices. Five key informants were selected through purposive sampling, consisting of three farmer group leaders, each representing one research location, and two staff members of the Sleman Regency Agriculture, Food, and Fisheries Office (DP3). Farmer group leaders were selected based on their leadership roles, direct experience, and knowledge of SEB-related practices, as well as recommendations from DP3 and the Agricultural Extension Centers (BPP), while DP3 staff were selected based on their direct involvement in organic agriculture and SEB-related programs.

Primary data were collected through semi-structured in-depth interviews and field observations, while secondary data were obtained from DP3, BPP, policy documents, program records, statistical data, and other relevant sources. Data credibility was strengthened through triangulation by comparing information across farmer and DP3 informants and cross-checking interview findings with field observations and secondary documents. The data were analyzed manually using an iterative thematic coding approach, in which interview data and field

notes were reviewed, coded, and grouped into key themes, including SEB implementation, institutional support, sustainable cultivation practices, marketing and market access, technological adoption, and implementation challenges (Niam et al., 2024). These themes were then compared across informants and research locations and interpreted within the SEB framework to identify implementation patterns and key barriers to achieving a more integrated SEB system.

RESULTS AND DISCUSSION

Implementation of the SEB Program in Sleman Regency

The implementation of the SEB program in Sleman Regency is part of a sustainable agricultural development policy to increase the production of healthy food with high economic value. As a policy framework, SEB is intended to integrate three interrelated dimensions: smart farming technologies, ecologically based cultivation practices, and sustainable bioproduction systems. At the institutional level, the SEB program in Sleman Regency does not merely represent a technological or managerial innovation, but rather a cross-sectoral collaboration involving local government, higher education institutions, certification bodies, agricultural extension agents, and farmer groups. The success of the SEB program is highly dependent on synergy among stakeholders and strong institutional commitment to supporting ecologically based farming practices. However, as elaborated in the following sub-sections, the empirical evidence gathered in this study indicates that the eco and bioproduction dimensions of SEB have been implemented more consistently at the farmer level, whereas the smart or technology-based dimension remains at an early and limited stage. Accordingly, farm-level practices described in this study are referred to as SEB-aligned practices or as a transition toward SEB, rather than as the full implementation of the SEB concept, since they largely reflect organic and agroecological methods without the integration of digital or precision-based tools.

At the regional level, the implementation of the SEB program in Sleman Regency is derived from Sleman Regent Regulation Number 62/2023 (Peraturan Bupati Sleman Nomor 62 Tahun 2023) concerning Area-Based Organic Agriculture Development, which serves as the legal foundation for the provision of incentives, certification financing, and the establishment of organic farming zones. According to information from the DP3 Sleman, this policy was formulated in response to challenges such as agricultural land fragmentation, declining soil quality due to intensive chemical inputs, and the growing market demand for healthy food products. The objective is not only to enhance agricultural productivity, but also to foster farmers' awareness of producing food that is safe for consumption and competitive in the market. This approach is consistent with the findings of Rachmawati (2020), which indicate that SEB constitutes an adaptive strategy to address agricultural resource degradation while simultaneously creating opportunities to improve the competitiveness of local agricultural products.

"There is a legal guideline and support from the local government in Sleman Regency, namely Sleman Regent Regulation Number 63 of 2023 on Area-Based Organic Agriculture. Because of this regulation, organic farmers receive legal priority. The government also provides facilities for participating in organic product exhibitions, a scholarship or financial support for organic farmers, and tax payments are given a discount. We are also assisted with organic certification." (SR, DP3, interview, 29 August 2025).

The statement indicates that the implementation of the SEB program in Sleman Regency operates not only at the technical level but is also supported by strong structural and administrative support from the local government, such as technical irrigation for organic farming land, subsidies for certification costs through collaboration with the Organic Certification Body (Lembaga Sertifikasi Organik - Lesos), facilitation of farmer group participation in agricultural product exhibitions, the provision of training scholarships for organic farmers, and fiscal incentives in the form of land tax reductions. These measures demonstrate that the Sleman local government has integrated SEB principles into regional development policies oriented toward sustainable agriculture.

"The planning of organic agriculture in Sleman Regency is based on several considerations. Agricultural land here is getting smaller, and most farmers only own small plots. So if they grow conventional rice, it is difficult to compete with other regions. That is why we encourage organic farming, because it has higher value and a clearer market. This is especially relevant since culinary tourism in Sleman Regency is quite strong. Thankfully,

organic products from farmer groups have always sold well so far.” (SR, DP3, interview, 29 August 2025)

The statement above indicates that the implementation of the SEB program in Sleman Regency is not solely oriented toward agricultural production, but is also integrated with the local economic and tourism sectors. This integration reinforces the concept of SEB as a holistic production system that combines environmental, social, and economic dimensions (Tarigan, 2020). Accordingly, the implementation strategy in Sleman Regency does not focus merely on crop yields, but also on building a market ecosystem that supports the long-term sustainability of farmers’ livelihoods.

The implementation of the SEB program in Sleman Regency is carried out through several systematic stages, namely: (1) initial assessment and planning, (2) socialization and selection of potential farmer groups, (3) training and farmer field schools, (4) mentoring and supervision through the Internal Control System (ICS), and (5) certification and marketing of organic products. The implementation process begins with an initial assessment and planning phase involving Universitas Gadjah Mada (UGM) over a two-year period, encompassing data inventory, institutional planning, and the dissemination of organic cultivation techniques. At this stage, higher education institutions play a role as scientific partners by providing a knowledge base and technological innovations to support stakeholders at the field level.

“At first, we identified interested farmers through the Organic Field School. We even collaborated with Universitas Gadjah Mada for studies, data collection, and benchmarking visits to Bali, Boyolali, and Banyuwangi. Instead, we focused on assisting existing farmer groups that were already serious and committed. Groups that showed strong commitment were then supported to proceed with organic certification. We usually select clustered land areas to make the process easier; when plots are small and scattered, we combine them so that the certification costs become more manageable.” (R, DP3, interview, 29 August 2025)

Based on the interview findings, this stage illustrates that the implementation of the SEB program is selective and gradual, adjusting to the social and technical readiness of each farmer group. This approach is consistent with the diffusion of innovation perspective proposed by Everett M. Rogers (2003), which emphasizes that the successful adoption of innovations depends on social readiness, perceived benefits, and institutional support.

At the operational level, the implementation mechanism of SEB is carried out through the Internal Control System (ICS), which functions as an internal monitoring mechanism and a quality control instrument for organic products. The ICS involves the active roles of agricultural extension worker (PPL) and the Heads of Agricultural Extension Centers (BPP) in inspection and verification processes. The system is responsible for overseeing cultivation practices to ensure compliance with organic standards, conducting internal inspections, and managing certification processes through collaboration with the Organic Certification Body (Lesos)). According to Juniarti et al. (2022), participatory control systems such as ICS constitute a critical element in maintaining public trust in organic products and enhancing farmers’ accountability..

“Here, we also run the Healthy Crop Cultivation Program. Basically, this program focuses on reducing the use of chemical inputs, both pesticides and fertilizers. You could say it’s an initial step before fully moving to organic farming, because for organic farming, the requirement is that there should be no chemical inputs at all, and it has to be officially recognized through certification.” (SR, DP3, interview, 29 August 2025)

Based on the results of observations and interviews, the implementation of the SEB program is also integrated with the Healthy Crop Cultivation Program (BTS) as an initial stage toward full organic agriculture. This program focuses on reducing the use of chemical pesticides and fertilizers, while simultaneously strengthening farmers’ awareness of the importance of soil health and food safety. The synergy between SEB and BTS reflects a gradual, realistic, and adaptive approach to the socio-economic conditions of farmers.

“Thankfully, our group has already adopted organic farming. We’ve been fully organic since 2020. The process took a long time. To become fully organic, it took us almost five years, starting around 2015. Now it’s 2025, so we’ve been fully organic for about five years.” (S, Head of Gamparan Farmer Group, interview, 25 September 2025)

The transition toward SEB-aligned practices in Sleman Regency is also characterized by a gradual and continuous adoption process. Based on interviews with the head of a farmer group, the application of organic farming practices within the group began in 2015 and only reached the stage of full organic production in 2020. This indicates that farmers' transition toward SEB-aligned practices at the group level is not carried out instantaneously, but rather through a prolonged process of social learning, technological adaptation, and long-term facilitation. The five-year transition from conventional agriculture to a fully organic system reflects the stages of innovation adoption as described by Everett M. Rogers (2003), namely the stages of knowledge, persuasion, decision, implementation, and confirmation. These findings demonstrate that farmers' progress toward SEB-aligned practices in Sleman Regency is largely determined by consistency in implementation and sustained institutional support, rather than short-term or ad hoc interventions.

"The process was long. The village head first tried it himself on his own land—about 6,000 square meters—for almost four years starting in 2015. He felt comfortable with the method and believed in it. Only after that did he invite one or two farmers to try it. At the beginning, we slowly reduced chemical fertilizers and started adding manure. It wasn't until 2020 that we were finally able to completely stop using chemicals. The early adoption stage was really difficult. Our first harvest dropped significantly, to only about 50 percent of what we used to get with chemical farming. Selling the products in the local market was also hard, because people in the village didn't believe us when we said the crops were organic, since we didn't have certification yet. We only became fully confident and more serious after a cooperative (Pak Bangun) got involved through the agricultural extension officer and started assisting us. He was the one who eventually helped us with the certification process." (S, Head of Gamparan Farmer Group, interview, 25 September 2025)

This excerpt illustrates that the transition toward SEB-aligned practices in Sleman, particularly in Gamparan, originated from a locally grounded experiment based on farmers' experiential knowledge. The shift from conventional farming systems to fully organic practices indicates that this transition is both transformational and adaptive, involving a prolonged process that begins with the gradual reduction of chemical inputs, followed by their substitution with organic fertilizers, and culminating in certification. This process further demonstrates that the success of this transition is not determined solely by policy frameworks, but also by the continuity of institutional support, such as assistance provided by agricultural extension worker (PPL) and local cooperatives that facilitate technical guidance and market access. Overall, farmers' transition toward SEB-aligned practices in Sleman constitutes a social process that evolves from the grassroots level (bottom-up implementation), in which local actors play a critical role in shaping the direction and pace of innovation adoption. It is important to note, however, that this bottom-up process has so far centered on ecological and organizational change—reducing chemical inputs, adopting organic inputs, and securing certification—rather than on the adoption of smart or precision-based technologies.

"If we encounter other pests, we make our own natural mixtures. We use materials from the surrounding environment, such as bitter-tasting leaves, for example soursop and chinaberry leaves, mixed with garlic. We also use *Dioscorea Hispida* (gadung), which is very effective in killing snail pests. In terms of land management, our fields here are grouped together in one block. As a result, there are no chemically managed fields located in the middle of our organic land, in order to avoid contamination." (S, Head of the Gamparan Farmer Group, 2025)

Based on the results of observations and interviews, the adoption of SEB-aligned practices at the farmer group level has demonstrated significant behavioral changes. Farmer groups function as the primary actors driving this transition at the field level. According to interviews with the head of the Gamparan farmer group, the adoption of healthy farming practices has begun through the use of botanical pesticides and the reduction of chemical fertilizers. This statement indicates a shift in paradigm in farming practices. Although the system has not yet fully transitioned to organic agriculture, measures such as reducing chemical inputs and applying botanical pesticides represent SEB-aligned practices at the micro level, particularly within the eco and bioproduction dimensions, emphasizing resource efficiency, soil conservation, and local self-reliance (Altieri & Nicholls, 2020). These practices, however, remain manual and experience-based; no digital monitoring devices, soil or climate sensors, or other IoT-based and precision farming tools were identified in the field, indicating that the smart/technological dimension of SEB has yet to be realized at the farmer level.

"As for the agricultural extension officers, especially Mr. Haryanto, the interaction is very frequent. They

regularly visit the fields, particularly during the rice planting season—sometimes as often as once a week. They observe field conditions, and if there are signs of pest attacks, they immediately inform us about what actions should be taken. We also often report problems via WhatsApp when issues arise. Then there are district-level programs such as synchronized planting or synchronized harvesting, our group is often selected as a demonstration group. Even now, Universitas Gadjah Mada (UGM) continues to monitor our activities. They visit to check whether the equipment they provided is still being used and remains beneficial.” (S, Head of the Gamparan Farmer Group, 2025)

Beyond the technical aspects of cultivation, another crucial component in supporting the transition toward SEB is intensive facilitation by agricultural extension officers, who function as intermediaries between the government and farmers. Extension activities are conducted regularly through field meetings, inspection visits, and digital communication using platforms such as WhatsApp for rapid reporting. Agricultural extension worker (PPL) serve as a linkage between farmers and government agencies in activity reporting, extension services, and the monitoring of field-level implementation. This pattern of interaction among farmers, extension officers, and government agencies illustrates a collaborative facilitation system that constitutes a key institutional characteristic supporting SEB-aligned practices. This approach reflects the adoption of a simple smart extension communication model, which integrates basic communication technologies to strengthen information linkages among agricultural actors. It should be noted, however, that this form of digital communication functions primarily as a reporting and coordination tool rather than as a precision-agriculture technology; unlike IoT-based soil and irrigation monitoring, remote sensing, or drone-assisted field mapping, WhatsApp-based reporting does not generate or process field data automatically, and therefore does not by itself constitute the smart/technological dimension of SEB. Such two-way communication patterns have nonetheless been shown to enhance the effectiveness of agricultural innovation adoption. According to Saputro (2021), the effectiveness of agricultural innovations increases when communication among actors is conducted intensively, openly, and based on mutual trust.

In addition to technical aspects, the transition toward SEB is further strengthened by infrastructural support in the form of agricultural tools and machinery (alsintan), organic fertilizers, and facilitation of certification processes. The Sleman Regency Agricultural Office provides assistance in the form of tractors, water pumps, and rice threshers as incentives for farmer groups that consistently apply environmentally friendly practices. It is worth noting that this mechanical equipment primarily supports labor efficiency in land preparation and post-harvest handling, and is distinct from the sensor-based or data-driven technologies associated with the smart dimension of SEB; no such precision equipment has yet been provided to or adopted by the farmer groups studied. Nevertheless, this support indicates that the transition toward SEB does not rely solely on the individual commitment of farmers, but is also underpinned by concrete and measurable public policies. According to Suroso et al. (2021), institutional support and regional financing are key determinants of the sustainability of ecologically based agricultural innovations. Furthermore, the SEB program adopts a cross-institutional collaboration principle, commonly referred to as a triple helix partnership involving local government, higher education institutions, and farming communities. This synergy has been shown to enhance program effectiveness, both in terms of technical facilitation and market access. Ultimately, the success of the transition toward SEB is highly dependent on the integration of scientific knowledge, policy support, and community participation as the primary actors within the food system.

Accordingly, the development of SEB in Sleman Regency can be categorized as a collaborative implementation model that integrates policy, institutional, and social dimensions. When assessed against the three core dimensions of the SEB concept, the findings indicate an uneven pattern of development. The institutional and policy dimension is comparatively strong, evidenced by a clear regulatory basis (Sleman Regent Regulation No. 62/2023), sustained certification financing, and multi-actor collaboration among government, academia, and certification bodies. The eco and bioproduction dimensions are also relatively well established at the farmer level, reflected in the consistent use of organic fertilizers, botanical pesticides, and block-based land management to prevent chemical contamination. In contrast, the smart or technology-based dimension remains the weakest component, as farmer groups continue to rely on manual field observation, conventional irrigation, and basic communication tools such as WhatsApp, without the adoption of IoT-based monitoring, precision irrigation, or other digital farming technologies. This imbalance suggests that what has been achieved in Sleman Regency to date is more accurately described as a transition toward SEB, anchored in strong ecological and institutional

foundations, rather than the full realization of an integrated SEB system. This process reflects a paradigm shift from conventional agriculture toward a sustainable production system grounded in local knowledge, though further development of the technological dimension will be needed to fully realize the SEB concept. Such a model nonetheless has the potential to serve as a best practice for other regions in developing healthy food systems aligned with the Sustainable Development Goals (SDGs), particularly Goal 2 (Zero Hunger) and Goal 12 (Responsible Consumption and Production)..

Implementation of SEB in Supporting the Healthy Food Program in Sleman Regency

The application of SEB as a sustainable agricultural innovation is aligned with the policy framework of the Sleman Regency Government as stipulated in the Regent Regulation on the Regional Action Plan for Food and Nutrition (RAD-PG) for the period 2023–2026. The regulation outlines the local government's commitment to achieving sustainable food and nutrition security through strengthening the availability, accessibility, and consumption of safe, high-quality, and nutritionally balanced food. In this context, the government strongly encourages the adoption of smart farming technologies, the efficient utilization of local resources, and the development of environmentally friendly food systems. As a follow-up to this policy, this study was conducted to examine institutional support and farmers' experiences in the transition toward SEB in Sleman Regency.

a. Sleman Regency Agriculture, Food, and Fisheries Office

Local government institutions, particularly the Sleman Agriculture, Food, and Fisheries Office, play a central role in driving the transition toward SEB through organic farming programs in Sleman. The Office carries out its function as the implementing agency of regional policies, specifically Sleman Regent Regulation No. 62 of 2023 on Area-Based Organic Agriculture Development, which serves as the legal basis for providing incentives to organic farmers and covering organic certification costs for the first three years.

"In Sleman, programs related to technology or environmentally friendly practices are actually very closely connected to the development of organic agriculture. We have an Organic Agriculture Program, and one of its most important components is support for organic certification. The costs are very high—it can reach up to 50 million rupiah for three years per farmer group. At present, these costs are fully covered by the government, including annual surveillance and the administrative requirements of the certification system. Without this kind of support, many farmer groups honestly would not be able to continue operating." (SR, Sleman Regency Agriculture, Food, and Fisheries Office, 2025)

In addition, the local government actively provides assistance to farmers through agricultural extension worker (PPL), supplies production inputs such as seeds and organic fertilizers, and ensures that cultivation processes ICS. The local government also plays a role in fostering cross-institutional collaboration by engaging higher education institutions such as Gadjah Mada University (UGM), certification bodies such as LESOS, and sub-district-level Agricultural Extension Centers (BPP).

"The implementation of organic farming in Sleman begins with education through the Organic Farmer Field School. Farmers first learn the techniques, and then they are given a year to practice. If they show serious commitment, we continue to support them through the certification process. The certification costs are quite high, around 50 million rupiah for three years, but these costs are now fully covered by the Office. We also provide equipment for producing organic fertilizers so that farmer groups can become more self-reliant. Field-level assistance is carried out by agricultural extension officers, who routinely supervise activities and serve as part of the group's ICS. In this way, monitoring takes place on a daily basis, rather than only during annual certification." (R, Sleman Regency Agriculture, Food, and Fisheries Office, 2025)

Considering its overall roles and responsibilities, the Sleman Regency Agriculture Office functions as a facilitator, capacity builder, and primary driving force within the SEB based sustainable agricultural system. The local government does not merely formulate policies, but also ensures the continuity of technical assistance, financial support, and the institutional strengthening of farmer groups. Thus, the Office serves as a critical bridge between policy formulation and field-level implementation, which constitutes a key factor in the successful development of smart, organic, and environmentally friendly agriculture in Sleman Regency. In line with the

findings of Reganold and Wachter (2016) published in *Nature Plants*, the success of organic agriculture and similar innovations is highly dependent on strong public policy and institutional support, including facilitation of certification processes, enhancement of farmers' technical capacities through training and extension services, and the expansion of access to markets that value environmentally friendly products. Therefore, the role of the Agriculture Office extends beyond administrative or instructional functions, acting instead as a catalyst that ensures effective coordination among stakeholders—government agencies, extension officers, business actors, consumers, and farming communities—so that the adoption of smart agricultural technologies and innovations such as SEB can be sustained over time.

b. Farmer Groups

From an actor-based perspective, the transition toward SEB-aligned practices in Sleman Regency has been operationalized through the active engagement of multiple farmer groups, including Ngudi Waluyo Group (Ngaglik Sub-district), Mekar Group (Ngemplak Sub-district), and Makmur Group (Prambanan Sub-district), which have progressively transitioned toward organic farming systems since the mid-2010s. The diffusion of these SEB-aligned practices among these groups was initially driven by localized initiatives and reinforced by local government support, particularly following the enactment of Sleman Regent Regulation No. 62 of 2023 on Area-Based Organic Agriculture Development and Regional Regulation No. 63 of 2023 on Organic Agricultural Zones.

In their implementation processes, farmer groups have benefited from intensive multi-actor support involving the local Department of Agriculture, Agricultural Extension Centers (BPP), field extension services, and academic institutions such as Universitas Gadjah Mada (UGM), encompassing technical capacity building, provision of agricultural machinery and equipment, and facilitation of organic certification. Such cross-institutional collaboration has reinforced farmers' roles as central actors in the integrated application of SEB-aligned practices. Furthermore, partnerships with cooperatives and private-sector entities, including PT Lentera, have enhanced market access for agricultural outputs and ensured the availability of key production inputs. From the perspective of motivation, farmers are strongly driven by health considerations and long-term economic sustainability. As expressed by one member of the farmer group,

“Our main motivation is definitely health. Because we consume the products ourselves, we want the best quality. In addition, what keeps us motivated is the certainty of marketing. We already have a contract with Mr. Bangun, so we do not have to worry about where to sell our produce. The prices are much more predictable and higher. We are committed to continuing this practice.” (S, Head of the Gamparan Farmer Group, 2025)

Beyond technical and economic considerations, family-based role modeling and the intergenerational transmission of natural farming traditions have functioned as critical motivational drivers. The convergence of policy support, sustained technical facilitation, and culturally embedded personal motivations has enabled the transition toward SEB-aligned practices in Sleman to evolve in a socially embedded and enduring manner at the practitioner level. This pattern aligns with the findings of Nurlaela et al. (2022), which highlight that local cultural values, collective cohesion within farmer groups, and intergenerational learning processes represent dominant social determinants of successful adoption of sustainable agricultural practices. External interventions from governmental or extension institutions are most effective when they complement farmers' intrinsic motivations and traditional value systems that prioritize ecological balance and autonomy, thereby forming a shared ecological ethic that reinforces the long-term resilience and sustainability of innovation at the grassroots level.

“I was first introduced to it by my parents, especially my father, who is now elderly. He would not eat food unless it came from his own crops. That was what led me to start practicing organic farming. Later on, I also received encouragement and support from the Agricultural Office and the BPP.” (M, Head of Ngalian Farmer Group, interview, 23 September 2025)

At the operational level, cultivation practices adopted by organic farming actors in Sleman Regency are grounded in the principles of agroecological management and the efficient utilization of locally available resources. Agricultural production is carried out without the use of synthetic chemical inputs across key stages, including

soil preparation, nutrient management, and pest control. Solid organic amendments primarily consist of livestock manure sourced from goats, poultry, and cattle, while liquid organic fertilizers are formulated from fermented rabbit or goat urine, combined with rice-washing water (air leri), sugarcane molasses, or probiotic inoculants such as Yakult to enhance the presence of beneficial microorganisms.

“We use various approaches. For fertilizers, we apply solid inputs such as composted manure, goat manure, and chicken manure. For liquid fertilizers, we use rabbit urine and goat urine. These liquids are sometimes mixed with rice washing water, or supplemented with Yakult and molasses or granulated sugar.” (S, Head of Gamparan Farmer Group, interview, 25 September 2025)

In terms of pest management, farmers rely on natural materials readily available in their surrounding environment. A mixture of soursop leaves (*Annona muricata*), neem leaves (*Melia azedarach*), garlic, and gadung tubers is processed into botanical pesticides to control planthoppers, golden apple snails, and other insect pests. The outcomes of this practice have been reported as relatively significant, as expressed by farmers,

“For pest control, thankfully, over the past five years our fields have been free from major pest attacks. Our organic plots were not affected by planthoppers, even though the chemically farmed fields across the road were heavily infested. If other pests appear, we make our own natural mixtures. We use materials from the surrounding environment, such as bitter leaves like soursop and mindi, mixed with garlic. We also use gadung, which is very effective in killing golden apple snails.” (S, Head of Gamparan Farmer Group, interview, 25 September 2025)

Land management is implemented through an integrated block-based approach to minimize the risk of contamination from adjacent non-organic fields and to preserve the purity of organic cultivation practices.

“In terms of land management, our fields are arranged in one block. This means there are no chemical-based fields located within our organic area, so contamination can be avoided.” (S, Head of Gamparan Farmer Group, interview, 25 September 2025)

Several farmer groups have even established group-scale organic fertilizer production units that utilize livestock waste as the primary raw material, ensuring a stable supply of organic inputs throughout the planting season. Moreover, during the post-harvest phase, farmers also rely on natural materials to maintain the quality of agricultural produce. This cultivation system not only generates healthier food products but also contributes to maintaining soil fertility, reducing dependence on external inputs, and strengthening farmer self-reliance through innovations grounded in local ecological knowledge and resource-use efficiency.

Notably, the cultivation practices described above—organic fertilizer preparation, botanical pest control, and block-based land management—are carried out entirely through manual labor and locally available materials, without the support of IoT-based sensors, automated or precision irrigation systems, drone-assisted field monitoring, or other digital tools commonly associated with the smart dimension of the SEB concept. None of the farmers interviewed in this study reported exposure to such technologies, and no precision agriculture equipment was observed in the field during data collection. This technological gap can be linked to at least three interrelated factors. First, farmers’ limited technical and digital capacity, particularly among older farmers whose knowledge of organic cultivation has been built mainly through experiential and intergenerational learning rather than formal digital training. Second, the orientation of current extension services: interviews with agricultural extension worker (PPL) and BPP officials indicate that assistance has concentrated on cultivation techniques, ICS supervision, and certification facilitation, with comparatively little attention given to introducing digital or precision-farming tools. Third, institutional and budgetary priorities at the district level, where public investment mandated by Sleman Regent Regulation No. 62/2023 has so far been directed mainly toward certification subsidies and conventional agricultural machinery (alsintan) rather than digital infrastructure. Taken together, these findings suggest that narrowing the technological gap in SEB implementation will require not only the provision of precision-farming tools, but also parallel investment in farmers’ digital literacy and a reorientation of extension programs and institutional funding toward building smart-farming capacity.

These findings are consistent with the study by Hardaningsih et al., (2024), which emphasizes that organic farming systems are fundamentally based on the maximal utilization of local resources, the reduction of synthetic

chemical inputs, and the preservation of biological functions within soil and agroecosystems to sustain balance and productivity. The study further highlights that the integration of crop and livestock systems, along with the use of naturally available materials from the surrounding environment, constitutes a key determinant of the sustainability of organic agriculture—one that not only produces healthy food but also conserves agricultural land and supports the advancement of smart and sustainable agriculture in Indonesia.

“For post-harvest handling, we apply a mixture made from coriander and ginger, with the addition of kaffir lime leaves. This helps keep the rice durable during storage and prevents insect infestation while it is stored here.” (M, Head of Ngalian Farmer Group, interview, 23 September 2025)

From an actor-oriented perspective, the transition toward SEB-aligned practices in Sleman has progressed through a synergistic interaction between grassroots farmer initiatives, agricultural extension services, academic engagement, and supportive local policy frameworks. Farmer groups act as key operational agents that translate SEB principles into integrated organic farming practices, including on-farm production of organic inputs, ecologically based pest management, and partnership-oriented supply chain governance. Institutional backing and incentive-based policy instruments have enabled farmer groups to move beyond their role as technical implementers and emerge as transformative agents driving the transition toward smart, healthy, and sustainable agri-food systems in Sleman Regency. The capacity of farmer groups to adapt to and internalize innovation highlights the central role of institutional support in ensuring the effective adoption of sustainability-oriented agricultural systems such as SEB. Through collective action, continuous technical capacity building, and participatory production governance, farmer groups facilitate innovation diffusion, enhance farmer self-reliance, and contribute to the long-term resilience of local agricultural systems (Farmia, 2022).

Challenges and Constraints in the Implementation of SEB

Stakeholders acknowledge the potential benefits of the SEB concept. However, in practice, the transition toward SEB faces a number of challenges. These challenges and constraints are not solely technical in nature but also involve social and economic dimensions, which are critical to the long-term sustainability of the SEB concept. The complexity of these implementation challenges indicates that the success of SEB does not depend merely on technological readiness or cultivation techniques, but also on systemic support encompassing infrastructure, market access, and the strengthening of farmers' capacities. This argument is further supported by evidence suggesting that farmers' adoption of new concepts is significantly influenced by non-technical factors, which tend to be more determinative in the long term (Liu et al., 2018).

At the technical production level, farmers face two major constraints, namely limited water availability and an insufficient supply of organic fertilizers. The SEB concept relies heavily on soil and plant health to achieve optimal production. In this context, inadequate water availability can reduce the effectiveness of fertilizers and biological agents, while also increasing plant stress. Furthermore, insufficient supplies of organic fertilizers constitute a major barrier to crop cultivation. The growing demand for organic fertilizers in both plantation and agricultural systems has continued to increase, driven by fluctuating prices of chemical fertilizers as well as the long-term adverse impacts associated with their use (Sihombing et al., 2024).

“First, water. This is the number one problem, Ma'am. Our land here depends on rainfall. During the dry season, we have to take turns watering our fields because the wells can't handle being used by everyone at the same time. Second, the lack of organic fertilizer. We often don't have enough organic fertilizer, especially to reach the ideal amount needed for optimal yields.” (S, Head of Gamparan Farmers Group, 2025)

From an economic perspective, particularly in relation to marketing systems, financing, and market access, several challenges have emerged that require immediate attention. Harvests from organic cultivation often lack sufficiently broad distribution channels, causing farmers to remain embedded within conventional marketing systems. At the same time, farmers' digital marketing capabilities remain limited, resulting in restricted market reach. This limitation is consistent with the broader technological gap identified in the smart dimension of SEB (Sub-section 3.2): farmer groups have yet to adopt digital tools even at the marketing stage, let alone precision or IoT-based tools at the production stage, pointing to a shared underlying constraint in farmers' digital literacy and the limited digital-skills training currently provided through extension services. This limited ability to utilize

digital platforms leads to farmers' continued dependence on intermediaries. In contrast, e-commerce platforms enable farmers to sell their produce directly to consumers, while marketplace applications can serve as effective intermediaries connecting farmers with potential buyers and enhancing marketing efficiency (Nuraisyah et al., 2024). Therefore, the utilization of digital platforms is considered crucial for expanding farmers' market access.

"... I actually really want to sell my products online, you know, Ma'am. It's just that I honestly don't have the time to learn and manage it. Other young farmers feel the same way. If we could enter the online market, we would be very happy." (S, Head of Prumpung Farmers' Association, interview, 10 October 2025)

From a social perspective, variations in farmers' interest and commitment constitute a major challenge for institutions such as the BPP commitment to fully transition toward the SEB concept remains uneven. Some farmers continue to express reservations regarding the transition toward SEB, particularly due to economic considerations, expected production outcomes, and the perceived practicality of cultivation practices. Moreover, this variability in commitment may weaken social cohesion within farmer groups, which are the primary actors in the transition toward SEB. These dynamics underscore the importance of an approach that goes beyond a purely technical focus and incorporates an understanding of psychosocial and institutional factors, such as age, income, education, farming experience, and landholding size, that influence farmers' decision-making processes in adopting SEB (Ayati et al., 2018).

"If I had to sum it up, the biggest obstacle is farmers' interest in fully implementing organic farming and sustaining it long enough to achieve organic certification." (R, DP3, interview, 29 August 2025)

"When farmers switch from chemical inputs to organic practices, production tends to decline at first, and that can reduce their interest. Using chemical inputs already gives high yields, so when organic farming results in lower production, farmers become reluctant." (R, DP3, interview, 29 August 2025)

Overall, the analysis of various constraints in the transition toward SEB in Sleman Regency reveals that achieving a fully sustainable, smart-eco-bioproduction-based agricultural system cannot rely solely on changes in cultivation practices at the farm level. Instead, the challenges are interrelated, encompassing technical production constraints (water availability and organic fertilizer supply), technological constraints (the limited adoption of IoT-based and precision farming tools, shaped by farmers' digital capacity and the current orientation of extension and institutional support), economic aspects (market access), and social dimensions (farmers' interest and commitment), which together form a multidimensional system of barriers. Consequently, the success of SEB is highly dependent on an integrated and systemic approach that addresses not only the ecological and institutional foundations—where progress has been most evident—but also the technological dimension, which remains the least developed. Effective cross-stakeholder collaboration is essential to realize SEB as an agricultural ecosystem that is not only environmentally sound and ecologically sustainable, but also economically viable, technologically advancing, and socially resilient for farmers and other key actors.

CONCLUSIONS

This study concludes that the transition toward SEB in Sleman Regency illustrates how elements of a sustainable agricultural system can be progressively operationalized through coordinated institutional and farmer-level actions. In line with the study objectives, the findings demonstrate that this transition is shaped by the interaction of technical, economic, and social factors rather than by cultivation practices alone. The structured involvement of local government agencies, extension services, academic institutions, and farmer groups has enabled the gradual adoption of environmentally sound, organic production practices while maintaining organizational control through mentoring and monitoring mechanisms. However, these achievements remain concentrated in the institutional, ecological, and bioproduction dimensions of SEB; the smart or technology-based dimension particularly the use of IoT-based sensors, precision irrigation, and other digital farming tools, has not yet been adopted at the farmer level. Accordingly, what has been achieved in Sleman Regency is more accurately characterized as SEB aligned practices, or a transition toward SEB, rather than the full implementation of an integrated SEB system. Although constraints related to market access, certification costs, and farmers' technological and digital capacity remain evident, this transition contributes to improved system integration and decision-making processes within sustainable agricultural management. From an industrial engineering and

systems perspective, this study advances understanding of how integrated governance, institutional support, and human factors influence the effectiveness of sustainable production systems at this transitional stage. These findings emphasize that fully realizing sustainable innovation in agriculture requires not only strengthening the ecological and institutional foundations already achieved, but also targeted investment in smart-farming technologies, digital literacy, and extension capacity, alongside systemic coordination and adaptive management across stakeholders.

RECOMMENDATION

Based on the results conducted, there are several recommendations that can be implemented to support the implementation of SEB in order to promote the healthy food program in Sleman Regency. First, improve farmers' digital literacy and market access by conducting integrated extension programs, developing village digital teams, and providing device assistance. In addition, farmers should be assisted in selling their crops directly to consumers through e-commerce platforms to expand market reach. Second, improve the irrigation system by repairing local water channels through farmer groups, utilizing village funds, and constructing rainwater reservoirs. Furthermore, active participation of farmer groups and the community in planning and maintenance is needed so that this decentralized irrigation system can be sustainable and enhance water resilience for agricultural land. Third, to address dependence on farmer group leaders, a farmer-to-farmer learning system and leadership rotation can be implemented. All these steps need to be carried out together with multi-stakeholder coordination, clear performance indicators, and adaptive monitoring so that digital literacy, irrigation, market access, and institutional support reinforce one another, enabling SEB to be applied more widely beyond Sleman as a sustainable agricultural model that combines environmental, economic, and social aspects.

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