Sustainable Agricultural Modernization Productivity Tools in Asia

Asian Productivity Organization

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SUSTAINABLE AGRICULTURAL MODERNIZATION PRODUCTIVITY TOOLS IN ASIA

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Sustainable Agricultural Modernization Productivity Tools in Asia

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FOREWORD

In an era defined by the pressing need for sustainable solutions, the agricultural sector stands as both a pivotal challenge and a transformative opportunity. As the global population continues to grow, demands for food security, resource efficiency, and environmental stewardship have converged, emphasizing the importance of sustainable agricultural practices.

The agricultural sector in Asian countries has been continuously evolving. This includes a transition from a traditional low-intensification to more modern, higher-intensification systems and growing capital intensity, characterized by mechanization and larger-scale farms. At the same time, the sector has remained heterogeneous, with farms at different modernization levels and scales coexisting. However, sustainability has become an increasingly important consideration in terms of natural resources, environmental preservation, and health, in addition to economic sustainability. Achieving sustainable modernization of the agricultural sector is therefore a critical goal in Asia.

The APO conducted research to examine the agrifood system landscapes that are characterized by both significant modernization and emerging challenges, including resource scarcity, environmental degradation, and climate uncertainty, in India, Indonesia, the Philippines, Thailand, and Vietnam. Based on that research, this publication recommends policies that can contribute to sustainable modernization of the agricultural sector in those member economies.

It is with great pleasure that I introduce this research report on Sustainable Agricultural Modernization Productivity Tools in Asia. This comprehensive study delves into the intersection of modern technology and sustainable agricultural practices, shedding light on innovative tools that hold the promise of transforming how we produce food. This volume reflects collaborations among scholars, experts, and stakeholders working toward a more resilient, prosperous agricultural landscape. It underscores the importance of harnessing technology, informed decision-making, and adaptive strategies to usher in an era of agricultural modernization which is both productive and sustainable.

The APO extends sincere gratitude to Chief Expert Dr. Hiroyuki Takeshima, International Food Policy Research Institute, USA and the national experts from India, Indonesia, Philippines, Thailand, and Vietnam, who conducted the research and wrote this publication. We hope that *Sustainable Agricultural Modernization Productivity Tools in Asia* will serve as a useful guide for readers and that the policy recommendations will contribute to sustainable agricultural modernization in APO member economies and elsewhere.

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OVERVIEW

Background

Raising agricultural productivity has been considered one of the primary drivers of rural development, realized through its contribution to food security improvement and poverty reduction, rural income growth and livelihood enhancement, and human capital formation [22, 23, 26, 39, 58, 80, 84, 94, 95, 159].

The agricultural sector in Asian countries has been continuously evolving. In particular, this includes a transition from a traditional low-intensification system to a more modern, higher-intensification system, and growing capital intensity, characterized by mechanization and larger-scale farms. At the same time, the agricultural sector has remained heterogeneous, with farms at different modernization levels and scales coexisting [123]. However, most critically, sustainability has become an increasingly important consideration in terms of natural resources (e.g., water, energy/fuels, and biodiversity) and environmental and health concerns (e.g., overuse of pesticides and chemical fertilizers), in addition to economic sustainability. Achieving sustainable modernization of the agricultural sector is, therefore, an increasingly critical goal in Asia [112].

Agricultural productivity indicators become an important tool to facilitate such sustainable agricultural modernization both at micro level (e.g., for agricultural organizations like cooperatives) and macro level (e.g., policymakers). At least three important issues arise. First, understanding how different productivity indicators can be used for various aspects of sustainable agricultural modernization is important, given the evolving nature of the agricultural sector described above. Various indicators for measuring agricultural productivity have been developed, ranging from total factor productivity (TFP) and partial factor productivity; efficiency (technical, scale, allocative, etc.) [46], as well as production-function characteristics such as economies of scale and scope [62], flexibility, and resilience [122]. These indicators have been, and continue to be, applicable to different aspects of sustainable modernization of agriculture in APO countries. For example, TFP has been used to assess the overall productivity growth jointly determined by technological advancement, infrastructure, knowledge, and enabling environment. Partial factor productivity, such as land productivity (e.g., yield) and labor productivity, has been used as a simpler proxy than TFP, but also for assessing policy implications in specific input markets (e.g., land market and labor market), as well as for assessing the stages and patterns of structural transformation occurring in the rural economy [62, 112].

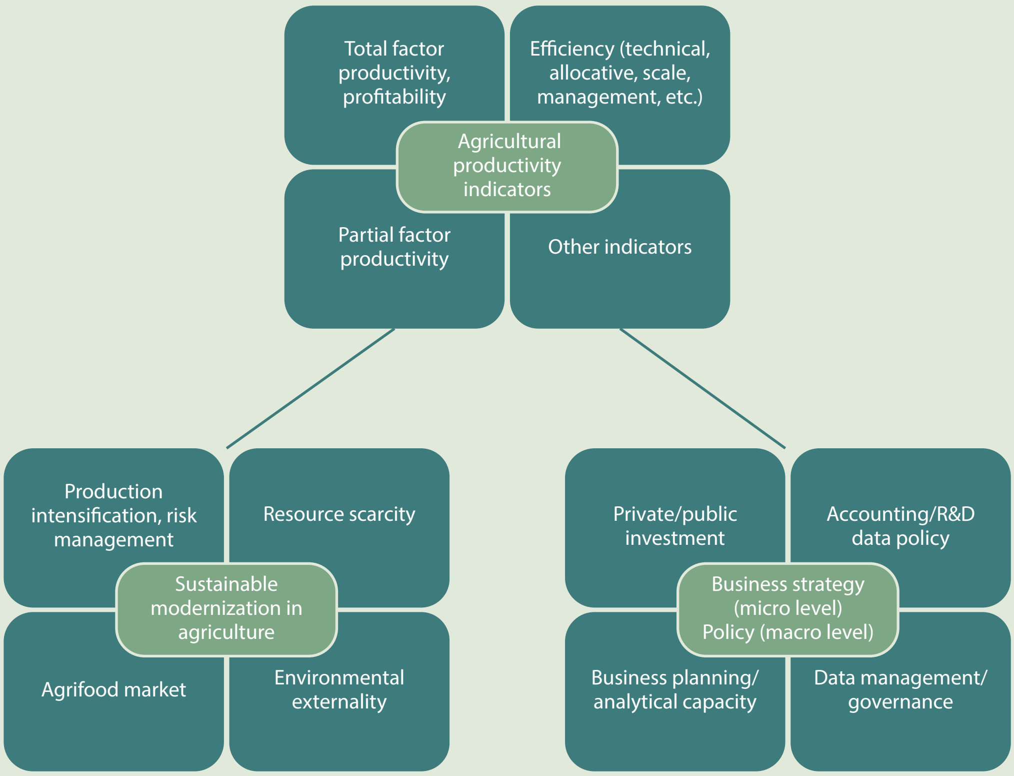
Various efficiency indicators (technical, scale, and allocative) have been used to identify what is feasible in the short term for productivity enhancement and how to achieve it through knowledge diffusion by agricultural extension and training. Economies of scope, flexibility, and resilience have been used for risk mitigation in agriculture and promoting rural livelihood diversification. Other tools to properly account for resource extraction during the intensification process have also been conceptualized and developed for assessing the sustainability of production systems [92]. At the micro level, achieving sustainable profitability of the business models employed by the organization is an important benchmark. At the macro level, key aspects also extend to sustainable realization of food security, economic growth, and positive environmental externality.

Second, understanding how to manage and utilize various types of data to develop productivity indicators is another important issue. Farm household and enterprise-level panel surveys, in conventional formats, continue to be important tools for estimating productivity indicators and their heterogeneity. At the same time, an increasingly richer set of more modern tools have been emerging that can be mobilized for supplementing conventional survey data. At the macro level, these include, but are not limited to, remote sensing-based yield assessment [21]; GPS-based plot area measurement [25]; and other big data combined with modern farming (e.g., precision farming) [51]. At the micro level, relevant issues include farm accounting skills, profitability assessment skills, as well as the active use of related technologies provided by various service providers (e.g., mechanization service providers offering services to measure plot size, etc.).

Third, from a policy standpoint, another important angle is to identify how to link productivity indicators to policies that promote sustainable agricultural modernization [44, 81, 150]. At the macro level, these include both assessing the effects of various policies on agricultural productivity and policies for capacity building in data management and R&D for productivity analyses. At the micro level, related issues include improved farm business planning skills (e.g., simple simulation of different policy-induced scenarios in market conditions, climate risk exposure levels, etc.).

FIGURE 1

CONCEPTUAL FRAMEWORK.



This overall report focuses on key guiding questions pertaining to important aspects of sustainable agricultural modernization (SAM) tools, which are a large body of relevant research tools that have been developed and applied in past research, and key roles played by the public sector and the APO in supporting the effective use of these tools for fostering SAM in APO member economies.

The remaining part of this chapter discusses in more detail the three key questions highlighted earlier and the relevant frameworks for organizing relevant sets of tools that have been developed. It also presents a summary of key individual research works and snapshots of examples of SAM tools, which are described in more detail in the subsequent chapters.

The subsequent chapters provide detailed expositions of various SAM tools and their applications as case studies. These case studies consider the experiences from five APO member economies, namely India, Indonesia, the Philippines, Thailand, and Vietnam. Each case study chapter describes contexts in each country in which SAM tools are applied; advantages and strengths of SAM tools; and key contextualized illustrations of insights obtained from their application in each country.

Key Productivity Indicators for SAM

Main Points

SAM must be balanced, while minimizing the risk of increased vulnerability in any aspect of the production system. Generally, these key aspects belong to economic, environmental, or social dimensions.

In developing countries, among APO members, productivity growth rates are relatively high but volatile, and vary considerably across space and over time. The agricultural sector also consists of resource-poor smallholders vulnerable to various shocks. Table 1 summarizes the general attributes of sustainable systems in agriculture and their relevant criteria, modified from the framework[1] provided by López-Ridaura, *et al* [85]. Table 1 also shows the key aspects and scopes where modernization has key implications. In this framework, sustainable systems have five key attributes, namely, (1) productivity; (2) stability/resilience/reliability; (3) adaptability; (4) equity; and (5) self-reliance.

FIGURE 2

KEY ATTRIBUTES OF SAM.

1 Recent studies provide a similar set of sustainability indicators in agriculture [79, 132, 156].

TABLE 1

KEY ASPECTS OF SUSTAINABLE SYSTEMS AND AGRICULTURAL MODERNIZATION IN APO MEMBER ECONOMIES.

Attribute	Diagnostic criterion	Modernization scope (costs and returns for modern methods to achieve each goal)
Productivity	Physical productivity/ efficiency	Productivity of conventional inputs (improved seeds, fertilizers, agrochemicals, machines, land, labor, water,[2] air, natural resources, and feed)
		Productivity of the following advanced technologies: • ICT (for monitoring, crop sensors, cameras, apps/programs, blockchain, etc.); modern machines (drones, robots, etc.)[3] • Controlled weather facilities[4]
		Wastage and loss reduction, reuse of residues, damage abatement, carbon footprint reduction
	Profitability	Value addition (output quality improvement, processing, premium markets) and cost reduction
		Resource management (crop, feed management in livestock); allocative efficiency
	System-level efficiency	Supply chain efficiency, collective actions, law enforcement for property rights protection
	Coherence	Coherence of production activities with suitability (based on soil conditions, climate conditions, local ecosystems, etc.)
Stability, resilience, reliability	Biological diversity	Biodiversity preservation
	Economic diversity	Income diversification across crops/livestock (economies of scope)
	Environmental vulnerability	Pest and livestock disease management
		Quality/stock of natural resources (e.g., soil and water) Preserving/enhancing natural resources
	Economic vulnerability	Enhancing availability/accessibility of inputs and services
		Reducing price fluctuations
	Climate vulnerability	Climate change adaptation
	Social vulnerability	With aging of farmers, fostering youths as successors
Adaptability	Capacity for change	Raising farmer capacity for adaptation, economic flexibility
Equity/ inclusiveness	Distribution of benefits, and decision-making power	Raising equitable distribution (with regard to gender, minority, etc.)
Self-reliance	Participation	Facilitating participation in collective actions and enhancing social capital of farmers (through cooperatives, farmer organizations, etc.)
	Self-sufficiency and autonomy	Decision-making power in agricultural activities

Source: Modified from López-Ridaura, *et al* [85].

[2] Improved water usage can include seawater farming promoted in coastal areas by cultivating mangroves, salicomia, casuarinas, and appropriate halophytic plants [137–140].

[3] This has been used in some modern livestock farms in India [137–140]. Robotic milking equipment has arms or cups with sensors that may be fitted to the teats of cows individually. Sensors can detect whether or not the cow or one of its teats is ready for milking. Robots can milk cows at any time of day rather than on a set schedule and thus increase milk output.

[4] This can include cold chains and greenhouses. Also, modern livestock farms use a thermal insulation system in India [137–140]. Insulation acts as a barrier to heat flow, reducing heat gain in summer to keep the house cool and reducing heat loss in winter to keep the house warm. Thermal insulating material like aluminum bubble sheets can be used as false ceiling material by placing it under the asbestos roof. Thermal insulation and other cooling mechanisms provide more comfort to dairy animals, thereby resulting in higher milk production.

Supplementary Details

Attribute productivity relates to both physical productivity and economic productivity (profitability). The productivity of conventional inputs and resources, as well as more advanced technologies, can be affected by modernization.[5] Wastage and loss reduction, along with residue usage, are also important aspects of efficiency.[6] Damage abatement and carbon footprint reduction[7] are important indicators of productivity of ecofriendly production practices. Reducing carbon footprint often also has direct local benefits.[8] Similarly, profitability is affected by modernization that promotes value addition (such as output quality improvement,[9] food safety, processing,[10] information products like labeling and traceability,[11] and linkages with premium markets), and cost reduction in acquisition of inputs/raw materials. Profitability can also depend on the modernization of management methods and the managerial ability for production and use of inputs and resources, including feed management,[12] which can relate to allocative efficiency [108]. Agrofood system-level efficiency, such as supply chain efficiency, collective action (e.g., cooperatives/associations), and law enforcement for property rights protection[13] are becoming increasingly important as well, as producers are increasingly integrated into more complex value chains [119]. Productivity is also increasingly dependent on "coherence," such as coherence with the natural conditions of the production environment, with community capacity, or local customs and policies, which indicate the suitability of production systems given the multidimensional nature of production contexts [104].

Attributes of stability/resilience/reliability can depend on "diversity" and "vulnerability" in both biological and economic factors, as well as climate and social vulnerability. Modern methods in preserving biodiversity, including genetic diversity, and enabling income diversification by diversifying into production of more crops, as well as livestock animals, often directly contribute to reducing risks [29, 38, 63, 133] and also raising productivity [110]. Modernization can also address various types of vulnerability. Pest, livestock disease management, and environmental

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5 Some recent modern applications include real-time crops/livestock conditions of livestock health. For example, in India, a machine learning platform developed by startup MooFarm (Fitness Tracker for Cattle) will help tackle mastitis, a disease of the cow udder [137–140]. Similarly, some modern farms use sensor-driven grooming brushes [137–140]. Brushes swing left and right, about 45° in each direction. These brushes access the cow's back and are more accessible for her. Rotation is activated when the cows move the brush and continue until the arm remains horizontal. This equipment (1) enables reduction in the number of parasites and organisms on the cow's coat; (2) allows cows to bond with their herd mates and reduces the impact of the boss cow/submissive cow hierarchy within the herd; and (3) facilitates cows to use grooming to cope with stressful situations.
Other applications include the reduced cost of monitoring crops and livestock. In some modern livestock farms in India, livestock managers are wiring up their barn feedlots and pastures with cameras that send images back to the central location like an office or a home computer. They can keep a closer eye on the animals when they are away or at home for the night [137–140]. Drones are also used for cattle monitoring. Improved management of livestock traffic between milking stalls and back to barns can reduce the risk of injuries [137–140]. Some farms in India use automated cattle traffic management systems. There are computer-controlled gates that open and close electronically. These gates can sort the livestock based on their readiness to milk. The livestock ready to be milked is moved to the milking area while others are put in the waiting area or returned to the barns. Companies like Delmer, Bump Gates, Fullwood Packo, and Lely are known for their automatic cattle traffic systems [137–140].

6 Wastewater treatment in the dairy industry in India is done in three phases through filtration systems, effluent treatment systems, and aerobic treatment [137–140].

7 The dairy industry has a large carbon footprint from the farm to the retail supply chain during milk processing.

8 For example, black carbon caused by burning is a significant contributor to local and regional warming [161].

9 In India, for example, buffalo milk is preferred by dairy processors not only for higher total solids (33% more than cow milk) but also for its higher fat content. Its superior whitening property renders it more suitable than cow milk for manufacturing dairy products, particularly powders. Value premiums have risen for reduced adulteration/toxins, higher processing suitability, hygiene, and compliance with international quality standards.

10 Processing efficiency includes minimizing fat/protein losses during processing, controlling production costs, saving energy, and extending shelf life.

11 In India, some modern farms already apply blockchain technologies to improve the traceability of milk along the supply chain (Singh 2022, 7.2.6).

12 The feed requirement of cattle depends on their health and weather. For example, a sick or pregnant cow may need more nutrition. A hot and humid climate means that cattle need more glucose in their feed. Several feed technologies produce formulated feed additives, supplements, premixes, and base mixes to maintain optimal milk production throughout the year. For example, the National Dairy Development Board (NDDB) has developed bypass protein technology to produce specially treated protein supplements that can be fed to cattle to increase milk yield and quality [137–140].

13 This can depend on factors such as storage temperature, cold chain availability, weather, perishability/shelf life, first- and last-mile distance, packaging, etc.

management can be improved by, for example, modern breeding of pest-and-disease-resistant varieties and livestock breeds of certain characteristics (for example, controlling sex ratio [137–140][14]; integrated pest management; and conservation and improvement of soil, water, and other natural resources [115]. Modernization can also improve the availability/accessibility of agricultural inputs and services and reduce market price fluctuations through improved storage and market networks that stabilize prices over time and across space, thus mitigating economic vulnerability. Modern technologies, including climate-smart agriculture, can reduce farmers' vulnerability to climate change. Climate-smart technologies can range from improved varieties [64]; crop diversification [18]; and institutions like climate-resiliency field schools [28], among others. Modern methods, including ICT, also have the potential to address the aging of farmers through a facilitated intergenerational transfer of farming skills or property rights to the youths who will succeed in farming [14, 66], thereby mitigating social vulnerability. Social sustainability is missing from current agriculture 4.0 debates [125].

The attribute of adaptability relates to the ability to adapt to changing agriculture environments (agroecological and socioeconomic environments). Modernization of human capital development, such as education of farmers and financial capacity, can help farmers to be more adaptable [50, 103].

The attribute of equity is key to sustainability because it ensures social stability [68] and often contributes to income growth [16]. Modern technologies can enhance equity by addressing various sources of inequality, including age [86] and gender gaps [106].

The attribute of self-reliance can include participation in collective action, enhancing the social capital of farmers (cooperatives, farmer organizations, etc.), and decision-making power in agriculture, which ensures that farmers can choose locally sustainable agriculture.

Data Selection and Analytical Methods

Data

Table 2 summarizes the data/survey relevant to sustainable modernization of agriculture, modified from López-Ridaura, *et al* [85]. These include conventional farm surveys, market surveys, and climate data.[15] These data should be analyzed to extract productivity measurements relevant to each attribute of SAM, particularly those noted below:

- Direct methods to estimate TFP with sustainability parameters can inform whether outputs (both quantity and quality) are produced efficiently and sustainably from a set of resources.

- Impact evaluation methods can offer unbiased productivity estimates when agrifood system of interest is complex and hard to be fully characterized.

[14] In India, some modern livestock industries use ultrasound. Ultrasound is not only for checking on baby animals in the womb, it can also be used to discover what quality of meat might be found in an animal before it goes to the market. The testing of DNA helps milk producers to identify animals with good pedigrees and other desirable qualities. This information can also be used to help farmers to improve the quality of their herds.

[15] For harvesting, methods to collect better information have emerged. In India, completing harvest and weighing of demonstration plots by or in presence of monitoring and evaluation staff is being practiced. Yield estimates of major crops are being obtained through analysis of crop cutting experiments (CCEs) conducted under the scientifically designed General Crop Estimation Survey (GCES). In India, more than 95% of the production of foodgrains is estimated on the basis of yield rates obtained from the CCEs. Stratified multi-stage random sampling design is being adopted for carrying out the GCES at tehsil, taluka, and block levels.

- Production functions can distinguish changes in technologies from changes in production environments. SAM requires improvements in technologies, not simply improvements in production environments.

- Expert opinions should be used to verify assumptions underlying statistical models used above, and/or assess productivity potentials of new technologies for which data are limited.

- Composite indicators can help monitor progress in SAM across many relevant sustainability attributes, particularly resilience, adaptive capacity, equity/inclusiveness, and self-reliance.

TABLE 2

INDICATORS AND MEASUREMENT METHODS FOR DIFFERENT DIMENSIONS OF SAM.

Attribute	Diagnostic criterion	Strategic indicators	Measurement methods
Productivity	Productivity	TFP Partial productivity	Farm surveys Productivity estimation
		Produce quality	Random sampling to determine percent of low-quality crops
	Profitability	Marginal cost/benefit	Cost–benefit analysis
		Labor demand	Socioeconomic survey
		Net income/total income	Socioeconomic survey
Stability, resilience, reliability	Biological diversity	Number of managed species	Surveys of flora
	Economic diversity	Income from various crops	Census of plants and products
		Market diversification	Marketing process
	Environmental vulnerability	Pest incidence	Random sampling in plots
		Erosion	Measuring in runoff plots
		Nutrient balance	Soil, compost, and crop analyses
		Pollution	Soil/water quality
	Economic vulnerability	Input availability	Technical monitoring dossier per plot
		Price fluctuations	Price data
	Social vulnerability	Permanence of producers in the system	Local producers' registry
Adaptability	Capacity for change	Producers and area cultivated per system	Local producers' registry
Equity	Distribution of benefits, and decision-making power	Decision-making mechanisms	Interviews with the local Directive Board, etc.
		Distribution of returns and Benefits	Institutional survey
			Women's Empowerment in Agriculture Index (WEAI)
Self-reliance	Participation	Attendance to assemblies and other events	Socioeconomic survey (e.g., India Human Development Survey) Institutional survey
	Training	Number of producers trained	Quantification of training courses
	Self-sufficiency	Reliance on external resources	Financial statistics of the district, etc.

Source: Modified from López-Ridaura, *et al* [85].

There have been significant improvements in the technologies for selecting various data. Examples include [137–140] monitoring and controlling crop irrigation systems via smartphones, and monitoring efficiency of fertilizer applications with crop sensors (optical sensors can see how much fertilizer a plant may need, based on the amount of light reflected to the sensor). Soil composition and moisture content are measured, and nutrient detection is also done. Cameras and drones for cattle monitoring, fitness trackers for cattle, and ultrasounds for livestock quality are used. Also, automated cattle traffic management systems have been deployed in some farms.

Analytical Methods to Assess Sustainable Productivity

Table 3 summarizes examples of analytical tools to assess the productivity of sustainable modernization methods for each attribute. Analytical tools can include (1) direct methods to estimate TFP and its variants; (2) reduced form model methods; (3) direct estimation of production function; (4) perception-based methods; and (5) development of composite indicators, among others.

Direct methods to estimate TFP and its variants include standard approaches like Growth Accounting Method; Malmquist Index; Fisher's Index based on Data Envelopment Analyses; and Fisher, Törnqvist, and Hicks–Moorsteen TFP indices [46, 157]. TFP estimation methods have been applied to various sustainable modernization methods. Recent studies have extended TFP estimation methods to incorporate sustainability issues. Intertemporal TFP [4, 34, 42] accounts for resource degradation.[16] Supply-chain level TFP over multiple different periods, such as The Bennet TFP indicator and Luenberger indicator [53], enables capturing the sustainability of TFP.[17]

Reduced-form model methods have been applied to various sustainable modernization issues. Impact evaluation methods, such as combinations of difference-in-difference, propensity score-based methods, and sample-selection methods, have been applied to assess the micro-level productivity impacts of various modern sustainable technologies. These include assessing the productivity/profitability of controlled-weather facilities like cold storage for potatoes in India [98]; solar-powered cold-storage [151]; effects of agrifood market development on crop diversification [144]; adaptive capacity like economic flexibility [151]; productivity impacts of IPM information dissemination on insecticide use in South Vietnam [121]; productivity impacts of conservation agriculture in South Asia [100]; productivity impacts of collective payment for ecosystem services (PES) in Cambodia [31]; productivity/profitability/quality impacts of SMS-based information in India [43]; profitability impacts of sustainability certification for tea in Vietnam [54]; profitability impacts of food traceability systems in the Republic of China (ROC) [82]; productivity/profitability impacts of contract farming in Nepal [99, 100], Pakistan [71], Bangladesh [118], and Indonesia [56]; and decomposition of sales price premiums (profitability) for improved quality of rice in Bangladesh [97]; among others. Standard panel-data analysis approaches have been applied to assess the productivity impacts of various technologies over a more extended period. Examples include the roles of ICT on price stability, e.g., the historical model in PR China [57] and productivity effects of cooperatives on the safety of dairy products in India [76], among others.

[16] Intertemporal TFP account for the unpriced contributions from natural resources stock and their unpriced production flows. A system will be said to be sustainable if the associated intertemporal TFP index, which incorporates and values changes in the resource stock and flow, does not decrease. Accounting for changes over time in resource quality-related variables such as soil's organic matter, available phosphorus, soil pH, soluble salts, and water quality (residual carbonate and electroconductivity of groundwater)) can inform environmental sustainability of TFP growth.

[17] Gaitán-Cremaschi, *et al* [53] internalizes the social and environmental externalities of food production, and accounts for the sustainability effects of stages along agri-food supply chains.

Estimations of production functions and their variants have been essential in characterizing the determinants of productivity-related indicators. Assessing output elasticity with respect to labor inputs is a critical way to assess labor productivity and income and its change over time, affecting economic and social vulnerability. Other examples include measurements of economies of scope (related to crop diversification) [148]; economies of flexibility (related to adaptive capacity) [151]; production function for agricultural cooperatives (related to participation in collective action) [163]; production function of biodiversity [29]; and production function of byproducts and/or reused residues [89]. Yet other examples include the production function of damage abatement/loss reduction related to the productivity of pest management through transgenic crops [116, 117, 136], and skill improvement [27], among others.

Perception-based methods rely on experts' opinions and respondents' perceptions to assess key productivity information. These methods help reflect factors that are difficult to quantify but are essential in determining productivity. Examples include identification of more effective climate-smart agriculture practices among various options based on stakeholders' perceptions [72]; productivity of various sustainable intensification methods based on expert views [114]; productivity impacts of modern methods like contracting [118]; and experts' views on the relative importance of different factors in selecting from various sustainable modernization options used in analytic hierarchy process (AHP) and multi-criteria evaluation (MCE), as also described in the subsequent section. Meta reviews of studies on specific sustainability attributes are tools belonging to perception-based methods. Examples include meta reviews of productivity issues associated with agricultural entrepreneurship development, which affects social vulnerability attributes [36].

Various composite indicators have been developed based on combinations of survey-based methods and/or estimations. A few examples of these indicators include ease of doing business indicators in agribusiness [124]; environmental quality indicators [61]; indicators set to capture the resilience of agriculture to inform decision-making frameworks and policies [19]; soil-based Climate-Smartness Index (SCSI) [12], a composite index of adaptive capacity of farming systems to climate change in IR Iran [1]; the Women's Empowerment in Agriculture Index (WEAI) [6] and its application to Southeast Asia [2]; and machine learning techniques (LASSO) to reduce the number of indicators in the index applied to India [130], among others. Simpler indicators are also used to assess various attributes of sustainable modernization, such as adoption rates of various technologies. For example, an adoption rate reaching 10% is sometimes used to indicate the commercial availability of technologies [62].

TABLE 3

ANALYTICAL TOOLS TO ASSESS PRODUCTIVITY OF SUSTAINABLE MODERNIZATION METHODS.

Attribute	Diagnostic criterion	Modernization scopes (costs and returns for modern methods to achieve each goal)	Analytical tools to assess the productivity of corresponding sustainable modernization methods
Productivity	Physical productivity/ efficiency	Productivity of conventional inputs (improved seeds, fertilizers, agrochemicals, machines, land, labor, water, air, natural resources, and feed)	Approach to incorporate sustainability in productivity measurement • TRP [29] • Adjusted TFP [20] • Intertemporal TFP [34, 42]: • Models to assess impact of controlled-weather facilities (e.g., cold storages [98, 152].
		Productivity of advanced technologies	

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Attribute	Diagnostic criterion	Modernization scopes (costs and returns for modern methods to achieve each goal)	Analytical tools to assess the productivity of corresponding sustainable modernization methods
Productivity	Physical productivity/ efficiency	Wastage/loss reduction, reusage of residues, damage abatement, carbon footprint and environmental pollution reduction	• Damage abatement [27, 116, 117, 136] • Reuse of residues / byproducts [89] • Impacts on food safety improvement practices [31]
	Profitability	Value addition (output quality improvement, processing, premium markets); cost reduction Production management (crop, feed management in livestock) (allocative efficiency)	• Models to assess the impact of quality improvement, e.g., impact of consumer demand for rice quality improvement on rice producers in Bangladesh [97] • SMS-based information in India [43] • Profitability impacts of sustainability certification for tea in Vietnam [154] • Profitability impacts of food traceability systems in the ROC [82] • Impact of contract farming in Nepal [99, 100], Pakistan [71], Bangladesh [118], and Indonesia [56]
	System-level efficiency	Supply chain efficiency, collective actions, law enforcement for property rights protection	• Supply-chain level TFP [53] • Ease-of-doing-business indicators in agribusiness [124]
Stability, resilience, reliability	Biological diversity	Biodiversity preservation	• Productive value of biodiversity [29] • Effects of market participation in crop diversity [144] • Productivity impacts of IPM information dissemination on insecticide use [121]
	Economic diversity	Income diversifications across crops/livestock (economies of scope)	• Impacts of supermarket sales participation on crop diversification in India [142]
	Environmental vulnerability	Pest, livestock disease management	• Damage abatement [27, 116, 117, 136]
		Quality/stock of natural resources (soil, water)	• Environmental quality indicators [61] • Production efficiency taking into account the environmental effects (eco efficiency) [128] • Productivity impacts of conservation agriculture in South Asia [11, 100]

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Attribute	Diagnostic criterion	Modernization scopes (costs and returns for modern methods to achieve each goal)	Analytical tools to assess the productivity of corresponding sustainable modernization methods
Stability, resilience, reliability	Economic vulnerability	Enhancing availability/ accessibility of inputs and services	• Adoption rates of various technologies: 10% adoption rates are sometimes used to indicate commercial availability of technologies [62]
		Reducing price fluctuations	• Role of ICT on price stability (historical model in PR China) [57]
	Climate vulnerability	Climate change adaptation	• Indicator set to capture the resilience of agriculture [19] • Soil-based Climate-Smartness Index (SCSI) [12] • Identification of more productive climate smart agriculture practices among various options based on stakeholders' perceptions [72]
	Social vulnerability	Aging of farmers, fostering youths as successors	• Agricultural entrepreneurship [36]
Adaptability	Capacity for change	Raising farmer capacity for adaptation, economic flexibility	• Flexibility [151] • Composite index of adaptive capacity of farming systems to climate change in IR Iran [1]
Equity	Distribution of benefits, and decision-making power	Raising equitable distribution by gender, and for minorities	• Women's Empowerment in Agriculture Index (WEAI) [6] • Machine learning techniques to reduce the number of indicators [130] • Women's empowerment in agriculture in South Asia [2]
Self-reliance	Participation	Facilitating participation in collective action, enhancing social capital of farmers (cooperatives, farmer organizations, etc.)	• Productivity effects of cooperatives on quality and safety standards in PR China [164] • Efficiency/production function of cooperatives in PR China [163] • Impact of cooperative membership on milk food safety [76]
	Self-sufficiency and autonomy	Decision-making power in agricultural activities	Same as for the equity attribute

Source: Authors' compilations.

The three text boxes highlight examples from case study chapters on India, the Philippines, and Indonesia.

BOX 1

CASE STUDIES OF SAM FOR DAIRY IN INDIA AND OBJECTIVES.

Assessment of sustainable productivity performance of dairy processing plants and milk producers.

Key SAM indicators in dairy sector

- Overall productivity/profitability indicators
- Use of modern sustainable technologies
- Accounting/handling of waste materials, waste water
- Milk safety
- Pollution prevention

Factors associated with adoption of SAM practices in the dairy industry

- Improved knowledge of SAM practices
- Technologies of SAM practices
- Data-based business management skills
- Incentives for environment-friendly production practices

Key perceptions on SAM practices in dairy industry captured through qualitative survey

- Innovative packaging material used and shelf life of the product
- Potential modern equipment/technologies usable
- Future scope for improvement on
  - Energy consumption
  - Quality of milk
  - Labor management
  - Technology upgradation
- Technologies as systems
  - Energy-efficient systems (e.g., solar water heating system; lithium bromide-based vapor absorption refrigeration system; thermo-vapor recompression system)

Challenges in and potential tools for capturing SAM-related information in dairy industry

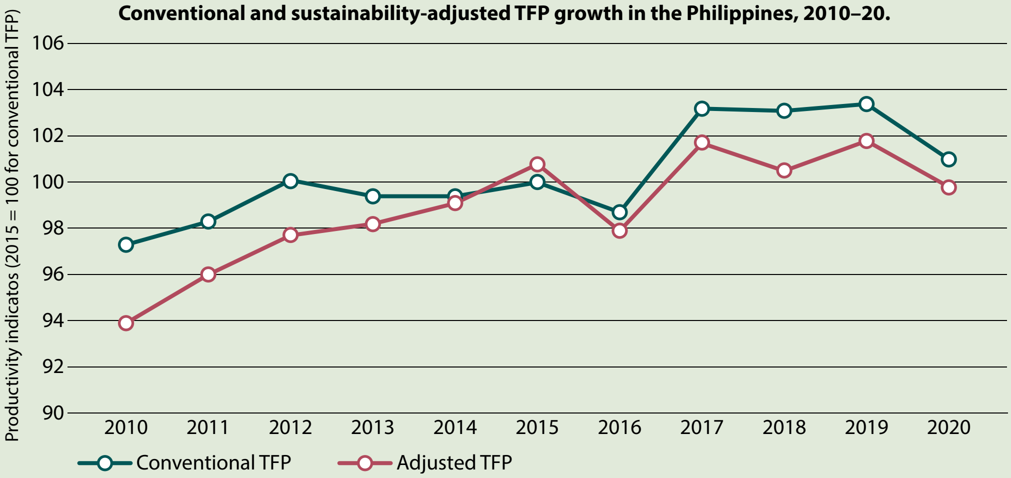
- Waste materials
  - Waste plastic materials
  - Used boxes
  - Used gunny bags
  - Sludge received from effluent treatment plants (ETPs)
- Waste water
- Quantity
- Cost
- Frequency of disposal

BOX 2

KEY ENVIRONMENTAL INDICATORS FOR THE PHILIPPINES.

Greenhouse gas emission	Physical emissions in CO_2 equivalent
Soil nutrient loss	Nutrient loss/buildup in the soil
Coral reef degradation	Natural capital for key marine habitats affecting fisheries

Conventional and sustainability-adjusted TFP growth in the Philippines, 2010–20.



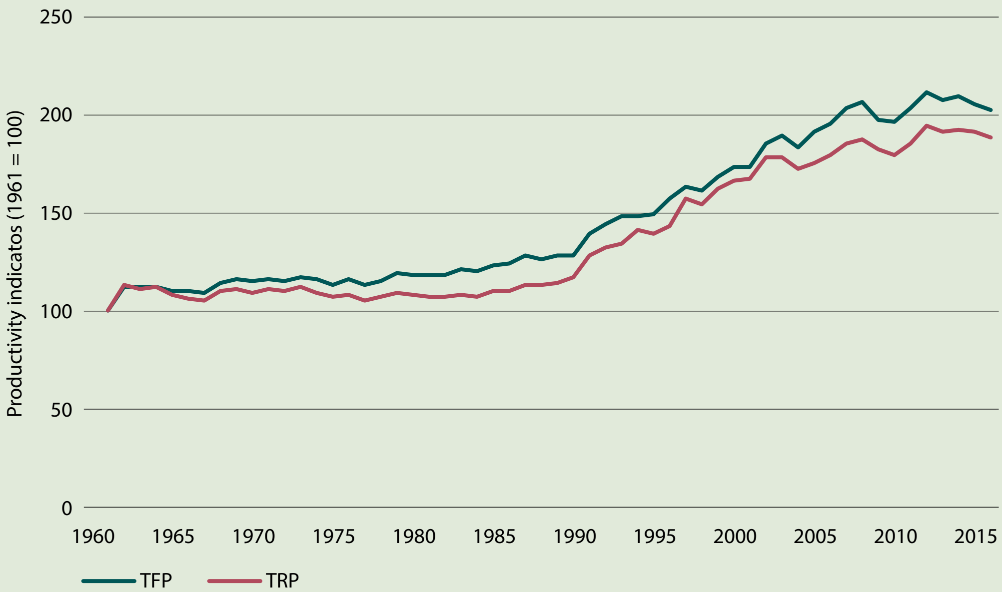
Source: [20].

BOX 3

INTEGRATION OF TRP IN AGRICULTURAL CENSUS IN INDONESIA.

Net farm income	Purchasing power parity (in rupiahs)/units of labor used
Risk mitigation mechanism	Volume of output access to credit and insurance
Prevalence of soil degradation	Volume of output/area of degraded soil
Variation in water availability	Volume of output/water used
Management of fertilizers	Volume of output/ecofriendly fertilizer usage
Management of pesticides	Volume of output/ecofriendly pesticide usage
Use of practices that support agrobiodiversity	Volume of output/agrobiodiversity usage
Wage rate in agriculture	Volume of output/wage rate of unskilled labor
Food Insecurity Experience Index	Volume of output/amount of food insecurity households
Secure tenure rights to land	Volume of output/amount of household owning land

Examples of TFP and TRP trends in Egypt.



Source: Fuglie et al [52].

Applying Productivity Indicators to Promote SAM Policies

Figures 3, 4, and 5 illustrate some examples of how to apply productivity indicators to promote SAM policies/decision-making. These include public sharing of SAM-related indicators/statistical data; assessment of the linkage between policy/decisions and SAM-related productivity; and selection and prioritization among SAM technologies/options.

FIGURE 3

PUBLIC SHARING OF SAM-RELATED INDICATORS AND STATISTICAL DATA.

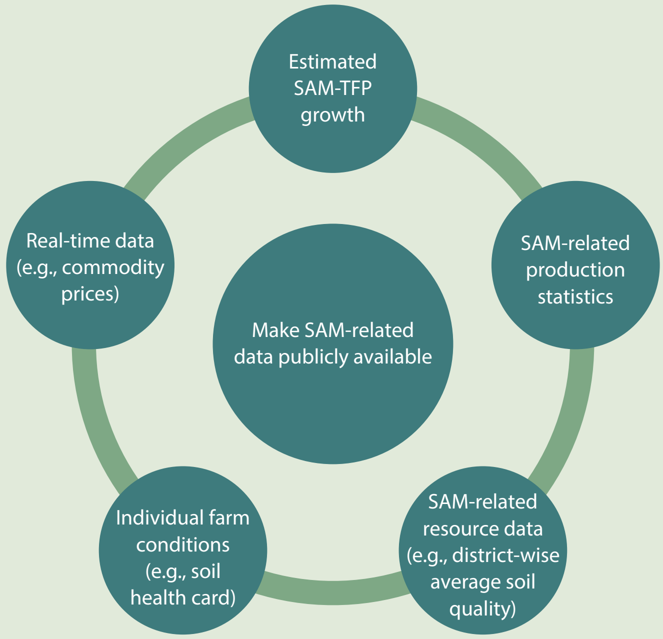


FIGURE 4

ASSESSMENT OF THE LINKAGE BETWEEN POLICY DECISIONS AND SAM-RELATED PRODUCTIVITY.

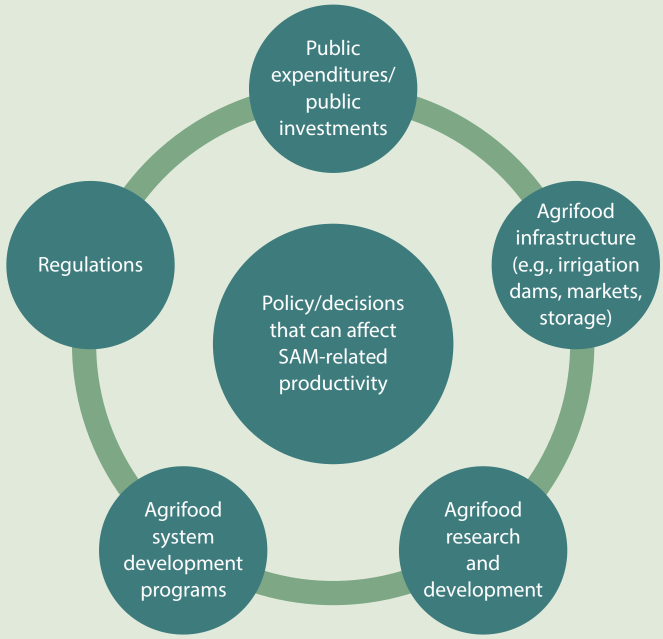
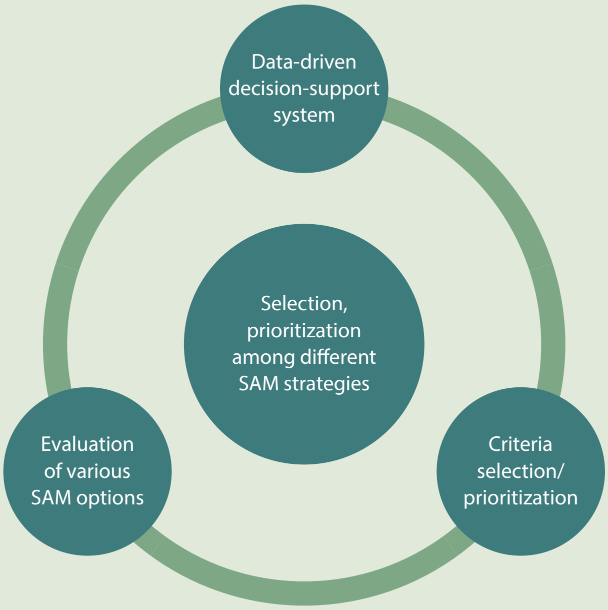


FIGURE 5

SELECTION AND PRIORITIZATION AMONG SAM TECHNOLOGIES/OPTIONS.



Supplementary Details

Table 4 summarizes examples of applications of sustainable modernization productivity indicators to aid decision-making at macro and micro levels. Among others, there are three key ways in which productivity indicators related to sustainable modernization are applied or used to aid decision-making: (1) sharing productivity-related indicators for tracking and better decision-making; (2) assessment of the linkage between policy/decisions and productivity; and (c) selection and prioritization among various options.

Sharing various productivity-related indicators with the public is one of the most critical roles of the public sector [44]. An example of such data can be found among estimates of agricultural TFP published by IFPRI [65], USDA [155], or various statistics published by governments [87]. The statistics on TFP and other productivity indicators estimated by the USDA [155] have been used in studies like Takeshima, *et al* [150] to assess the level of agricultural transformation (including the relative growth of land productivity and labor productivity) in south Asia. Statistics by MAFF [87] include subnational statistics of production revenues and costs; food industry and marketing costs; number of management entities engaged in organic farming; conservation of resources; mutual relief and insurance for agriculture; number of newcomers in agriculture; female participation status in agricultural commissions; agricultural cooperatives and fishery cooperatives; and gathering status of rural communities (e.g., number/length of gathering held by meeting topic, etc.). These relate broadly to various elements of sustainable modernization, i.e., profitability, system-level efficiency, environmental vulnerability, social vulnerability, equity, and self-reliance. Other examples include the production and sharing of 'Soil Health Card'[18], and tracking/publication

[18] A scheme for improvement in soil fertility through the Soil Health Card is a flagship scheme of the Government of India. Under this scheme, soil health cards have been distributed to farmers after testing their soil samples. The details of major and minor nutrients and recommended doses of fertilizers for the main crops have been mentioned on the Soil Health Card for the consideration of farmers [137–140].

of sustainable agricultural practices such as the share of sustainable land based on input use (e.g., practices to mitigate the risk of chemical inputs), based on SITASI in Indonesia [49],[19] and real-time data sharing of commodity price [111]. Sharing/publication of natural resource data, for example, soil and water quality, allows the estimation of sustainability-adjusted TFP discussed in the previous section for Pakistan [24].[20] Similar data for parts of PR China have also provided new insights into long-term trends in soil quality [83]. Measures of genetic diversity in farmers' fields have recently been developed, which may be proxies for potential losses due to pests and diseases in Pakistan [141].

The assessment of the linkage between policies/decisions and productivity identifies the effects of macro-level policies or public investments on agricultural productivity and the development of the decision-support system at micro-entity levels. Examples of the effects of policies/public investments on agricultural productivity include the effects of public expenditures; public investments (agricultural R&D, infrastructures like dams and storage); public programs (such as input subsidies, market development, and field schools); and environmental regulation on partial productivity, TFP, economic flexibility, inputs access/availability, crop and economic diversification, environment-friendly practices in the livestock industry, sustainable intensification, youth participation in agriculture, gender equality, and climate-smart agriculture. Other assessments include the effects of broader public investments in ICT, property rights, education on facilitating collective action in agriculture, and effects on financial autonomy/self-reliance of local entities for sustainable development (such as financial independence of irrigation schemes). While these examples are not exclusive, they offer insights into how similar assessments of different public policies/investments/programs can be extended to other productivity aspects relevant to SAM.

Tools for selection and prioritization among various options help decision-makers to compare and select key strategies by identifying critical criteria and generating various quantitative indicators. Some such methodologies include the analytical hierarchy process (AHP)[21] and MESMIS (a Spanish acronym for Framework for Assessing the Sustainability of Natural Resource Management Systems), which evaluate the sustainability of complex socioenvironmental systems[22], i.e., total resource productivity (TRP). Appendix A describes AHP in more detail. AHP has been applied in various contexts related to SAM. These include determining the best strategy for developing organic agriculture [48]; identifying which irrigated area is to be developed, given the budget constraints [131]; identifying the major factors of land suitability that affect sugarcane production [3]; prioritization of the importance of criteria of second-generation bioethanol [67], saltwater intrusion adaptation options in Vietnam [104]; essential factors associated with agricultural production among Vietnamese farmers [160]; suitability of land for sugarcane residue production in the Philippines [54]; and characterization of various options [104].

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[19] Results of SITASI in three provinces of Indonesia (West Java, East Java, and West Nusa Tenggara) in 2020 illustrated that 90% of agricultural land use in the provinces was in the substandard category of productive management for ensuring sustainable agriculture. Based on the management of pesticide use, 98.5% of the agricultural land was categorized as sustainable land, comprising 36% in the "desirable" category and 62% in the "acceptable" category. In East Java, in 68% of agricultural land farmers used fertilizers, but none of the specific measures to mitigate the risk of using fertilizers were considered. So, it was categorized as unsustainable agricultural land. Based on the subindicator of farmers' net income, 97% of agricultural land was categorized as sustainable land, with 32% being desirable and 65% being acceptable, while the remaining 3% was categorized as unsustainable agricultural land.

[20] Byerlee & Murgai [24] argue that these data should be collected over a long term (more than five years). District-level secondary data offer the best opportunity to analyze long-term sustainability, provided more emphasis is given to finding innovative means to track resource quality.

[21] Appendix provides more a detailed description of AHP.

[22] MESMIS is a reference evaluation framework, which provides principles and guidelines for derivation, quantification, and integration of context-specific indicators through a participatory process involving local actors. The MESMIS evaluation cycle features an inextricable link between system evaluation, system design, and improvement. It is based on two core steps complemented by a preliminary description of contexts and systems, with the inclusion of a facultative typology and a final analysis and participatory interpretation of results.

TABLE 4

APPLICATIONS OF SUSTAINABLE MODERNIZATION PRODUCTIVITY INDICATORS IN DECISION MAKING.

Attribute	Diagnostic criterion	Example applications of productivity indicators to promote SAM policies/decision-making		
		Sharing productivity-related indicators for tracking and better decision-making	Assessment of the linkage between policies/decisions and productivity	Selection and prioritization among different SAM strategies
Productivity	Physical productivity / efficiency	• Publication of agricultural TFP [65, 155]	• Effects of PE on productivity [151] • Effects of public investments in agricultural R&D on spatial distribution of TFP [146]	• Decision support tools for livestock farming for improved animal health, welfare, and greenhouse gas emissions [13, 105] • Decision support systems for precision agriculture [113] • Collection tools for quantification of waste materials [91]
	Profitability	• Subnational statistics of production revenues and costs, for example, in Japan [87] • Identify the important factor related to corn price [74]	• Effects of storage infrastructure on profitability [152]	• Decision support systems for forest management [134] • Land suitability assessment for sugarcane production [3]
	System-level efficiency	• Food industry and marketing costs, for example, in Japan [88]	• Effects of R&D on productivity of agrifood companies, food firms, etc. [7, 93]	• Decision support tools for agrifood supply chains/ logistics [158]

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Attribute	Diagnostic criterion	Example applications of productivity indicators to promote SAM policies/decision-making: Sharing productivity-related indicators for tracking and better decision-making	Assessment of the linkage between policies/decisions and productivity	Selection and prioritization among different SAM strategies
Stability, resilience, and reliability	Biological diversity		• Effects of PE on genetic preservation [149]	• Effects of market growth on varietal diversity on millet in India [144]
	Economic diversity	• Evaluation of the appropriateness of land use for agriculture in lower Prachinburi watershed [126] • Assessment of agricultural land suitability in India [135]	• Effects of PE on economic flexibility [151] • Effects of food-market development on farm-nonfarm diversification [147]	• Effects of value-chain development on crop diversification in India [142] • Effects of input subsidies on crop diversification [129]
	Environmental vulnerability	• Statistics on number of management entities engaged in organic farming, conservation of resources in Japan (farmland, forests, irrigation ponds/lake, rivers/waterways) [87] • Soil Health Card [137–140] • Share of "sustainable land" [49] • Statistics on soil quality, e.g., Pakistan [4] • Selection of eco-friendly crop farming in northern Thailand [78] • Drought Risk Assessment in Lam Ta Kong Watershed [162]	• Effects of environmental regulation on environment-friendly practices in pig industry [30]	• Decision support system for sustainable irrigation application [10], irrigation, and nutrient management [55] • Strategy selections for developing organic agriculture [48] • Prioritization of the importance of criteria of second-generation bioethanol [67] • Prioritization of the importance of criteria in water resource management in Thailand [153]

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<table>
<tr><th rowspan="2">Attribute</th><th rowspan="2">Diagnostic criterion</th><th colspan="3">Example applications of productivity indicators to promote SAM policies/decision-making</th></tr>
<tr><th>Sharing productivity-related indicators for tracking and better decision-making</th><th>Assessment of the linkage between policies/decisions and productivity</th><th>Selection and prioritization among different SAM strategies</th></tr>
<tr><td rowspan="3">Stability, resilience, and reliability</td><td>Economic vulnerability</td><td>• Mutual relief and insurance for agriculture, forestry and fisheries in Japan [87]
• Real-time data sharing of commodity prices [111]</td><td>• Effects of inputs subsidies on inputs availability/ productivity [15, 45], sustainable intensification [73]</td><td>• Price stabilization policies/ regional trade policies on domestic price stabilization [40]</td></tr>
<tr><td>Climate vulnerability</td><td></td><td>• Effects of dam infrastructure on climate resilience [145]
• Effects on climate-resiliency field school in the Philippines [28]</td><td>• Decision tools in climate-smart agriculture [70]
• Saltwater intrusion adaptation options in Vietnam [104]</td></tr>
<tr><td>Social vulnerability</td><td>• Number of newcomers in agriculture [87]</td><td colspan="2">• Policy effects on youth participation in agriculture, labor productivity/ income, and youth employment [15]</td></tr>
<tr><td>Adaptability</td><td>Capacity for change</td><td></td><td colspan="2">• Effects of PE on economic flexibility [151]</td></tr>
<tr><td>Equity</td><td>Distribution of benefits, and decision-making power</td><td>• Female participation status in agricultural commissions, agricultural cooperatives, and fishery cooperatives in Japan [87]</td><td colspan="2">• Roles of agrifood system modernization on achieving gender equality [90]</td></tr>
<tr><td rowspan="2">Self-reliance</td><td>Participation</td><td>• Gathering status of rural communities (e.g., number/ length of gathering held by meeting topic, etc.) in Japan [87]</td><td colspan="2">• Roles of ICT, property rights, and education policies on facilitating collective action in agriculture [17, 32]</td></tr>
<tr><td>Self-sufficiency and autonomy</td><td>• Understanding smallholder perceptions of conservation agriculture adoption in Nepal and India [120]</td><td colspan="2">• Effects on financial autonomy/ self-reliance of local entities for sustainable development [35], including local water resource management/irrigation schemes [37]</td></tr>
</table>

The boxes below highlight illustrative examples from case-study chapters on Thailand and Vietnam, which are described more in detail in the respective chapters.

BOX 4

CASE STUDY OF AHP IN THAILAND

Objective: To compare different technologies for the rice sector in Thailand.

Step 1: Criteria selection and assigning of importance weights

- The appropriateness of technology in the Thai context = 0.314
- Benefits of technology = 0.269
- Readiness to use technology by related parties = 0.247
- The cost of using technology = 0.170

Step 2: Ranking of technology options

- Community area-based research and crop management = highest rank and most suitable technologies to be pursued
- Fertilizer/integrated pest management = 2nd rank
- Rice breeding technology = 3rd rank
- Precision farming = 4th rank

Technology alternatives	Criteria				Weighted average scores	Rank
	The cost of using technology	Benefits of technology	Readiness to use technology by related parties	The appropriateness of technology in Thai context		
	Importance weight					
	0.170	0.269	0.247	0.314		
	Score					
Community area based research and crop management	0.354	0.260	0.343	0.290	**0.306**	**1**
Fertilizer/integrated pest management	0.219	0.216	0.283	0.268	**0.249**	**2**
Rice breeding technology	0.270	0.250	0.251	0.203	**0.239**	**3**
Precision farming	0.156	0.273	0.123	0.239	**0.206**	**4**

Source: Rice Technology Roadmap Project 2017 cited in Ongkunaruk [111].

BOX 5

CASE STUDIES OF MCE IN VIETNAM

Objective: Evaluate the importance of technical, socioeconomic, and environmental aspects for rice and vegetable production.

Methods: Expert interviews including managers, scientists, and people directly involved in rice and vegetable production

Assign weights in multi stages

TABLE

WEIGHT OF FACTORS AFFECTING HIGH-TECH RICE AND VEGETABLE PRODUCTION

Level 1 factor	Level 1 factor weight (W1)		Level 2 factor	Level 2 factor weight (W2)		Overall weight (W=W1*W2)	
	Rice	Vegetable		Rice	Vegetable	Rice	Vegetable
Technique	0.52	0.50	Soil preparation	0.07	0.06	0.04	0.03
			Varieties	0.26	0.25	0.13	0.13
			Sowing technique	0.05	0.11	0.03	0.06
			Water management	0.09	0.09	0.05	0.04
			Applied technique	0.23	0.25	0.12	0.13
			Production model	0.04	0.04	0.02	0.02
			Processing and preserving	0.11	0.09	0.06	0.04
			Harvest method	0.14	0.11	0.07	0.06
Economy	0.25	0.31	Consumption market	0.59	0.65	0.15	0.20
			Investment cost	0.29	0.23	0.07	0.07
			Profit	0.12	0.12	0.03	0.04
Society	0.15	0.12	Farmer's knowledge	0.27	0.28	0.04	0.03
			Management capacity	0.21	0.21	0.03	0.02
			Social infrastructure	0.08	0.14	0.01	0.02
			Consultants	0.12	0.13	0.02	0.02
			Land use right	0.07	0.08	0.01	0.01
			Labor force	0.15	0.07	0.02	0.01
			Environmental treatment	0.05	0.06	0.01	0.01
			Support policy	0.04	0.04	0.01	0.00
Environment	0.08	0.07	Soil degradation	0.57	0.61	0.04	0.04
			Biodiversity	0.30	0.23	0.02	0.02
			Plant diseases	0.13	0.15	0.01	0.01

Source: Research Institute for Climate Change.

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INDIA

Background

The dairy industry in India has been on a steady path of progress since the country's Independence. It has transformed India from a country of acute milk shortage to the world's top producer. India has grown from producing 17 million tons of milk in 1951 to producing 210 million ton in 2021–22, accounting for 23% of the world's total milk production. This solid progress is primarily attributable to structural changes in the Indian dairy industry. The increase in milk production so far has been achieved through better pricing, organized marketing, and technological changes.

Technological changes in the dairy industry have substantially increased India's milk production. It is essential to find out the new areas for improving milk production to meet the demand for liquid milk for consumption as well as processing purposes. The per capita availability of milk during 2020–21 was 427 gram per day. As per the study on demand for milk conducted by the National Dairy Development Board (NDDB), the estimated demand by 2030 at all-India level is 266.5 million metric ton for milk and milk products. On the other side, the *Niti Aayog* estimates that the country is expected to increase its milk production to 330 million metric ton by 2033–34 from the current level of 210 million metric ton. The dairy industry is now at a stage where the focus should be on productivity rather than only addition of new capacity.

A mushrooming growth of dairy plants since the delicensing has resulted in cutthroat competition in milk procurement. The plants that neither created their own infrastructure to procure quality milk nor exercised proper checks while procuring milk through contractors or village-level commission agents, produced substandard dairy products and consequently low revenue, thereby turning their businesses into losing ventures. In order to achieve the desired level of self-reliance going forward, the Indian dairy industry will have to make strenuous efforts to upgrade the quality of its products to become economically viable and self-sustaining. Only a small percentage of dairy products available in the market can meet international standards of quality and be considered safe for human consumption.

In comparison with developed countries, the productivity of the dairy industry in India is very low. For productivity improvement, there is a need to measure productivity at the unit level. Traditional profitability indicators are fine but to make the measurement meaningful, they should be linked with productivity because profits are largely affected by productivity improvement efforts. There are no such norms for any of these productivity indicators that could readily be used by the dairy industry. It is quite obvious that a starting point for any productivity improvement plan can be thorough assessment of existing productivity levels. This will not only help ascertain the present status of the selected dairy processing plants but also identify the constraints responsible for their low productivity levels. Once this exercise is successfully completed, it will become easier to evolve strategies to overcome the constraints and improve productivity performance.

Generally, wastage of raw materials, manpower, and energy are rampant, with little quality control in most of the dairy units. A large number of dairy plants in the country that are financially unviable and struggling for their existence, need in-depth investigation of reasons underlying their sickness so that appropriate measures could be taken to improve the overall status of the dairy processing industry. The problem is acute in case of small-scale processing units. No concerted efforts have been undertaken to evaluate the methods and techniques used by the processors. Therefore, it becomes imperative that indicative norms should be established through micro- and macro-level productivity assessment studies.

Productivity measurement is a prerequisite for productivity improvement. Adopting a strategy for productivity improvement is not possible unless the existing level of productivity is known. As a diagnostic tool, it helps to identify the strong and weak areas of dairy units, which in turn affect management decision-making. It is useful for planning and monitoring inter-firm comparison as well as arriving at a proper understanding to share the gains of higher productivity with employees. Productivity is also linked with profitability. In fact, productivity ratios provide an alternative way of viewing profits. In the pursuit to improve productivity, administrators and managers are required to plan and monitor productivity as their basic function. In addition, productivity measurement at the unit level also leads to clearly identifying the contributions made toward improving productivity by various components such as capital, labor, raw material, and energy. This leads to equitable sharing of productivity gains, thus ensuring sustained motivation for productivity improvement.

The methods to carry out the different operations in the dairy industry vary from farm to farm and dairy to dairy, depending on the economic condition, the technology available, the labor situation, and the consumer demand. In some dairy units, methods adopted are traditional and there is a large scope for improvement. Even in places where the latest technology has been adopted, there is a possibility for conserving resources. There is no denying the fact that there is immense scope for enhancing productivity and profitability of the dairy industry in India. A study of work methods and measurement may help in optimizing operations at procurement and processing levels with respect to time and technology. Productivity norms and technological plans can be developed for dairy units of varying capacities.

Efficiency in dairying will need to be reflected in several activities. Efficiency in milk production and collection is one such activity that is very important. With an increase in the production of milk, there has been an increase in processing facilities to reduce wastage. Most of the dairy plants work toward a reduction of long-term debts in their overall capital structure. Many of the large plants have a debt–equity ratio of one or below. However, there seems to be a declining trend in the productivity of the capital employed in the dairy industry as a whole. In addition to the management of long-term debts, there is a need for efficient working capital management to help reduce the overall interest burdens.

Energy cost is another significant area in the dairy processing industry. One not only has to conserve it but also develop energy-efficient systems and technologies to reduce energy costs. India has comparative advantages in milk production, employee costs, and product distribution costs but not perhaps in productivity per person in these areas. It would appear that the industry compares favorably in fat and solids-not-fat (SNF) processing costs. Inefficiency at the processing unit level can bring down the whole structure. However, till now, little thought has been put to measuring the productivity performance in dairy processing industry in order to improve the efficiency at various levels. Besides, no systematic productivity assessment at national level has been undertaken so far to benefit the industry. Therefore, the task for conducting a study on "Review of Productivity Assessment Tool for the Agriculture Sector," with special reference to sustainable modernization of the dairy industry in India, was assigned by the APO.

Objectives

The main objective of the study was to review the existing productivity assessment tools for the agriculture sector with special reference to sustainable modernization of the dairy industry involving system simplification, reduction of human interventions, value addition, work environment improvement, customer orientation, and continuous services benchmarking to enhance the quality of products and customer satisfaction with reduced product costs. The study has the following subobjectives:

- to review the existing agricultural productivity indicators and develop a new assessment tool for agricultural productivity to facilitate sustainable modernization of agriculture with special reference to the dairy sector in India;
- to promote understanding and adoption of agriculture productivity assessment tools and indicators for farmers, the private sector, and policy makers in APO member economies; and
- to formulate sustainable agricultural modernization business strategies and policies based on the latest productivity assessment tools with special reference to sustainable modernization of the dairy sector in India.

With a view to achieving the goal with respect to the above-mentioned objectives, a study was conducted to assess the productivity performance at various levels, identify the constraints impeding the dairy sector in achieving higher productivity performance, and suggest measures to overcome the constraints for higher productivity performance.

Scope and Coverage of the Field Study

The study was confined to the agriculture sector with special reference to sustainable modernization of the dairy sector. The scope of the study broadly included

- agricultural productivity indicators with special reference to the dairy sector;
- agribusiness modernization with special reference to the dairy sector;
- agricultural modernization policies for the dairy sector;
- agribusiness innovation with special reference to the dairy sector; and
- sustainable agricultural modernization (SAM) with special reference to the dairy sector

The coverage of the study included the following:

(1) Milk producers

a) Availability of milch animals including

- cows (indigenous and crossbred);
- buffalos (*desi* or indigenous and improved breeds);

- number of animals purchased on loan; and
- insurance status.

b) Availability of required infrastructure including

- veterinary hospital/AI centers;
- availability of veterinary mobile van;
- artificial insemination (AI) technicians; and
- facilities for sale of milk.

c) Expenditure incurred on maintaining the milch animals comprising

- fixed costs; and
- variable cost.

d) Net income including

- income from sales of milk; and
- income from sales of dung.

e) Adoption of the modern technology including

- silage making;
- AI with sort-sex semen ;
- automatic feeding and watering system; and
- milking with machines.

f) Major constraints impeding performance of dairy farming, including

- inadequate availability of dry fodder;
- non-availability of green fodder throughout the year;
- non-availability of quality breeds of animals in the local market;
- inadequate knowledge about clean milk production;
- inadequate knowledge about prevalence of diseases and their preventive measures;

- government veterinary hospitals not well equipped with modern facilities such as X-ray, endoscopy, scanners;
- insufficient visits of veterinary doctors/paravents/AI technicians;
- non-availability of doctors on call during emergency;
- inadequate availability of sort sex semen;
- higher cost of milking machine;
- inadequate facilities for marketing of animal dung;
- non-adoption of good hygiene practices among dairy farmers due to lack of knowledge;
- non-maintenance of data related to cost of milk production;
- receiving less price of cow milk;
- bad effect of climate change on animal production;
- fodder and feed cost increasing fast in the market;
- cost of minerals mixture, medicines, and hormones being very high; and
- not receiving the premium price for quality milk.

g) Social impact of dairy farming, including

- expenditure incurred on children's education;
- expenditure incurred on food and clothing;
- expenditure incurred on healthcare;
- expenses on recreational/social events; and
- nutritional level of the family.

(2) Productivity measurement at the following levels:

a) Procurement, including

- milk procurement models of cooperatives and private dairies;
- milk procurement prices during flush and lean seasons;
- modern transportation technology (cooperatives versus private dairies); and

- transportation costs (cooperatives versus private dairies).

b) Processing, including

- modern processing technology (cooperatives versus private dairies); and
- processing cost (cooperatives versus private dairies).

c) Marketing, including

- distribution models of cooperatives and private dairies; and
- marketing costs of milk and milk products.

(3) Productivity indicators for dairy processing industries such as

- capacity utilization;
- manpower utilization;
- energy utilization; and
- financial indicators (capital output ratio, debt-equity ratio, return on investment, etc.).

(4) Major constraints impeding higher productivity

- availability of quality raw material;
- seasonal variation;
- technological constraints;
- wastage at various levels;
- lack of qualified manpower;
- processing for manufacturing of the dairy products;
- packaging materials;
- distribution system; and
- branding, image building, etc.

(5) Measures to overcome constraints including

- at milk producer level;

- at chilling center level; and
- at dairy processing industry.

(6) Formulating strategies for sustainable modernization of the dairy industry, including

- public investment;
- private investment; and
- business development.

(7) Developing latest productivity assessment tools including

- those based on traditional practices; and
- those based on latest practices.

With a view to obtaining information from dairy units, eight dairy processing units (five from the cooperative sector and three from the private sector) were selected randomly ensuring representative coverage of the processing units. The criteria taken into consideration in the selection of dairy units included the size of the unit, geographic location, and ownership. Further, 10 milk producers of various categories (landless, marginal, small, semi-medium, medium, and large), who were selling milk at the procurement centers or selling to milk vendors, were also covered for each of the selected dairy plants. Thus, a total of 80 milk producers were covered for obtaining the primary information such as availability of infrastructure; number of milch animals (owned and purchased); fixed costs; variable costs (including feeding cost, labor cost, and mineral and medicine costs); quantity of milk sold; sales price of milk; gross income; net income; constraints impeding dairy farming; adoption of new farm equipment and machines, and socioeconomic impact and suggestions of farmers for making dairy farming a profitable venture.

Methodology

The study pertaining to productivity assessment tool for agriculture sector with special reference to sustainable modernization of the dairy industry is a maiden attempt in the country. However, some isolated area-specific exercises have been undertaken at an organizational level that do not encompass all the factors influencing productivity of agriculture in general and dairy industry in particular. The specific methodology for conducting the detailed study covered the following activities:

Desk review: This part includes scanning of literature and discussions with various apex bodies. As a first step, an extensive literature study was carried out of both published and unpublished sources to review various approaches adopted for productivity measurement at different levels. Subsequently, field data collection was undertaken to assess the productivity performance at various levels.

Development of questionnaires and checklists for obtaining primary data: This envisaged collection of data, information, inputs, feedback, and suggestions from various stakeholders on issues related to productivity assessment for the dairy sector. Information on both quantitative and qualitative aspects was gathered with the help of pre-structured questionnaires and checklists designed for the purpose in consonance with the objective of the study.

Pretesting and finalization of study tools: The study tools were thoroughly pretested at one dairy plant and by having discussion with a few milk producers before finalization of both the questionnaires for their efficacy. The questionnaires and checklists were used as tools during the course of the field survey. Pretesting of these tools enabled the finalization of the right questions with the best possible flow, keeping in view the objectives of the study.

Data collection: A field survey was launched at the national level to assess the productivity performance of the dairy sector. The primary data related to dairy processing units and milk producers was collected for the years from 2018–19 to 2021–22 with the help of pre-\\structured and pretested questionnaires developed specifically for the survey purpose. The collected information was triangulated to ensure the quality of information from the field.

Data entry and tabulation: In case of quantitative data, the latest available software, i.e., Statistical Package for Social Science (SPSS) was used for the purpose of data analysis and generating standard tables, as SPSS is today one of the most popular quantitative analysis software used in such research. It was ensured that checks were made at different levels of data entry, so as to control abnormal data and inconsistency in the raw data. After the clean data was available for analysis, standard tables were generated as per requirements outlined in the approach to address all the issues pertaining to productivity measurement of dairy processing units.

Data analysis and report preparation: Data thus collected from various dairy plants and milk producers were analyzed with the help of software to draw inference and conclusions in line with the objectives of the study by using appropriate productivity measurement techniques, particularly the Quick Productivity Appraisal Technique developed at the Philippines Center of Productivity. For analysis of the findings, the two forms of collected information, i.e., quantitative and qualitative, were processed into an interpretable form. The parameters that have direct bearing on the performance of the dairy industry were considered to assess the overall productivity performance of the industry and referred for consolidating the findings. These parameters included procurement of milk, sourage improvement, procurement price per liter, transportation cost per kg of milk, capacity utilization of the dairy plant in percentage, profitability ratio, return on total assets, total assets turnover ratio, fixed assets turnover ratio, working capital utilization ratio, inventory turnover ratio, sales per employee, labor productivity, energy productivity, capital-to-labor ratio, and debt–equity ratio. Further, with a view to calculating the cost of milk production, information related to the number of animals maintained by the milk producers, i.e., availability of cattle sheds, fodder and feed, credit and insurance facilities, sales price of milk and cow dung, net return, etc. were collected. Emphasis was put on presenting the findings in self-explanatory tables, charts, and diagrams. The final report was submitted to the APO after incorporating the suggestions received from the chief expert.

An Overview on Dairy Industry in India

Besides agriculture farming, the allied sector is also the priority area in the agenda of the Government of India (GoI) and has steadily gained importance in the last decade, led by strong growth in animal husbandry and fish production. The Indian livestock sector had attained a record growth of 6.6% during the last decade (2010–19), with India emerging as a major producer of milk, egg, and meat in the world (GoI, 2019). With operational land holding size declining gradually, livestock is emerging as an important source of stable livelihood for not only the small and marginal farmers but also for the landless laborers [2].

1. India has emerged as the world's largest producer of milk, pulses, jute, and spices, and has the world's largest cattle herd (buffaloes). It is the second-largest producer of rice, wheat, cotton, sugarcane, tea, groundnut, fruits, vegetables, and goat meat. However, its share in global trade of agricultural and allied-sector products has only doubled from 1.1% in 2000 to 2.2% in 2018 as per Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare.

TABLE 1

MILK PRODUCTION IN INDIA IN MILLION TON.

S. No.	Years	Milk production
1	2015–16	155.49
2	2016–17	165.40
3	2017–18	176.35
4	2018–19	187.75
5	2019–20	198.40
6	2020–21	208.00
7	2021–22	210.00

Source: Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, GoI.

The Indian dairy sector is characterized by high fragmentation. It is dominated by the unorganized sector comprising 70 million rural households. Milk production is an integral component of Indian agriculture supporting livelihoods of more than two-thirds of the rural population. The country exhibits coexisting organized sector (cooperatives and modern-style private dairies, including multinationals) and unorganized sector (private milk vendors, traditional *halwais,* etc.) for marketing of milk and dairy products. Dairy cooperatives comprise the single-largest formal organization in terms of available infrastructure and network for milk procurement. However, the informal sector still has to play an important role in the Indian dairy sector as a supplier of fresh milk. Cooperative and private sectors share around 40% and 60% of the marketable milk surplus, respectively. However, the cooperative sector sells liquid milk more than milk products unlike the private processors who produce more of dairy products. Unless India's dairy production increases at the pace required, there is a possibility of a widening gap in the supply of milk products, which can lead to a dependency on imports.

Despite the fact that the country is having the largest bovine population (about 20% of the world's bovine population), India's share in world milk production is only about 23%. This is mainly due to the relatively low productivity of milch animals. The situation is further accentuated due to poor nutritional availability and inadequate health cover. Small and marginal farmers, landless laborers, and other vulnerable segments of the rural community rear one or two milch animals, mainly using crop residues and byproducts as feed and deploying family labor, especially women and children. In the absence of stable employment opportunities for these vulnerable segments of the rural population, dairy animals play an important role in offering a somewhat stable source of family income.

The organized sector in India handles only about 40% of the marketable milk surplus. Since there is a need for growing children to increase their intake of milk and milk products to ensure bone health, therefore in the interest of both producers and consumers, it is imperative that the share of the organized sector comprising cooperative, private companies, and producer companies is increased. Milk is highly perishable and requires immediate processing, storage, and preservation, to move it from production areas to demand centers. Processing and market linkages are, therefore, prerequisites for value creation and addition. It is now well-known that development of milk processing infrastructure like silos, pasteurizers, storage tanks, and refrigerators has increased the nation's capacity to convert milk, a highly perishable commodity, into a commodity that may be stored and traded worldwide.

In India, there exists a long chain of intermediaries in milk processing systems, which adversely affects the quality of milk marketed and increases the cost of dairy products. However, quality and safety standards in domestic and export value chains are managed through a number of regulations and implementing authorities such as Food Safety and Standards Authority of India; Agricultural and Processed Food Products Export Development Authority; and Export Inspection Council of India. Further, in India, milk is consumed mainly in a raw form and a large proportion is converted into traditional products such as cottage cheese, *ghee,* cottage butter, *khoya,* and curd by the unorganized sector. Also, the unorganized sector still dominates the milk production, processing, and distribution. The infrastructural facilities for collection and transportation of milk are quite poor. Milk procurement price is either on fat basis or on fat-and-SNF basis. In India, 53% of the total milk is produced solely by buffaloes.

There are so many factors affecting productivity growth in the Indian dairy processing industry. Analysis of sources of milk output growth has not received as much attention as it deserves. In this study, productivity function will be used to explain the productivity growth in India's dairy processing industry. Besides, elasticity of dairy output with respect to inputs used in processing, efficiency levels, and input slacks observed in the dairy industry; market conditions affecting the productivity growth and sources of growth of milk output; and the present state of milk processing in India will also be described in detail.

In spite of India being the number one milk producing country in the world, only about 35% of milk produced in the country is processed. Moreover, even that faces a number of challenges in terms of infrastructure, operational efficiencies, quality, and marketing, among others.

Market Overview

The dairy market in India reached a value of INR13,174 billion in 2021. Looking forward, the IMARC Group expects the market to reach INR30,840 billion by 2027, exhibiting at a CAGR of 14.98% during the period 2022–27. We have also tracked and evaluated the direct as well as the indirect influence of the COVID-19 pandemic. These insights are included in the report as major market contributors.

Both national and international players are entering the Indian dairy industry, attracted by its size and market potential. The focus is on value-added products such as cheese, yogurt, probiotic drinks, etc. They are also introducing innovative products keeping in view the specific requirements of Indian consumers. These players are also improving their milk procurement networks, which is further facilitating the development of the dairy industry in India.

Export Market

Despite being one of the largest milk producing countries in the world, India accounts for a negligible share in the worldwide dairy trade. The ever rising domestic demand for dairy products and a large demand-supply gap could lead India to becoming an importer of dairy products in the near future. Thus, a significant potential for exports and the rapid growth in domestic demand pose huge challenges as well as opportunities for the Indian dairy industry.

Even on the exports front, India is lagging due to lack of quality measures. This results in products with high bacteria and pathogenic count as well as residual pesticides. As the world is getting integrated into one market, quality certification is becoming essential. However, there are very few plants in the country that have successfully obtained the ISO and the Hazard Analysis and Critical Control Points (HACCP) certifications. This noncompliance with international quality and food safety norms such as International Product Standards, HACCP, and Good Manufacturing Practices (GMP)/GHP is a major bottleneck, which becomes a barrier to India's competitiveness in exports.

There is a wide scope to improve and increase the processing capacity of the dairy industry and achieve a more significant share of milk and milk products through the formal channel. With the shift toward convenience products, there is a need for advancements in the processing and packaging of milk products. Appropriate R&D interventions and newer developments in the field of dairy processing, along with a focus on novel aspects of emerging technologies, can help alleviate the quality of these products in the domestic and international markets. India's low share of dairy exports globally (0.36%) can be increased by increasing the processing capacity for products that hold potential in the global market, such as cheese, skim-milk powder, whole-milk powder, and butter, and by improving quality to meet international requirements.

The agriculture and allied sector contributed 14.2% to the total exports from India in 2020–21. It comprises a variety of commodities, both in raw and processed forms, ranging from cereals, horticultural crops, sugar, livestock, and marine products. Cereals have the highest share (22.3%) in India's farm export basket, mainly driven by the high demand for Indian rice (both basmati and non-basmati) in the world market. The share of animal husbandry in India's farm exports has almost doubled from 10.4% in 2000 to 20.2% in 2020, mainly driven by the export of buffalo meat. The shares of marine and horticulture products have remained almost stable at around 18% each, over the last two decades.

Changing Landscape of Indian Dairy Industry and Focus Areas

Changing Landscape of Indian Dairy Industry

The salient characteristics of the changing landscape of the dairy industry in India are as follows:

- The private sector is procuring more milk from farmers directly as well as through milk vendors/commission agents than the cooperative sector.
- More and more producer companies are entering the market (inclusive growth).
- Many corporate houses are entering the segment of large integrated dairy farms, including commercial dairies with 2,000–10,000 animals.
- Amul is emerging as a global brand with top position in Asia; and is expanding its horizons

by setting up dairy plants in the developed world as well as becoming the first company from India to become part of the global dairy trade network.

- Large multinationals like Lactalis, Danone, Nestle, Schreiber, Fonterra, Yakult, Kraft, Kerry, and a few others have expanded their presence in India.

- There is a growing private investment in the dairy sector both by Indian and multinational corporates.

- Private equity firms are offering an all-time high enterprise evaluation for the dairy industry at 1.1 to 1.2 times the turnover.

- Milk prices at farm gate as well as at the consumer's end are moving north.

- IT-enabled automatic milk collection units with bulk milk coolers are penetrating deep down the value chain.

- Ultra heat treatment (UHT) milk and other value-added products like cheese, sterilized flavored milk (SFM), and curd are booming in innovative packaging like PETHDPE.

- Regional players are becoming strong in north, west, and south India.

- IT-enabled dairy supply chain companies, with cold chain, are being established on the lines of developed world.

- Post the white revolution, Indian dairy industry has grown by 3–7% constantly even during global dairy slowdown.

- Fluid milk production shot to 210 million ton in the year 2021–22 on a normal monsoon, with increased demand for dairy products and rising consumer income.

- Strong farm gate prices and rising demand for value-added products are stimulating increased milk production.

- Branding to enhance realization of packaged foods is estimated up to 30% by 2030.

- Significant growth in domestic consumption is leading to limited surplus for exports.

- Exports are highly concentrated in skim milk powder (SMP), casein, and *ghee* contributing close to 45%, 30% and 15%, respectively, of the total exports.

- EU-FTA is being posed as a threat to the Indian dairy industry.

- National Program for Dairy Development (NPDD) has been implemented across the country since 2014 and was restructured/realigned in July 2021 with a total outlay of INR17,900 million. The restructured NPDD scheme is being implemented from 2020–21 to 2025–26.

Focus Areas

The focus is to

- develop critical mass for economies of scale both through community projects and by supporting setting up of large dairy farms;
- create transparency in pricing of milk/quality of milk;
- improve capacity utilization of existing capacities by making value-added products;
- develop best manufacturing practices and standards/norms;
- create opportunities of higher ROI in the industry by selecting specific products;
- upgrade raw milk handling in terms of physio-chemical and microbiological attributes of the milk collected;
- improve the operational efficiencies with a view to improve yields, reduce waste, minimize fat/protein losses during processing, control production costs, save energy, and extend shelf life;
- adopt latest packaging technologies that can retain nutritive value of packaged products and extend their shelf life;
- strengthen cold chain, storage, and transportation;
- adopt GMP and HACCP to manufacture milk products conforming to international standards and thus make exports competitive; and
- have a proper traceability system and recall procedure in place.

SWOT Analysis of Dairy Sector

The efficiency of the dairy industry with regard to milk handling, transportation, processing, and marketing also plays a critical role in the overall profitability of the dairy plants. In view of this, an attempt has been made to enumerate the major strengths, weakness, opportunities, and threats concurrently facing the sector.

Strengths

- The country has the largest cattle population, which has resulted in the highest milk production in the world. Besides, the dairy sector is the highest contributor to the agricultural GDP of the country.
- There exists a wide gap between the procurement and selling prices of milk. Due to this, there remains considerable margin to be exploited in the trade.
- The industry has sound technical knowhow and skilled manpower.

- With the existence of various dairy development agencies, both at regional as well as national levels, this sector enjoys strong institutional support in almost every sphere including production, processing, and marketing.

- The presence of large domestic market for both the liquid milk as well as milk products provides enough resilience to the milk processing units.

- Buffalo milk accounts for more than half of the country's milk production. It is notable for its efficiency as a converter of coarse feeds into rich milk. It is preferred by dairy processors not only for higher total solids (33% more than the cow milk) but also for its higher fat content. Its superior whitening property renders it more suitable than cow milk for manufacture of dairy products, particularly powders.

Weakness

- The dairy farming activity is scattered and not taken up extensively as an organized commercial activity, which has disadvantages such as lack of proper planning with respect to procurement, processing, marketing, and distribution. Besides, it contributes to inefficiencies in milk collection and leads to higher related costs.

- The immediate problem of dairy industry is not mere shortage of milk availability, but poor infrastructure for transporting, processing, and distributing rurally produced milk to major consumer centers in urban areas. Improvement in quality of raw milk by its chilling and refrigerated transport leaves much to be desired in the system for making quality products of international standard.

- Limited marketing support handicaps rural producers seriously. Presently, urban milk supplies largely come from major milk shed districts. Dairy farmers in remote areas are neglected.

- Limited investment in setting up or expansion of milk procurement network is another bottleneck. The rapid expansion of milk processing capacities has not kept pace with production and procurement.

- The cost of processing milk is comparatively higher, which results into higher prices of finished products. This bottleneck puts indigenous dairy products in disadvantageous position in the vast domestic market as well.

- Due to poor hygiene and non-compliance with international quality standards, Indian dairy products have, by and large, little demand in the international market, so their share is insignificant in the total agricultural export of the country.

Opportunities

- New initiatives and investments to strengthen the infrastructure in milk production would lead to modernization of this long-neglected sector. It also holds the promise to transform the quality of life in the rural hinterland.

- For Indian dairy products, General Agreement on Tariffs and Trade (GATT) offers promising prospects. With the reduction in heavy subsidies that support dairy producers in the West, India's low-cost milk will become price competitive. Another advantage is the country's geographical location, surrounded by milk-deficit countries in Asia that form the world's fastest growing market for dairy products.

- The mass production of traditional milk-based sweets in modern dairy plants can tap the growing demand for such products. With a significant population of non-resident Indians (NRIs) overseas, exports of these products can be promising.

- Training farmers on clean milk production would reduce the chances of standard plate count (SPC) and e-coli.

- Production of innovative products of high shelf life such as UHT milk will go a long way in triggering the demand for such products in domestic as well as international markets.

Threats

- With the liberalization and the entry of MNCs, there has been a huge rush in the dairy sector, leading to a creation of overcapacity and insufficient availability of milk. At the same time, there exists a major threat from the unorganized sector that has been procuring a substantial portion of the milk produced.

- Stringent quality norms followed at international level pose another threat to the expansion of exports markets for Indian dairy products.

- High cost of packaging will have a direct influence on the demand of processed dairy products in the domestic market. In case of international markets, this can make the products non-competitive with respect to prices.

Technological Changes for Sustainable Modernization of the Dairy Sector

In the past few years, the Indian dairy industry has received a tremendous boost through technology-driven products, services, and solutions, the credit for which deservingly goes to agricultural and dairy startups. Some of the technologies are already in practice in India, even though the adoption is still quite low while many others are yet to penetrate the industry. No doubt, technology is playing a key role in modernizing the Indian dairy industry. An overview of the key new-age dairy technologies is given below.

Feed Management

The feed requirement of the cattle depends on their health and weather. For example, a sick or pregnant cow may need more nutrition. A hot and humid weather means that cattle need more glucose in their feed. There are a number of feed technologies that produce formulated feed additives, supplements, premixes, and base mixes to maintain optimal milk production throughout the year. For example, the NDDB has developed a bypass protein technology to produce specially treated protein supplements that can be fed to the cattle to increase milk yield and quality.

There are also digital feed monitoring solutions to help farmers detect the quality of feed, manage feed inventory, and understand the cattle's feeding pattern. In fact, feed monitoring solutions can help design customized diet for each cow based on the assessment of body weight, milk quality, and yield, thereby improving fertility and productivity per cow. Some of the companies providing feed management solutions are Godrej Agrovat, DeLaval, and Dairy Margin Tracker.

Farm Management Technology

From accounting, finance, and labor management to livestock and supply chain management, a dairy farm has to ensure that all its operations run seamlessly. Farm management software can help automate and digitize end-to-end production and operations activities. It can give a holistic view of all farm activities, manage records, generate reports, and detect inefficiencies. Stellapps, MilcGroup, MyDairy Dashboard, and Nedap are some of the smart farm management solutions that exist currently.

Health Tracking Devices for Cattle

Health disorders reduce the productivity, longevity and reproductivity of the cattle. Every year, farmers invest huge amounts of money on their cattle's health and wellness. Thanks to wearable animal gadgets that are similar to human fitness trackers, farmers can track, monitor, and manage the cattle's health, nutrition, behavior, pregnancy, milking frequency, milk production anomaly, and activity level in real time. These smart animal trackers can be implanted in the cattle's ears, tail, legs, neck, or any other part of the body.

Last year, the Karnataka state government implanted GPS-enabled digital chips in the ears of 5.6 million animals across the state to track their health and do an early diagnosis of their medical condition. Some of the companies that have developed smart cattle health tracking devices are SmaXtec, Cowlar, Moocall, Smartbow, and Stellapps.

Sex Sorted Semen Technology

Dairy farm entrepreneurs are using imported sexed semen straw from ABS India. ABS India is known for quality production of sexed semen straw with high genetic potential, including purity of breeds, less dystocia incidence, etc. Semen having X- or Y-bearing sperm to produce progenies of a desired sex (with about 80–90% accuracy) is known as sexed semen. Sex sorting technology was developed by the United States Department of Agriculture (USDA). The technology was patented as "Beltsville Sperm sexing technology." Sperms are sorted by identifying differences between X- and Y-chromosome bearing sperms. The X-chromosome (female) contains about 3.8% more DNA than the Y-chromosome (male) in cattle. This difference in DNA content is used to sort the X-chromosome from the Y-chromosome bearing sperm. Among several methods for semen sexing, flow cytometry-based sorting has emerged as the most efficient. The technology has been refined over the past decades, and today sex sorting is possible at the purity of more than 90%. The technique is well standardized, patented and commercialized in the USA, Europe, and other countries. Other methods for sex sorting of sperm such as albumin gradient/Percoll gradient/gradient swim down; free flow electrophoresis; identification of H-Y antigen, centrifugal counter current distribution, and genetic approaches have also emerged, but these techniques need further finetuning for commercial viability.

Automated Cattle Traffic Management

It can be an extremely tedious task to manage and move cattle to milking stalls and back to barns. There is also a risk of injuries to the cattle. Automated cattle traffic management system has computer-controlled gates that open and close electronically. These gates can sort the livestock on the basis of their readiness to milk. The livestock ready to be milked are moved to the milking area while others are either put in the waiting area or returned to the barns. Companies like Delmer, Bump Gates, Fullwood Packo, and Lely are known for their automatic cattle traffic systems.

Robotic Milking Machines

Traditionally, cows have always been milked manually using hands. This is not only a time-consuming activity but also has labor costs associated with it, thereby increasing the price of milk.

Robotic milking machines are enabling farmers to eliminate the pressure on physical labor, maintain a hygienic milking process, milk the cows anytime of the day instead of following a fixed schedule and thus improve milk production.

The robotic milking machines have arms or cups with sensors that can be attached individually to cows' teats. The sensors can detect which of the teats are ready for milking. Once the milking starts, the machines can also identify impurities, color, and quality of milk. If the milk is not fit for human consumption, it is diverted to a separate container. The machines can also automatically clean and sanitize the teats once the task is over.

Supply Chain Technology

The Indian dairy industry's supply chain is quite complex owing to its dependency on a number of factors such as storage temperature, cold chains availability, weather, perishability/shelf life, first- and last-mile distance, packaging, etc. The fact that the Indian dairy industry is unorganized and fragmented also adds to the supply chain woes. However, a number of technological innovations are taking place in the dairy supply chain in India. Supply chain startups such as Stellapps, MilkManApps, and Trinetra Wireless, which are India based, are doing well.

Under supply chain, cold chain technology is expected to progress by leaps and bounds. The coming years will witness the rise of energy-efficient and cost-effective cold chain warehouses, cold boxes, phase changing material (PCM) pads, temperature-controlled cold chain packing, refrigerated vehicles, cold chain pallet shippers, and other advanced cooling technologies. Startups like Tessol and Warehouse-India are making their mark in cold chain infrastructure in India.

Milk Procurement

Over the years, reports and surveys by the FSSAI have shown high levels of adulteration and contamination in milk. More than 5% of the milk tested by the FSSAI in 2019 was reported to be contaminated with Aflatoxin M1 residues and deemed unfit for human consumption. Cases of intentional adulteration of milk to increase the volume by using water, increasing thickness through adulterants like glucose, starch, and paint have also been reported widely in the country. Rapid milk quality testing kits have been recently approved by the FSSAI, which can help curb these instances at the procurement level and monitor and maintain the quality of milk for processing and further value addition. The FSSAI-approved kits for detecting aflatoxins, antibiotics, and microbial contaminants in dairies are supplied by players such as Unisensor, 3M India Ltd, Jupiter GlassWorks, Delmos Research Ltd., etc. Apart from testing at the collection centers, at-home testing kits have also been developed by companies like Biosyl Technologies and VeriPure for customer reassurance.

Milk Freshness

Milk is a highly perishable product. In spite of pasteurization, freezing, and preservation processes, it has a tendency to go stale. Millions of ton of milk turn stale before timely consumption and go waste. Efforts are also being consistently made to increase the shelf life of milk without adding additives or preservatives.

Technology is now making it possible to detect the freshness of milk and store it for a longer period of time. Australia-based food technology company Naturo has developed a technology that can keep natural milk fresh in the refrigerator for at least 60 days without using any additives or preservatives. USA scientists have pioneered a new pasteurization technique that increases shelf life of fresh milk from 13 days to 40 days without changing its taste or nutritional value. In India, IIT Guwahati scientists have developed a smartphone-app aided paper sensor kit that can test the freshness of milk and inform how well it has been pasteurized. This kit can come quite handy in large kitchens, milk collection centers, and milk bars.

Processing and Transportation

With the increase in the complexity of the dairy supply chain system, consumers know very little about the products produced by the processors. Irregularities present in the dairy industry have serious concerns for human health, environmental sustainability, and welfare issues. There is a need to improve the communication between supply chain players to enhance coordination and maintain traceability. Blockchain adoption in the dairy industry can provide complete transparency in the end-to-end order and delivery process, thereby increasing adherence to regulatory norms and decreasing the instances of adulteration. This system can be used in tracing food information (including farm operations) and support building a trust level among various stakeholders. Reliable tracking of every batch in the milk value chain can help establish traceability, identify defective products, and discard the batches that have been impacted.

Although the dairy industry is not an energy-intensive sector, higher energy needs are required for proper storage and transportation of milk. Remote regions with many dairy farms do not have adequate electricity for maintaining cold chain facilities, thereby leading to losses. Dairy farms in remote locations with poor grid connectivity are at a severe disadvantage and face losses in quality and economic terms. According to Associated Chambers of Commerce and Industry of India (ASSOCHAM) estimates, about 3% of the milk produced gets wasted annually. A diesel generator for power backup is the current option for village-level chilling, which is expensive, less ecofriendly, and needs regular maintenance. Alternatives such as thermal energy-based storage and chilling systems by players such as Promethean Power Systems and Ecogen Energy can address the needs of dairy farms in off-grid locations. With thermal energy-based cold storage being a more cost-effective replacement for diesel-generator-based backup, collection centers and dairy processors can be assured of better quality and volume of milk and lower operational costs.

The dairy industry has a large carbon footprint during milk processing from the farm to the retail supply chain. Water consumption during milk production and processing is also high, which can be controlled through sustainable solutions. Wastewater treatment in the dairy industry in India is done in three phases through filtration systems, effluent treatment systems, and aerobic treatment. These methods require more efficiency with increased production capacities. The introduction of cloud-based technologies can help the dairy industry reach greater efficiency and reduce water consumption through smart monitoring and real-time water usage tracking. Fluxgen Engineering Technologies, a Bangalore-based startup uses IoT and AI to help manage and regulate water usage in dairy processing plants, which increases efficiency in such processes through digitization. Its AquaGen system helps in real-time productivity and water consumption monitoring; and has reduced water usage by 15% for a dairy farm in Puducherry, translating into monetary savings for the farm.

Retail and Distribution

Keeping track of trucks and tanker routes and capabilities for viewing, monitoring, and payments based on route or distance has been complex in a largely unorganized market in India. The Kerala state government is implementing a project to leverage the blockchain technology to streamline the state’s milk, fish, and vegetable purchase and distribution. The project aims to ensure speedy delivery of high-quality milk by continuously monitoring production, procurement, and distribution through an electronic ledger. A fault in the proper transfer of dairy items by such companies leads to spoilage of products due to the perishable nature of these food commodities. Integration of IoT with the blockchain platform helps gather the information needed during the transfer of goods from one place to another for ease of traceability.

RFID tags and mobile applications are being used to monitor the movement of trucks and refrigerated tanks to make sure they adhere to fixed parameters like the temperature in which the products are to be kept for maintaining their quality. Indian dairy-tech startup Mr. Milkman is a last-mile dairy supply chain software as a service (SaaS) platform that enables dairy food product companies to efficiently manage multiple aspects of dairy distribution, supply chain, customer subscriptions, and delivery requests.

With dairy-tech startups entering the space and bridging the gaps in cattle management and supply chain, the scenario is changing. There is a need for investment in technology to keep up with the changing consumer needs for transparency, traceability, and quality assurance. The future of the Indian dairy sector appears bright, as digitalization is expected to usher in a new era of growth.

E-commerce Marketplaces

Several online B2B marketplaces such as Agro Star and Gold Farm have been launched in India to make modern equipment and advisory services available to farmers at their doorsteps and to dairy manufacturers on their smartphones. Many B2C platforms such as FreshVnF, WayCool, and FarmLink have also emerged at a rapid pace. They pick up fresh produce from farms and deliver them at the doorsteps of retail customers, hotels, restaurants, and cafes.

The above list of technologies is inclusive but not exhaustive. Currently, most dairy technologies face adoption barriers in India because a large percentage of the Indian dairy industry still comprises small-scale and unorganized players who lack financial means, accessibility, and expertise to deploy the technologies. The good news is that this technological revolution has already begun in India, and it is only a matter of time that these technologies become commonplace.

Cattle monitoring via AI-based solutions is still in its infancy in India, with only a few companies providing this service. Stellapps Technologies is digitalizing and enabling supply chain traceability for dairy companies by developing a wearable technology that helps in efficient herd management. Companies such as Allflex and GEA are offering RFID tags for cattle management in India. Ag-tech startups like Brainwired and VetWare have developed herd management applications for better cattle record keeping.

Biotechnology

Biotechnology is a relatively emerging field in the dairy industry. However, it is being pushed as one of the most disrupting dairy technologies of the future. The potential of dairy biotechnology lies in areas such as increasing disease resistance among livestock; scientific feeding of cows; embryo transmit technology; artificial insemination; and development of new molecules and vaccines for prevention and disease management of animals, and development of dairy enzymes/proteins/probiotics, food-grade bio-preservatives, etc.

Some of examples of dairy biotechnology products that have made headlines are animal-free ice cream by Perfect Day, livestock disease diagnostic tools by Advanced Animal Diagnostics, and bovine genetics breeding by Genus ABS India. StaTwig, Ripe, AgriLedger, TE-Food, and Foodcoin are a few food biotech startups.

Technologies for Sustainable Modernization of Agriculture and Dairy Sector in India

Farmers today can use the benefits of the technological revolution to increase their yields from farming and livestock rearing. Some examples of modern technologies are given below:

Agriculture Sector

Monitoring and controlling crop irrigation systems via smartphones: The mobile technology is playing an important role in monitoring and controlling crop irrigation systems. With this modern technology, farmers can control their irrigation systems from a phone or computer instead of driving to each field. Moisture sensors in the ground are able to communicate information about the level of moisture present at certain depths in the soil.

Crop sensors: Crop sensors help apply fertilizers in a very effective manner, maximizing uptake. They sense how the crop is feeling and reduce the potential leaching and runoff into the ground water. Instead of making a prescription fertilizer map for a field and applying it, crop sensors tell application equipment how much fertilizer to apply in real time. Optical sensors are able to see how much fertilizer a plant may need, based on the amount of light reflected back to the sensor.

Agriculture sensors: Communications technologies have evolved rapidly in India and made smart farming a possibility. Sensors are now being used in agriculture to provide data to farmers to monitor and optimize crops as per the environmental conditions and challenges. These sensors are based on wireless connectivity and find applications in many areas such as determining soil composition and moisture content, nutrient detection, location for precision, and airflow. Sensors help farmers save on pesticides and labor and result in efficient fertilizer applications. They allow farmers to maximize yields using minimal natural resources.

Usage of mobile technology and cameras: Some farmers and researchers use apps like 'Foursquare' to keep tabs on employees. They also put up cameras around the farms. Livestock managers are wiring up their barn feedlots and pastures with cameras that send images back to a central location like an office or home computer. Thus, they can keep a closer eye on the animals when they are away or at home for the night.

Adoption of commercial drones: TRITHI Robotics, Dronitech, Sagar Defence Engineering, DJI Enterprise, and Sunbirds are among those companies that have made progress in developing commercial drones for a variety of applications in agricultural and livestock management.

Nearly everyone working on the future of modern agriculture is focused on efficiency. A wide range of technologies will enable the transition toward modern agriculture in the field. Some technologies will need to be developed specifically for agriculture, while other technologies already developed for other areas could be adapted for the agricultural domain. These include autonomous vehicles, artificial intelligence, and machine vision. If modern agriculture is applied widely in the near future, millions of farmers will be able to benefit from the acquisition of real-time farm information. Farmers need not spend significant amount of time on acquiring farm data and will have access to disaster warnings and weather information when a disaster event occurs. It is difficult to predict the future of technology in agriculture but there are many promising trends and pilot projects.

Dairy Sector

Indian dairy farming has evolved and changed substantially since the days of the white revolution. Technology, like any other industry, has assisted the sector and its stakeholders in a number of ways. Furthermore, the Indian hinterland and rural farmers remain unorganized and in serious need of technical support. Some of the technologies are currently in use in India, though the adoption is still very low, and many more are yet to come to the market. Some of the most important new dairy technologies are discussed below.

Drones for Cattle Monitoring

Farmers are required to maintain manual vigilance anytime the cattle leave the farm for grazing. There is a considerable possibility that the cattle may get lost, stolen, or attacked by other animals. Cattle monitoring drones can track the cattle and herd them back from the fields to the barns. Some drones are fitted with thermal sensing equipment, which enables tracking of cattle based on their body heat. Drones may also scan pasture lands and communicate whether they are suitable for cattle grazing or not.

Fitness Tracker for Cattle

Cattle productivity, lifespan, and reproductivity are all reduced by health problems. Farmers spend a lot of money on the health and wellbeing of their cattle every year. They may track, monitor, and control nutrition, behavior, pregnancy, milking frequency, milk output anomaly, and activity level in real time owing to wearable animal gadgets similar to human fitness trackers. These intelligent animal trackers may be placed in ears, tails, legs, neck, or any other part of the cattle's bodies. The Karnataka government has implanted GPS-enabled digital chips in the ears of 5.6 million animals around the state to track their wellbeing and detect medical conditions early. SmaXtec, Cowlar, Moocall, Smartbow, Stellapps, and other firms have created smart cow-health tracking devices.

Ultrasounds for Livestock

Ultrasound is not only for checking on baby animals in the womb; it also can be used to discover what quality of meat might be found in an animal before it goes to the market. The testing of DNA also helps milk producers to identify animals with good pedigree and other desirable qualities. This information can also be used to help farmers to improve the quality of their herds.

Milking via Robots

Cows have traditionally been milked manually. This is not only a time-consuming operation, but also has a labor cost, which raises the price of milk. Robotic milking allows farmers to minimize the need for physical labor, maintain a sanitary milking procedure, milk cows at any time of day rather than on a set schedule, and increase milk output. The robotic milking equipment has arms or cups with sensors that may be fitted to the teats of cows individually. The sensors can detect whether or not a cow or one of its teats is ready for milking. Once the milking process begins, the devices can detect contaminants, color, and milk quality. If the milk cannot be consumed by humans, it is directed to a different container. When the process is completed, the devices may also clean and disinfect the teats automatically.

Raghava Gowda of India invented a non-electric milking mechanism for cows. Among the numerous other startups that have launched automated milking systems are miRobot, GEA, DeLaval, Fullwood Packo, and Lely.

Automated Cattle Traffic Management

Managing and moving animals to milk stalls and back to barns may be a time-consuming process. There is also the possibility of livestock injuries. A computer-controlled gate that opens and closes electronically in an automated cow traffic management system has been included. These gates can categorize livestock based on their readiness to milk. The animals that are ready to be milked are transferred to the milking area, while the others are either placed in the waiting area or guided back to their barns. Automatic cow traffic systems are manufactured by companies such as Delmer, Bump Gates, Fullwood Packo, and Lely.

Customer Product Traceability Using Blockchain

Customers nowadays want to know where their dairy products come from (farm to table). This necessitates end-to-end supply chain transparency to increase client confidence. An increasing number of dairy producers, suppliers, and other stakeholders are utilizing the blockchain technology to provide customers with real-time data about their products.

This is accomplished by including a QR code on the packaging that customers can scan with their mobile devices to obtain information about the origin of the milk. They get to know where and how it was obtained and packed, how old it is, what type of transportation and cold milk chain facilities were used, and so on.

The Kerala state government is using the blockchain technology to streamline the purchase and distribution of milk, fish, and vegetables throughout the state. Nestle has partnered with the Australian firm OpenSC to use blockchain technology to strengthen its dairy supply chain. Carrefour, a French retailer, sells micro-filtered full-fat milk in bottles labeled with QR codes.

Microchip-based Animal Identification Ear Tag

Identification of an animal with a specific number is important to maintain its records. In collaboration with the Department of Medicine, Bombay Veterinary College, Maharashtra Animal and Fishery Sciences University, Nagpur, Infotech and Intel Corporation, a microchip-based animal identification ear tag has been developed. This tag is unique in that it also enables storing of lifetime production and breeding records. A reader that can be attached to a personal digital assistant (PDA) has also been developed. These devices could have domestic as well as export potential. Many developed countries provide financial help to the dairy industry, as part of their regulatory and registration requirements. On similar lines, the GoI may also take a policy decision.

Software Applications for Real-Time Animal Data Recording

For scientific and profitable dairy farming, recording and maintaining the cattle's breeding and milk production is a basic requirement. Periodic analysis of this data enables veterinarians to diagnose sub-clinical diseases and underperformances. This system of service is called herd health and productivity management (HHPM). Animal keeping generates lots of records, which can be managed and analyzed efficiently with the help of computers and dedicated software. This need led to the development of software applications required for e-administering veterinary services. For effective capturing of data at the farm itself, a PDA-adopted software application has been developed. The HHPM software suitable for commercial dairies, cooperative dairies, frozen semen centers, and AI centers, developed in collaboration with Chitale Dairy and tested and validated at their farms is now commercially available.

With the help of these software, each village dairy cooperative society's real-time animal data can be networked with milk unions and also be shared with the government. This can be part of the wider ERP solutions being implemented by milk unions. These software have been developed keeping the requirements of Indian dairy industry in view but also have good export potential. The microchip-based ear tag and the reader attached to the PDA, equipped with Herdman module, are now being evaluated. The concept of animal health delivery system revolving around real-time animal data recording, analysis for performance indices, protocol-based services, and village-based micro planning submitted by Department of Medicine, Bombay Veterinary College (in collaboration with the industry) to the World Bank received the 'India Country Development Marketplace Competition Award.' Currently the model is being validated in three milk unions with two more to be added soon. There is a need to conduct multi-center trials to further improve and finetune these software applications. For this, government support will be needed. A policy decision to encourage recording of animal data of at least 'good productive animals' in the initial phase would be a welcome step.

Village Herd's Metabolic Profiling

Protocols of metabolic profiling of dairy animals, considering village as a herd unit have been developed. With this system, subclinical metabolic problems and feed deficiencies can be predicted and corrected. Appropriate feeding strategies for clusters of villages have been developed using this method.

E-Pashu Bazar/Livestock Market

Sale and purchase of animals in India is still done traditionally. However, dislocating animals to livestock markets has a deleterious effect on animals. Second, there is lot of exploitation by the agents. Internet could be a good option to provide e-market facilities. A website has recently been developed in collaboration with Infovet. The idea is to encourage milk unions and veterinary service providers to become franchisees and provide these facilities to the farmers on a chargeable basis. If the health and production records of animals are available, these can also be displayed. The ultimate aim is to bring together animal buyers and sellers in contact with each other through milk unions. With government support and encouragement, this concept can be popularized.

Health and Fertility Diagnostic Laboratory

Chitale Dairy is probably a pioneer in developing reasonably modern diagnostic facilities, equipped with ultrasonography, dry chemistry serum analyzer, enzyme-linked immunosorbent assay (ELISA) and radioimmunoassay (RIA) facilities for the farmer community. The idea is to encourage scientific diagnosis and rational tackling of the problems in animals. If the right environment is created, Chitale could extend help in establishing such laboratories in other areas.

DATPRO System for Animal Data Recording

Chitale has evolved a simple and cost-effective system for providing dairy animal productivity enhancement services to farmers revolving around collection and analysis of animal data. At Chitale's headquarters, Dairy Animal Data Processing Center (DATPRO) has been established wherein Herdman server software has been set up for warehousing of data of individual animals stratified by villages. The server is connected to two computer terminals that are interfaced with mobile phones and managed by two veterinary support operators. All the veterinarians providing veterinary and productivity enhancement services have been provided with mobile cells so that expenses on telephony are minimized. Similarly, the database of farmers having mobile phones has also been created in the Herdman software program. This has enabled networking of veterinarians, farmers, and the central datawarehouse. Every morning, the DATPRO operator generates 'action' and 'alarm' lists of animals for each of the villages that have been assigned to him. The action list comprises animals predicted for first estrus after calving, estrus, non-return, and pregnancy test; expected for calving; and expected for drying off, milk measurement, and sampling. The list is conveyed to the veterinary service provider on his mobile phone which he takes down on the printed day-wise formats provided to him. Similarly, the identification numbers of animals that are in ‘alarm list,’ i.e., animals that are not performing as per defined parameters, are also conveyed. In the evening, the veterinary service provider again receives a call on his mobile from DATPRO and he dictates the actions taken on various activities during the day. The data for each animal is simultaneously updated by the operator.

In cases where the farmers’ mobile numbers are also available in the database, every morning the farmers also receive text messages informing them about the management actions expected for their animals. For example, a farmer receives the ID number of the animal that is expected for heat, PD, calving, etc., so that he is also kept informed about the farm management interventions expected from him. In addition, the farmer can also send a templated SMS message in case he needs breeding or production details for an animal.

Innovations and Advancements in the Dairy Sector in India

In recent years, there have been significant technological advancements in the Indian dairy industry, including a machine learning platform developed by startup MooFarm that will help tackle mastitis, a disease of the cow udder that leads to an annual loss of half a billion dollars in India. Supported by a grant from Microsoft, MooFarm is working to provide on-call support to farmers and plans to have staff located in rural areas.

Alongside technological developments to improve farming methods and organizational supply chain, big data is another area in which Indian companies are moving. In order to accurately predict consumer behavior and buying patterns, big data is the key as companies such as Doodhwala have discovered. Noticing a pattern in millennial consumers prioritizing convenience, Doodhwala has created a subscription-based milk delivery platform and now delivers more than 30,000 liter of milk every day before 7 am in Bengaluru, Pune, and Hyderabad.

Connecting with the changing needs of consumers is important for the dairy industry to stay on top of trends. The flavor profiles and preferences of Indian consumers are quite varied. However, milk is a staple diet for populations such as toddlers and senior citizens. The health benefits of milk are widely recognized, including its contribution to digestive wellness and advantages of dairy proteins. With consumers reconsidering their dietary choices, there has been a reduction in the consumption of carbohydrates and sugar, leading to an increase in protein-based diets.

Dairy has become an attractive source of natural proteins. As such, many dairy products are being positioned as functional foods and beverages. Indian companies including Amul, Karnataka Milk Federation, and startups such as Goodness are marketing milk to millennials as not just a health drink, but also as a functional drink. Recognizing the benefits of marketing to younger, health-conscious demographics, Goodness has removed all sugar from its products and has also seen success as the only Indian finalist in the World Dairy Innovation Awards in 2018.

Private Sector Innovations in Indian Dairy Industry

Over the last decade, India’s milk production has grown at an average annual rate of 5.5%. India has emerged as the largest milk-producing country globally, with an estimated production of 210 million ton in 2021–22. What is more interesting is that organized private players are increasing their portfolios in milk procurement. The projections made in the National Action Plan for Dairy

Development, Vision 2020, show that as of 2021–22, milk procurement by organized private dairy companies surpassed the procurement levels of dairy cooperatives. According to the NDDB, the "overall capacity created by private dairy companies in the last 15 years equals that set up by cooperatives in over 30 years."

Hatsun Agro Foods Ltd, the largest organized private dairy of India, procured 3.7 million liter per day (MLPD) of milk followed by, Heritage Foods Ltd, Dodla Dairy, and Lactalis with cumulative milk procurement of 4–5 MLPD. These companies have invested in building infrastructure to process milk into high-value products like butter, ice cream, curd, milk, and cheese. Hatsun Agro Foods Ltd has 20 processing plants and Dodla Dairy Ltd has about 13 milk processing plants spread across the states of Telangana, Andhra Pradesh, Tamil Nadu, and Karnataka to process milk into value-added dairy products.

Private companies like Genus Breeding India (ABS India), BAIF Development Research Foundation, and JK Bova Genix (an initiative of JK Trust) are heavily investing and developing assisted reproductive technologies (ART). Artificial insemination using sexed sorted semen and in-vitro fertilization (IVF) focus on predetermining the sex of the offspring and ensure genetic superiority, which leads to high milk yield.

BAIF Development Research Foundation, for example, has conducted more than 150,000 sorted-semen insemination with a conception rate of 44.3% and 90% female births. In IVF, JK Bova Genix is leading the initiative by offering Mobile Cattle ET and IVF labs at farmers' doorsteps. It was one of the first organizations to produce 14 IVF calves from a single Gir donor cow named Radha in one year. It also achieved a landmark in August 2020 by reproducing the first batch of IVF buffalo calves that took birth on a buffalo farm in Pune district.

On the feed and fodder fronts, Hydrogreens, a Bangalore-based startup has come up with a hydroponic green fodder unit named "Kambala" that allows farmers to grow fresh green fodder all year round without soil-controlled environment and limited water resources. It has set up more than 130 units across the country to overcome the green fodder deficit. A study by Kapoor et al (2018) on the biotechnological interventions in forage crops found that the recent development in genetic engineering of fodder crops by introducing foreign genes from unrelated species has improved the physical appearance, nutrients, yield, and growing conditions. Organizations like the Indian Agricultural Research Institute (IARI), Indian Grassland and Fodder Research Institute (IGFRI), and the Tamil Nadu Agricultural University (TNAU) have developed many varieties/crossbreeds of "hybrid napier," which is a cross between *bajra* and napier, over the last few years.

Development of colostrum powder as probiotic: In collaboration with the Department of Medicine, a method for lyophilization and fortification with herbal antiprotease has been developed. Worldwide, excess bovine colostrum is being used as a probiotic, especially in immuno-compromised patients suffering from enteric infection. This offers an important value addition to the dairy industry. Some preliminary work has also been done to produce hyperimmune milk (effective as a supplement in gastric infection). In collaboration with Chitale Dairy, Bombay Veterinary College has also developed rapid field tests for evaluating the quality of colostrum at the collection center. In fact, in the USA and Europe, colostrum powder as a medicinal supplement has become extremely popular. Chitale Dairy and Bombay Veterinary College are ready to further standardize colostrum and hyperimmune milk technologies.

Genetic improvement in cattle: Sumul has been conducting genomic selection for genetic improvement in cattle to expand the animal population. Now NDDB, GCMMF, and other milk unions of Gujarat have decided to collaborate on expanding the reference population for genomic selection. All the entities will together develop standard operating procedures for data analysis and monitoring. The accuracy of genomic selection will increase the reference population. Sumul also plans to focus on new trends for cattle breed improvement to increase cattle herd population through adoption of new techniques in animal breeding, natural breeding, embryo transfer technology, artificial insemination, sex sorted semen dos age, and fertility improvement program.

Innovations and Advancements at Commercial Dairy Farms in India

Dairy farmers are increasingly modernizing their farms. Automatic concentrate dispensers and automatic milking systems (AMS) have been utilized and several manufacturers have introduced automatic feeding systems (AFS) during the past decade.

The modernization plan adopted by a farmer in India to improve the economic parameters of the cattle is discussed below:

Housing

Thermal Insulation

Insulation acts as a barrier to heat flow, thereby reducing heat gain in summer to keep the house cool and reducing heat loss in winter to keep the house warm (see Figure 1). Thermal insulating material like aluminum bubble sheets can be used as false ceiling material by placing them under the asbestos roof (see Figure 1A). Thermal insulation, in addition to other cooling mechanisms, provides more comfort to dairy animals and results in higher milk production.

FIGURE 1

THERMAL INSULATION.

FIGURE 1A

WIDE SPANNED RIDGED ROOF.

High-pressure Fogger System

Foggers are small nozzles that produce very fine water droplets, which look like a fog or a mist. These are also called mist sprayers or mist systems. Most of the generated droplets evaporate before they can reach the ground. As they evaporate, they reduce the shed's temperature (see Figure 2). The high-pressure fogger (HPF) system plays an important role in the body comfort of the animals as is evident from the body temperatures and respiration rates of the dairy animals under this system. As per the study, the HPF system led to a significantly higher milk yield of 0.309 kg per animal/day.

FIGURE 2

FOGGING SYSTEM IN A DAIRY SHED.

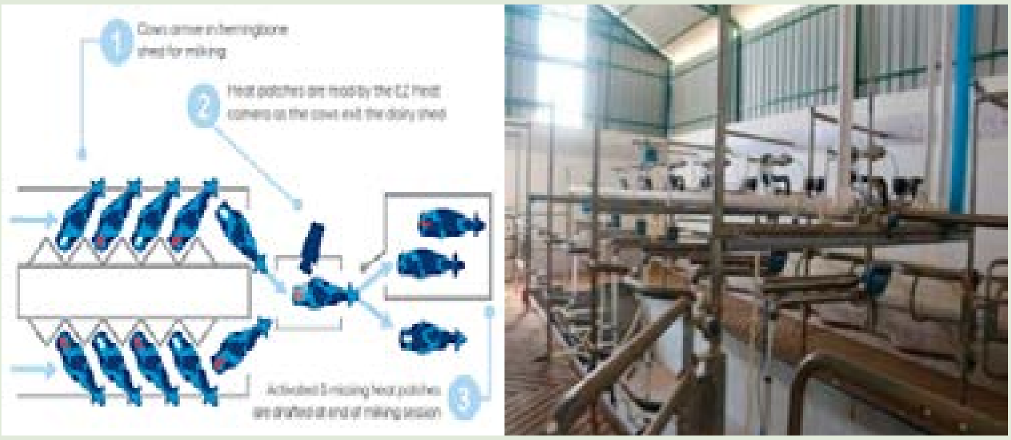
Automatic Milking System

Automatic milking systems (AMS) have been available in India since the beginning of 1998.The major advantages of AMS are reduction of labor for milking and enhanced production per cow due to higher milking frequency than a conventional milking parlor (CMP). Milk yield increases from 2% to 8% and labor decreases by about 18%. The AMS presents an opportunity for dairy farmers to not only improve their lifestyle and working conditions, but also saves on labor costs and/or increases the time available to focus on overall farm management.

In a herringbone (fishbone) milk parlor, where 12 cows can be milked at a time, cows stand on an elevated platform in a 45º angled or herringbone manner with their backs to the center of the milking area (see Figure 3). This exposes enough of the back half of the cow to milk her from the side. The milking cup is attached from the sides. There is a single entry and exit point for this milking parlor.

FIGURE 3

DESIGN AND SCHEMATIC DIAGRAM OF HERRINGBONE/FISHBONE MILK PARLOR.



On the other hand, in a parallel (side by side) milk parlor, lactating cows stand on an elevated platform at 90º facing away from the operator area. Access to the udder between the rear legs reduces the visibility of forequarters in this case (see Figure 3A).

FIGURE 3A

DESIGN AND SCHEMATIC DIAGRAM OF PARALLEL MILK PARLOR.

Sensor-driven Grooming Brushes

These brushes swing left and right, about 45° in each direction. The brushes access the cow's back and are easier for her to use (see Figure 4). Rotation is activated when the cow moves the brush and continues until the arm remains horizontal for a period of time. The advantages of this equipment are as follows:

(1) It leads to a reduction in the number of parasites and organisms on the cow's coat.

(2) It allows cows to bond with their herd mates and reduces the impact of the boss cow/submissive cow hierarchy within the herd.

(3) Cows also use grooming as a way to cope with stressful situations.

FIGURE 4

SENSOR-DRIVEN GROOMING BRUSHES.

Legend Heat Detection System

The pedometer is an electronic device that transmits information about the number of steps that a cow takes over a set time. The system serves as a tool to assess a cow's activity and how it relates to the overall animal health. The system requires the use of three main components: the pedometer; a receiving system that consists of antennas, a receiver, and a connection box; and the software program. The system collects and transmits the cow's activity data in real time via an antenna and receiver to the software program. The data from the pedometer is transmitted through radio frequency, which is picked up by antennas. The com card organizes the data, transfers it to the computer and finally to the "Legend Track a Cow" software program. The end result of using this product is to increase a dairy producer's profitability by reducing the amount of reproductive drugs used in breeding programs and lowering the number of services per conception while increasing conception rates as well as pregnancy rates.

FIGURE 5

LEGEND HEAT DETECTION SYSTEM.

Policy Framework for Sustainable Modernization of Dairy Sector in India

With over 98 million dairy farmers, the Indian dairy market achieved an annual output of 210 million ton of milk during 2021–22 at a growth rate of 6.20%. This was contributed by the rise in dairy cattle numbers as well as quality feed and fodder availability. Despite being the largest producer and consumer of milk, India's per capita dairy consumption levels are significantly lower than in developed countries. India is neither an active importer nor an active exporter in the milk sector.

Along with offering profitable business opportunities, the dairy industry in India serves as a tool for socioeconomic development. Keeping this in view, the GoI has introduced various schemes and initiatives aimed at the development of the dairy sector in the country. These are:

(1) Rashtriya Gokul Mission (RGM);

(2) National Programme for Dairy Development (NPDD);

(3) support for dairy cooperatives and farmers production organization engaged in dairy activities;

(4) National Livestock Mission;

(5) National Programme for Bovine Breeding;

(6) National Bovine Genetic Centre;

(7) Quality Mark;

(8) National Kamdhenu Breeding Centres;

(9) E-Pashuhaat portal;

(10) Dairy Entrepreneurship Development Scheme (DEDS);

(11) Livestock Census and Integrated Sample Survey; and

(12) Processing and Infrastructure Development Fund (DIDF).

Dairy farmers use manure not only as fertilizer, but also to generate biogas for clean energy. This is especially beneficial in rural areas, where there is no access to other energy sources. It also has a positive impact in areas where deforestation and pollution from cooking and heating are ruining the environment. Further, the dairy sector invests in programs that provide knowledge and skills. Sustainable technology is being introduced by farmers and many of these improvements also create employment opportunities for youth and women.

The dairy sector is continually finding new ways to improve sustainability such as increasing energy efficiencies, reducing greenhouse gas emissions, reducing water consumption, saving energy, and lowering operating costs of dairy farms. By using human food waste and animal manure as an effective fertilizer, along with establishing feed efficiencies, farmers are realizing yield improvements and decrease in environmental footprints.

Government initiatives can ensure sustainable growth of the dairy sector as well as boost incomes of millions of small and marginal dairy farmers. Linking animal husbandry with food processing industry, agriculture research and patents have the potential to make India a nutritional powerhouse of the world. Animal husbandry offers hope for India as well as the world.

Productivity Assessment Tools for Dairy Industry in India

The dairy sector in the country is undergoing many changes because of an increased milk availability and opening up of the sector to external players as part of the globalization. This is going to lead to a situation where milk producers as well as processors have to face the challenge in terms of quality as well as price. It is becoming increasingly important for dairy farmers to adopt improved scientific techniques for augmenting milk production for higher returns. Further, the dairy processing industry, which is currently vexed with a number of problems, such as excess capacity, high cost of inputs, low returns, and poor quality, will find it difficult to cope with the changed situation unless productivity improvements besides quality enhancement initiatives are undertaken at all operational levels.

In order to become globally competitive, processing plants cannot overlook value addition at minimal costs, coupled with judicious use of inputs for enhanced productivity. Simultaneously, it is important to share the gains accrued from the aforesaid measures with the farmers in terms of better remunerative prices for the milk. In view of this, an attempt has been made in this chapter to present a comprehensive assessment of the dairy sector covering milk producers and dairy processing plants in terms of both production and financial performance with special emphasis on major productivity indicators. The critical parameters affecting the performance of dairy processing plants have also been identified. With a view to assess the productivity of the dairy sector, the following activities were considered:

Collection of Data

A field survey was launched at the national level to assess the productivity performance of the dairy sector. The primary data related to dairy processing units was collected for the years from 2018–19 to 2021–22 with the help of prestructured and pretested questionnaires developed specifically for the purpose. Data pertaining to milk producers (dairy farmers) was collected only for the year 2021–22 due to the reason that milk producers were not maintaining records and could provide the required information based on recall method. Further, the collected information was triangulated to ensure the quality of information gathered from the field.

Analytical Framework

The productivity performance of the dairy sector was ascertained at different levels, i.e., at the levels of milk producers and dairy processing units. The main indicators considered at milk producers' level included

- cost of milk production per liter;
- sales price of milk per liter;
- sales price of dung; and
- gross as well as net income.

The productivity of the processing units was judged on the parameters of

- production/processing performance; and
- financial performance.

Determining the Cost of Milk Production:

Purpose of Determining the Cost

There are multiple benefits of determining the cost of milk production:

(1) Milk producers can compare the total expenditure with other milk producers and take judicious measures to reduce expenditure in production of milk.

(2) Milk producers may try to implement such principles of management that would help in reducing the cost of milk production.

(3) It helps in fixing a reasonable optimum price of milk suitable to both milk producers and consumers.

(4) It creates a competitive spirit among producers, which encourages them to produce milk at lower costs.

(5) It helps the government to fix the price per liter of milk to protect the interests of producers.

Methods of Determining Cost of Milk Production

(1) Survey method;

(2) Direct observation method; and

(3) Formula method.

Survey method: In this method, the investigator goes to an individual dairy farmer or dairy farm and collects information pertaining to the cost of milk production from the records maintained at the dairy farm. The data regarding expenses on feeding, labor, care, milk production, income from sale of milk, calf, and manure is collected for the desired period. The cost of milk production is determined by dividing the total expenses by milk yield. The investigator has the advantage of collecting data from a large number of dairy farms from their available records in a short period of time.

Direct observation method: In this method, an investigator observes all day-to-day expenses incurred on different items of milk production and keeps recording them. He does not depend on the data available from the records maintained by the farmer or on the dairy farm. Rather, he himself studies all the expenses on building, equipment, feeding, care, health, and labor that add to the cost of milk production to determine the cost per liter of milk in a similar manner as in the survey method. This method has an advantage over the first method as the data collected by the investigator are relatively more correct and actual. The limitation is that the investigator cannot record data from a large number of dairy farms in a given time.

Formula method: Pense, *et al* (1953–55) studied the cost of milk production and reported that feeding alone constituted 65–70% of the cost of milk production. A regression equation was also developed at the District Dairy Demonstration Farm, Mathura in the state of Uttar Pradesh in India, which helps determine the expenses on feeding:

$$X1 = KO + K1X2 + K2X3 + E,$$

where X1 denotes the expenses incurred on feeds of a cow; X2 and X3 denote the error in the equation due to effects of other factors not mentioned in the equation; and K1 and K2 are partial regression coefficients while KO is the constant of the hypothetical population square to determine the estimated value of X1.

These were estimated using the method of least of X1.

Sharma, *et al* (1987) made a study on the economic evaluation of dairy units and concluded that feed and fodder were the important factors influencing economics of milk production in different seasons. Among the inputs, the concentrate was the principal factor affecting milk production in the summer season. Dry fodder and concentrate in the winter season, and dry fodder and greens in the rainy season, played important roles in the economics of dairy units.

Factors Affecting the Cost of Milk Production

The key factors are

(1) milk yield per animal and breed;

(2) feeding policy, e.g., pasturing and proportion of green-to-dry fodder per animal;

(3) quantity and quality of fodders and concentrates;

(4) number of milking animals on the farm;

(5) expenses on water, medicines, etc.;

(6) care and supervision; and

(7) labor, etc.

Milk production depends on breeding, feeding, and management of animals. Several other factors, such as calving season, age at first calving, service period, stage of lactation, number of lactations, dry period, frequency of milking, age of animals, body size, etc., have considerable influence on the milk yield of animals. From economical point of view, various inputs provided for managing dairy animals are mainly responsible for the cost of milk production.

An Example for Calculating the Cost of Milk Production

A *Murah* buffalo was purchased for an amount of INR80,000 and produced 15 kg milk per day. The cost of milk production can be calculated as per the procedure given below:

Fixed costs:

(1) Herd expenses: These include depreciation and interest incurred.

(2) Building expenses: Around 70 sq ft floor area is required per buffalo. Assuming that the construction cost per sq ft is INR500, the total cost for the buffalo shed = 70 x INR500 = INR35,000. Now assuming that the life of this shed is 50 years, the depreciation per year would be INR35,000/50 = INR700. Interest incurred on building cost at the rate of 12% = INR35,000 x 12/100 = INR4,200.

(3) Equipment expenses: Actual non-recurring/fixed cost can be considered for equipment.

Variable cost/recurring expenses:

(1) Fodder cost (dry and green):

Let us assume that fodder requirement (both dry and green) for the buffalo per day is 40 kg and the calving interval average is 400 days. Then, total fodder needed for the lactation period = 40 x 400 kg = 16,000 kg or 160 quintal. Therefore, cost of 160 quintal fodder @ INR400 per quintal = INR64,000.

(2) Cost of concentrates:

Assuming that the maintenance requirement is met fully by fodders, the production requirement for 15 kg milk at the rate of 1 kg concentrate per 2.5 kg of milk will be 6 kg. Total concentrates required for the 10-month lactation period (305 days) = 305 x 6 = 1,830 kg, while concentrates for 300 – 305 = 95 days dry period @ 1.5 kg per day = 143 kg. Thus, total concentrate requirement = 1,830 kg + 143 kg = 1,973 kg

If the cost of concentrate is INR2,400 per quintal, then the cost of 1,973 kg (around 20 quintal) concentrate = 20.0 x INR2,400 = INR48,000.

(3) Labor cost:

Labor man hours per buffalo per day are estimated to be 30 minutes.

Assuming the wage of a casual labor per day is INR260 for eight hours of work, the cost of 30 minutes of man hour work = INR260/8 x 1/2= INR16

Total labor cost for 305 lactation + 95 dry days = 400 x INR16 = INR6,400

(4) Light and water cost:

Light and water cost at the rate of INR65 per month for 10 months = INR65 x 10 = INR650

(5) Medicine cost = INR1,000

(6) Miscellaneous = INR2,000

Total variable cost = INR122,050

Total fixed cost = INR27,312

Total fixed and variable costs = 27,312 + 122,050 = 149,312

Total milk produced in a lactation of 305 days = 305 x 15 = 4,575 kg.

Therefore, cost per kg of milk produced = 149,312/4,575 = INR32.64

Economics of Dairy Farming

The parameters adopted for working out the economics of dairy farming comprising ten animals (buffalo/crossbred cows) was separately worked out on the following techno-economic basis:

(1) The unit is managed by own family members with the help of one laborer.

(2) The average cost of a milch buffalo has been taken as INR80,000 and that of a crossbred cow as INR40,000.

(3) The milch animals are to be purchased during their second lactation and in first month of the lactation period.

(4) The average lactation period has been taken as 300 days in case of buffaloes and crossbred cows, followed by a dry period of 100 days in buffaloes and 80 days in crossbred cows.

(5) The average milk production per lactation has been taken as 2,500 liter in case of buffaloes and 3,600 liter in case of crossbred cows.

(6) The average sale price of milk per liter has been taken as INR50 for buffalo milk and INR35 for cow milk.

(7) At the time of purchase, as also during the period of rearing, the probability of producing male and female progeny is taken as 50:50.

(8) Insurance charges are calculated at the rate of 4% per animal per year.

(9) The costs of green fodder, dry fodder, and concentrates have been taken as INR160, INR1,250, and INR2,500 per quintal, respectively.

(10) The cost of rearing a calf has been taken as INR4,500 in the first year in case of buffaloes and INR5,500 in the first year for crossbred cows.

(11) Generally, the mortality rate of calves has been taken as 15–20% during the first year, while the adult mortality rate has been taken as 2–3%.

(12) Depreciation on milch animals (livestock), buildings, and equipment are calculated at the rate of 10%.

(13) Expense on veterinary aids has been taken as INR1,000 per animal per year both in case of buffaloes and crossbred cows.

(14) Male calves are to be disposed off for making them bullocks.

(15) Buffaloes are disposed off after 6–7 lactations and crossbred cows after 7–8 lactations. They are replaced with younger stock of known pedigree or with the heifers reared at the farm.

(16) Labor charges have been taken as INR6,000 per labor per month along with other facilities such as residential accommodation, etc.

(17) 0.75 hectare of irrigated cultivated land for fodder requirement is taken to be sufficient for five animals.

(18) One animal produces 12 kg of farm-yard manure (FYM) per day, which is sold at INR2 per kg.

(19) Regular supply of dry and green fodder and concentrates is a prerequisite for successful dairy farming.

(20) To overcome gynecological problems and vaccinations, and to improve the overall management at the farm, help is to be taken from veterinary services. For reducing calf mortality, preventive deworming, and reducing age at first calving, summer management including water bath may be practiced.

Investment

The economics of rearing buffaloes and crossbred cows are given keeping in view the conditions prevailing in most of the villages. The average investment on fixed and working capital, average milk yield and its value, value of inputs, net profit, cost of production per liter of buffalo and crossbred cow milk, and input-output ratio for 10 milk buffaloes/crossbred cows are as given below:

1. The costs of production per liter of milk of buffaloes and crossbred cows, including operating fixed costs are INR29.68 and INR26.40, respectively.

2. Net profit can vary depending on the mode of marketing.

3. The input-output ratios for buffaloes and crossbred cows, including operating fixed costs are 1:1.29 and 1:1.27, respectively.

4. Dairy farming can be more profitable if good feed and fodder are made available.

Productivity Measurement at Milk Producers' Level based on Sample Responses

Commensurate with the objectives of the study, a comprehensive exercise was undertaken to analyze various parameters to measure the productivity of the dairy industry. The focus has been on highlighting the critical parameters and their influence on milk production, collection of milk by dairy plants, and processing and distribution.

The starting link, i.e., the milk producer, is very vital from the viewpoint of productivity analysis due to the reason that wide variations in breeding, feeding, and management practices are being found that vary from producer to producer and region to region. This becomes the primary area of concern on which the survival of the industry depends. In most of the places, dairy farming is supplementing the incomes of village people, so it is necessary that this subsidiary activity, besides being an alternative employment source, should be made economically viable and profitable lest the people switch over to other agricultural activities once they find that dairying is less remunerative. With the cost of agriculture labor increasing every day, dairying should impute a reasonable value to such labor. The main parameters that have been considered to assess productivity at the farm level are:

- milk producers' profiles;
- typing of milch animals and their breeds;
- infrastructural availability;
- feeding and management practices being followed;
- producers' awareness;
- cost of milk production inclusive of various fixed and variable costs; and
- return per liter of milk.

Milk production at primary producers' level is influenced by various factors such as breeds of animals, feeding practices followed by milk producers, quality of fodder and feed, management practices, age of the first calving, lactation period, intercalving period, and availability of the required infrastructure.

There could be an endless list of parameters that affect the cost and return for dairy enterprises, but for this study, the aforesaid important parameters were considered, which play a crucial role and have direct bearing on milk production and productivity. These factors, however, vary from farmer to farmer and region to region.

Sample Profile

With a view to ascertain the productivity at milk producers' level and arrive at per liter cost of milk production and return, a sample was taken of 80 milk producers comprising various categories of farmers. Further, in order to broadbase the findings of the study, the requisite information was also collected from dairy farmers supplying milk to cooperative societies or private vendors/commission agents. The gathered information has been compiled on the basis of the categories of farmers as well as the types of animals.

Distribution of milk producers based on their castes has been illustrated in Table 2. This classification comprises general, backward class (BC), scheduled caste (SC), and scheduled tribe (ST) categories of milk producers. It can be seen from this table that the maximum percentage (45%) belongs to the general category, followed by BC (42.50%), SC (10%), and ST (2.50%) categories of milk producers.

TABLE 2

DISTRIBUTION OF MILK PRODUCERS BASED ON THEIR CASTES.

Sl. no.	Category of milk producers	Number of respondents	Percentage
1	General	36	45.00
2	OBC	34	42.50
3	SC	8	10.00
4	ST	2	2.50
	Total	**80**	**100.00**

Socioeconomic Characteristics of Sample Milk Producers

The socioeconomic characteristics of sample milk producers have immense influence on the decision-making process and profitability of dairy enterprises. An effort was, therefore, made to highlight the socioeconomic profiles of milk producers and study the impact on milk production. The various characteristics that may affect the productivity of dairy enterprises, including the size of land holding; education status; family size; average herd size (number of milch animals); composition of herd; production tracts of the milch animals (age of first calving, lactation length, dry period, inter calving period, and order of location); milk production; marketing of milk; and finally the economics of milk production are discussed here.

Size of Land Holding

Land holding plays an important role, as animal husbandry is often associated with agriculture in rural households. Even the landless rural households depend on dairy farming as a source of livelihood. In a developing country like India, land is the most crucial resource in dairy farming. It mainly provides fodder (both dry and green) and some other feed for dairy animals. The distribution of milk producers based on their land holding is presented in Table 3A. It may be seen from the table that the "large" category of farmers have an average land holding of 10.74 ha while marginal farmers have only 0.56 ha land. Further, the area under fodder crops is maximum (0.32 ha) in the case of semi-medium category of farmers and minimum (0.13 ha) in case of large category of milk producers. The area under fodder crop has direct relation with the number of animals maintained by milk producers.

TABLE 3A

AVERAGE LAND HOLDING AND AREA UNDER FODDER CROPS.

Sl. no.	Category of milk producers	Number of respondents	Average land holding (ha)	Area under fodder crops (ha)
1	Landless	3	NA	NA
2	Marginal (<1 ha)	29	0.56	0.16
3	Small (1–2 ha)	20	1.22	0.19
4	Semi-medium (2–4 ha)	13	2.78	0.32
5	Medium (4–10 ha)	10	5.35	0.27
6	Large (>10 ha)	5	10.74	0.13
	Total	**80**	**4.13**	**0.21**

Source of Irrigation

Source wise details of irrigation are given in Table 3B. It can be seen from this table that overall, 76.62% milk producers had tube wells to irrigate their fields while 23.38% milk producer irrigated their lands/fields through canals.

TABLE 3B

SOURCES OF IRRIGATION.

Sl. no.	Category of milk producers	Number of respondents	Tube well	Canal
1	Marginal	29	21 (72.41)	8 (27.59)
2	Small	20	16 (80.00)	4 (20.00)
3	Semi-medium	13	10 (76.92)	3 (23.08)
4	Medium	10	8 (80.00)	2 (20.00)
5	Large	5	4 (80.00)	1 (20.00)
	Total	**77**	**59 (76.62)**	**18 (23.38)**

Family Size

Dairy farming is a labor-intensive enterprise. Under Indian conditions, labor is required for feeding, cleaning, milking, and looking after the animals. The size of the family is one of the most important factors influencing labor availability and cost of maintenance of animals. It may be observed from Table 3C that the average number of the family members in various categories of farmers varies from four to seven. The corresponding figures in case of males as well as females varies from one to two and in case of children from one to three. Further, the analysis of data with respect to earners and dependents (presented in Table 3D) reveals that the maximum number of earners is five (found in case of landless category of milk producers) while the minimum number of earners is one (found in the large category of milk producers). In case of children, the average number of dependents is three across all categories of milk producers except the landless category where the average number of dependents is two.

TABLE 3C

FAMILY SIZE (MALES, FEMALES, AND CHILDREN).

Sl. no.	Category of milk producers	Total family members	Males	Female	Children
1	Landless	7	2 (28.57)	2 (28.57)	3 (42.86)
2	Marginal	6	2 (33.33)	1 (16.67)	3 (50.00)
3	Small	6	2 (33.33)	2 (33.33)	2 (33.33)
4	Semi-medium	5	2 (40.00)	1 (20.00)	2 (40.00)
5	Medium	5	1 (20.00)	2 (40.00)	2 (40.00)
6	Large	4	2 (50.00)	1 (25.00)	1 (25.00)
	Total	**33**	**11 (33.33)**	**9 (27.27)**	**13 (39.40)**

TABLE 3D

DETAILS OF EARNERS AND DEPENDENTS.

Sl. no.	Category of milk producers	Total no. of family members	Earners	Dependents
1	Landless	7	5 (71.43)	2 (28.57)
2	Marginal	6	3 (50.00)	3 (50.00)
3	Small	6	3 (50.00)	3 (50.00)
4	Semi-medium	5	2 (40.00)	3 (60.000
5	Medium	5	2 (40.00)	3 (60.00)
6	Large	4	1 (25.00)	3 (75.00)
	Total	**33**	**16 (48.48)**	**17 (51.52)**

Further, the distribution of earners amongst males, females, and children are presented in Table 3E. It can be seen from this table that women are not involved in dairy farming activities in case of large milk producers. Similarly, children are also not involved in any category of milk producers except the landless category. The overall average percentage of male earners engaged in dairy farming is 56.25% while female and child earners are 37.50% and 6.25%, respectively.

TABLE 3E

GENDER-WISE DISTRIBUTION OF EARNERS.

Sl. no.	Category of milk producers	Total no. of earners	Males	Females	Children
1	Landless	5	2 (40.00)	2 (40.00)	1 (20.00)
2	Marginal	3	2 (67.67)	1 (33.33)	–
3	Small	3	2 (67.67)	1 (33.33)	–
4	Semi-medium	2	1 (50.00)	1 (50.00)	–
5	Medium	2	1(67.67)	1(33.33)	–
6	Large	1	1(100.00)	–	–
	Total	**16**	**9 (56.25)**	**6(37.50)**	**1(6.25)**

Time Spent by Males, Females, and Children in Dairy Activities

The time spent by males, females, and children in dairy activities is given in Table 3F. It can be seen from this table that on an average males spend 4.23 hours per day in dairy activities while women spend 2.51 hour per day. Males and females in the landless category spend more time compared with other categories of milk producers. The time spent by both males and females decreases for higher categories of milk producers. The involvement of children (above 14 years) was reported by only landless category of milk producers and the time spent by them was 2.25 hours per day.

TABLE 3F

TIME SPENT BY FAMILY LABOR IN DAIRY FARMING IN HOURS PER DAY.

Sl. no.	Category of milk producers	Males	Females	Children (16–18 years)
1	Landless	4.50	3.15	2.25
2	Marginal	4.35	3.10	–
3	Small	4.25	3.05	–
4	Semi-medium	4.18	3.00	–
5	Medium	4.10	2.75	–
6	Large	4.02	–	–
	Total	**4.23**	**2.51**	**0.38**

Educational Status

The educational level of the head of the family influences the decision-making process in managing the dairy farms efficiently. Moreover, higher education is likely to mold the farmer's response in favor of improved technologies and practices. Most of the farmers have little knowledge of modern improved practices of cattle management. They are not aware of the proper nutritional ration to be fed to their animals, least-cost combination of dry and green fodders, detection of the heat, identification of diseases, and the time to vaccinate the animals. In view of this, information on the educational status of sample respondents has been collected and presented in Table 3G.

The distribution of the sample milk producers by education level reveals that on an average 5% of the heads of families of milk producers are illiterate, 40% have education up to primary level, 46.25% up to the high school level, and 6.25% up to the intermediate level. College education up to graduation and above has been attained by only 2.50% of milk producers. No definite trend among various categories of milk producers with respect to educational qualification is discernible.

TABLE 3G

CATEGORY WISE DISTRIBUTION OF MILK PRODUCERS BASED ON EDUCATION LEVEL.

Sl. No.	Category of milk producers	Illiterate	Primary	High school	Intermediate	Graduate and above	Total
1	Landless	1 (33.33%)	1 (33.33%)	1 (33.33%)	–	–	3
2	Marginal	2 (6.90%)	14 (48.28%)	12 (41.38%)	1 (3.45%)	–	29
3	Small	1 (5.00%)	8 (40.00%)	10 (50.00%)	1 (5.00%)	–	20
4	Semi-medium	–	5 (38.46%)	6 (46.15%)	1 (7.69%)	1 (7.69%)	13

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Sl. No.	Category of milk producers	Illiterate	Primary	High school	Intermedi-ate	Graduate and above	Total
5	Medium	–	3 (30.00%)	6 (60.00%)	1 (10.00%)	–	10
6	Large	–	1 (20.00%)	2 (40.00%)	1 (20.00%)	1 (20.00%)	5
	Total	**4 (5.00%)**	**32 (40.00%)**	**37 (46.25%)**	**5 (6.25%)**	**2 (2.50%)**	**80 (100%)**

Occupational Status

The occupational structure of the sample has been distinguished into two categories, namely, primary and subsidiary. The primary (main) occupation is one which provides the major portion of the income (>50%) while the other can be considered as subsidiary. The occupation wise distribution of the sample households with respect to agriculture and dairy as main and subsidiary activities is presented in Table 3H.

The classification of sample milk producers based on occupational category highlights that dairying is pursued as primary occupation by an overall 51.25% of the milk producers whereas it is taken up as a secondary occupation by 48.75% of the milk producers. Agriculture is pursued as a primary activity by 33.75% of the sample respondents and as a subsidiary occupation by 41.25% of the respondents.

Among various categories of households, the maximum proportion (66.67%) of milk producers adopting dairy farming as a primary occupation is observed in case of the landless category while the minimum proportion (20%) is observed in case of large milk producers. A decreasing trend has been observed among various categories of milk producers who have adopted dairy farming as a primary occupation while an increasing trend is observed in case of agriculture.

TABLE 3H

OCCUPATIONAL STATUS OF MILK PRODUCERS.

Sl. No.	Category of milk producers	Agriculture		Animal husbandry		Service		Business except dairy farming	
		Primary	Secondary	Primary	Secondary	Primary	Secondary	Primary	Secondary
1	Landless	–	–	2 (66.67%)	–	1 (33.33%)	1 (33.33%)	–	2 (66.67%)
2	Marginal	8 (27.58%)	12 (41.38%)	16 (55.17%)	16 (55.17%)	5 (17.24%)	1 (3.45%)	–	–
3	Small	6 (30.00%)	8 (40.00%)	11 (55.00%)	8 (40.00%)	2 (10.00%)	4 (20.00%)	1 (5.00%)	–
4	Semi-medium	4 (30.77%)	7 (53.85%)	7 (53.85%)	6 (46.150%)	2 (15.38%)	–	–	–
5	Medium	5 (50.00%)	3 (30.00%)	4 (40.00%)	7 (70.00%)	–	–	1 (10.00%)	–
6	Large	4 (80.00%)	3 (60.00%)	1 (20.00%)	2 (40.00%)	–	–	–	–
	Total	**27 (33.75%)**	**33 (41.25%)**	**41 (51.25%)**	**39 (48.75%)**	**10 (12.50%)**	**6 (7.50%)**	**2 (2.50%)**	**2 (2.50%)**

Distribution of Respondents Based on Number of Milch Animals

The distribution of sample respondents on the basis of number of milch animals is given in Table 3I. It can be seen from this table that the highest number (7) of milch animals were maintained by the semi-medium category of milk producers while the lowest number of milch animals (3) were maintained by the landless producers. The overall purchase cost of a local cow, crossbred cow, and buffalo was INR31,733.33, INR43,150.00 and INR69,788.33, respectively. It may also be seen from this table that the average purchase cost of a local cow, crossbred cow, and buffalo was the highest in the category of large milk producers, at INR34,500, INR45,220, and INR73,750, respectively. The lowest cost was in the case of landless milk producers, at INR28,750, INR41,500, and INR66,525, respectively. Overall, an increasing trend in the purchase cost of local cows, crossbred cows, and buffaloes can be seen among various categories of milk producers.

TABLE 3I

DISTRIBUTION OF MILK PRODUCERS BASED ON THE NUMBER OF MILCH ANIMALS MAINTAINED AND THEIR COSTS.

Sl. No.	Category of milk producers	Total number of milk producers	Average number of milch animals	Average number of milch animals			Average cost per milch animal (in INR)		
				Local cows	Crossbred cows	Buffaloes	Local cows	Crossbred cows	Buffaloes
1	Landless	3	3	1	1	1	28,750	41,500	66,525
2	Marginal	29	4	1	1	2	29,500	41,975	66,800
3	Small	20	5	1	2	2	31,250	42,350	68,900
4	Semi-medium	13	7	2	2	3	32,800	43,450	70,275
5	Medium	10	6	1	2	3	33,600	44,375	72,480
6	Large	5	3	1	1	1	34,500	45,250	73,750
	Total, average	**80**	**28 (4.67)**	**7 (1.17)**	**9 (1.50)**	**12 (2.00)**	**31,733.33**	**43,150**	**69,788.33**

Number of Respondents Getting Guidance for Purchasing Animals

The decision to purchase milch animals is influenced by a variety of factors, as has been illustrated in Table 3J. It can be observed from this table that overall 40% of the milk producers reported that they had received advise from the field officer of the lead bank for new purchase; 25% of milk producers had received guidance from the block development officer (BDO) or the area development officer (ADO); 22.50% had purchased the milch animals through their respective dairy plants; and 12.50% milk producers had been advised by the district manager of National Bank for Agriculture and Rural Development (NABARD). There is no denying the fact that if farmers get the guidance, they can purchase quality breeds of animals.

TABLE 3J

NUMBER OF RESPONDENTS GETTING GUIDANCE FOR PURCHASING MILCH ANIMALS.

Sl. no.	Category of milk producers	Number of respondents	Number of respondents getting guidance for purchasing animals			
			Lead bank	BDO/ADO	Dairy plant	NABARD
1	Landless	3	1 (33.33%)	–	1 (33.33%)	1 (33.33%)
2	Marginal	29	10 (34.48%)	7 (24.14%)	8 (27.59%)	4 (13.79%)

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Sl. no.	Category of milk producers	Number of respondents	Number of respondents getting guidance for purchasing animals			
			Lead bank	BDO/ADO	Dairy plant	NABARD
3	Small	20	8 (40.00%)	6 (30.00%)	4 (20.00%)	2 (10.00%)
4	Semi-medium	13	6 (46.15%)	4 (30.77%)	2 (15.38%)	1 (7.69%)
5	Medium	10	5 (50.00%)	2 (20.00%)	2 (20.00%)	1 (10.00%)
6	Large	5	2 (40.00%)	1 (20.00%)	1 (20.00%)	1 (20.00%)
	Total	**80**	**32 (40.00%)**	**20 (25.00%)**	**18 (22.50%)**	**10 (12.50%)**

Feedback Received from Milk Producers on the Health of the Purchased Milch Animals

Information related to the health of the purchased animals was obtained from the milk producers and is presented in Table 3K. It can be seen from this table that 43.75% milk producers informed that the health of their purchased animals was good, 40% said that it was very good, while 16.25% informed that it was average.

TABLE 3K

HEALTH OF THE PURCHASED MILCH ANIMALS.

Sl. no.	Category of milk producers	Number of respondents	Health of the purchased milch animals		
			Very good	Good	Average
1	Landless	3	1 (33.33%)	1 (33.33%)	1 (33.33%)
2	Marginal	29	10 34.48 (%)	13 (44.83%)	6 (20.69%)
3	Small	20	7 (35.00%)	10 (50.00%)	3 (15.00%)
4	Semi-medium	13	6 (46.15%)	6 (46.15%)	1 (7.69%)
5	Medium	10	5 (50.00%)	4 (40.00%)	1 (10.00%)
6	Large	5	3 (60.00%)	1 (20.00%)	1 (20.00%)
	Total	**80**	**32 (40.00%)**	**35 (43.75%)**	**13 (16.25%)**

Insurance of Milch Animals

Insurance of animals has played an imported role in providing the sum insured or market value of the animal (whichever is less) to milk producers at the time of death of the animal. In this way, insurance minimizes the risk in the event of outbreak of an epidemic, for example. The status on the number of sample respondents who have insured their animals and the extent of insurance coverage and the premium amount paid toward insurance or its renewal have been compiled and presented in Tables 3L through 3O. It can be seen from Table 3L that 63.75% of the milk producers were willing to insure their animals while the remaining 36.25% had not shown any interest in insuring their milch animals.

TABLE 3L

WILLINGNESS OF MILK PRODUCERS TOWARD INSURANCE OF ANIMALS.

Sl. no.	Category of milk producers	Total number of milk producers	Yes (%)	No (%)
1	Landless	3	2 (66.67%)	1 (33.33%)
2	Marginal	29	18 (62.07%)	11 (37.93%)

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Sl. no.	Category of milk producers	Total number of milk producers	Yes (%)	No (%)
3	Small	20	13 (65.00%)	7 (35.00%)
4	Semi-medium	13	8 (61.54%)	5 (38.46%)
5	Medium	10	7 (70.00%)	3 (30.00%)
6	Large	5	3 (60.00%)	2 (40.00%)
	Total	**80**	**51 (63.75%)**	**29 (36.25%)**

Insurance Coverage of Milch Animals

Table 3M reveals that overall, 31.37% milk producers had insured all their milch animals. The proportion of such milk producers varied from 16.67% (in case of the marginal category of farmers) to 67.67% in case of the large category of farmers. An increasing trend was observed among various categories of milk producers, as may be seen from this table. The percentage increased for the higher categories of milk producers. It can also be observed from Table 3M that a sizeable number of overall respondents (68.63%) had insured only those animals that were purchased on loan because it was mandatory. The maximum percentage among them was found in case of landless producers (100%), followed by marginal (83.33%), small (69.23%), semi-medium (62.50%), medium (42.86%), and large (33.33%) categories of milk producers. Clearly, this percentage decreased for the higher categories of milk producers. Further, the annual premium amount of the insurance was calculated either based on the actual purchase cost of the animal or decided by the veterinary doctor. Since the government is also supporting farmers by giving a subsidy in the insurance of the animals, the subsidized premium was calculated at the rate of 2.5%. The overall annual insurance premium amount in case of local cows, crossbred cows, and buffaloes was INR793.33, INR1,078.75, and INR1,744.70, respectively. Since the large milk producers were having costly and good-quality breeds of animals, the amount of insurance premium paid by them was the highest across all types of animals.

TABLE 3M

INSURANCE COVERAGE AND PREMIUM AMOUNTS FOR MILCH ANIMALS.

Sl. no.	Category of milk producers	Number of milk producers insured their animal	Insured all animals	Insured only purchased animals	Average insurance premium per animal in INR		
					Local cows	Crossbred cows	Buffaloes
1	Landless	2	–	2 (100%)	718.75	1,037.50	1,663.12
2	Marginal	18	3 (16.67%)	15 (83.33%)	737.50	1,049.37	1,917.00
3	Small	13	4 (30.77%)	9 (69.23%)	781.25	1,058.75	1,722.50
4	Semi-medium	8	3 (37.50%)	5 (62.50%)	820.00	1,086.75	1,756.25
5	Medium	7	4 (57.14%)	3 (42.86%)	840.00	1,109.37	1,812.00
6	Large	3	2 (66.67%)	1 (33.33%)	862.50	1,131.25	1,843.75
	Total	**51**	**16 (31.37%)**	**35 (68.63%)**	**793.33**	**1,078.75**	**1,744.70**

Status of Insurance Renewal

The details about the renewal of insurance were also gathered from those milk producers who had insured their animals, and are presented in Table 3N. It may be observed from Table 3N that insurance policies had been renewed by only 41.18% of the milk producers. The maximum renewal percentage (66.67%) was found in case of large milk producers while the semi-medium category of milk producers had the minimum renewal percentage (37.50%).

TABLE 3N

STATUS OF INSURANCE RENEWALS.

Sl. no.	Category of milk producers	Total number of milk producers	Status of insurance renewals	
			Yes (%)	No (%)
1	Landless	2	1 (50.00%)	1 (50.00%)
2	Marginal	18	7 (38.89%)	11 (61.11%)
3	Small	13	5 (38.46%)	8 (61.54%)
4	Semi-medium	8	3 (37.50%)	5 (62.50%)
5	Medium	7	3 (42.86%)	4 (57.14%)
6	Large	3	2 (66.67%)	1 (33.33%)
	Total	**51**	**21 (41.18%)**	**30 (58.82%)**

Reasons for not Renewing the Insurance Policy

Reasons for not renewing the insurance policy are given in Table 3O. As may be seen from this table, 25.49% of the milk producers were not aware that they needed to renew the insurance policy, 35.29% explained that their economic condition was poor, and 39.22% informed that they had not received the claim and hence were not willing to renew the policy.

TABLE 3O

REASONS FOR NOT RENEWING INSURANCE POLICIES OF ANIMALS.

Sl. no.	Category of milk producers	Total number of milk producers	Reasons for not renewing the insurance policy		
			Lack of awareness	Poor economic condition	Problems in getting the claim
1	Landless	2	1 (50.00%)	1 (50.00%)	–
2	Marginal	18	4 (22.22%)	8 (44.44%)	6 (33.33%)
3	Small	13	3 (23.08%)	6 (46.15%)	4 (30.77%)
4	Semi-medium	8	2 (25.00%)	3 (37.50%)	3 (37.50%)
5	Medium	7	2 (28.57%)	–	5 (71.43%)
6	Large	3	1 (33.33%)	–	2 (66.67%)
	Total	**51**	**13 (25.49%)**	**18 (35.29%)**	**20 (39.22%)**

Description of Milch Animals

The large farmers are maintaining livestock along with raising crops so as to have a balanced and productive system of farming. In the recent past, with the development of various breeds by crossing local animals with exotic germ plasma, the situation is changing fast and people are devoting more time for dairy farming. In order to ameliorate the economic development in a selected village, the knowledge about the age of first calving, lactation length, dry days and inter-calving period, and the order of location are basic prerequisites.

Age of First Calving

Late maturity of bovines results in higher costs of rearing animals. The age at first calving is governed by factors like maturity and conception rate, which in turn are influenced by the breeding, feeding, management, and environmental factors. It has been observed that the sample respondents have been keeping milch animals where there is significant variation in the age at first calving within some breed in the herd. Therefore, to present a comprehensive view, the minimum and maximum ages of first calving of different breeds have been considered. It can be seen from Table 4A that the overall minimum average age at first calving was lowest for crossbred cows (2.73 years) and highest for buffaloes (3.54 years), whereas it laid in between for local cows (2.86 years). A similar trend was exhibited when the maximum average age for the overall sample was considered. Mixed trends were visible when the average age at first calving was segregated on the basis of size of land holding for all the three types of milch animals.

TABLE 4A

CATEGORY WISE RESPONSES OF MILK PRODUCERS ON AGE OF FIRST CALVING.

Sl. No.	Category of milk producers	Local cows		Crossbred cows		Buffaloes	
		Minimum age in years	Maximum age in years	Minimum age in years	Maximum age in years	Minimum age in years	Maximum age in years
1	Landless	2.98	3.32	2.78	3.15	3.64	4.12
2	Marginal	2.94	3.29	2.89	3.20	3.63	4.08
3	Small	2.87	3.26	2.76	3.18	3.62	4.02
4	Semi-medium	2.82	3.23	2.65	3.12	3.50	4.00
5	Medium	2.79	3.19	2.68	3.15	3.47	3.95
6	Large	2.75	3.17	2.62	3.13	3.38	3.86
	Total	**2.86**	**3.24**	**2.73**	**3.16**	**3.54**	**4.01**

Lactation Length, Dry Days, and Inter-calving Period

The lactation length affects the total milk production and consequently the investment return from dairy animals. The longer and prolonged dry period puts the dairy farmers in a disadvantageous position since the animals are to be fed and taken care of during this period too, thereby increasing the cost of maintenance. The inter-calving period is the sum of milking days and dry days or the period between two successive calving. A short inter-calving period leads to higher number of lactations in the productive life of animals. Here, again due to variations in the lactation length, dry days, and inter-calving period within the milch animals of the same breed in a herd, effort has been made to present a comprehensive view by working out average minimum and maximum figures for the related parameters as discussed below:

Lactation length: It can be seen from Table 4B that the overall minimum and maximum lactation lengths for local cows were worked out as 271.68 days and 316.58 days, respectively. The minimum and maximum lactation lengths in case of crossbred cows were 278.71 days and 307.75 days, respectively. A variation ranging from 259.14 days to 322.89 days in lactation length was reported for buffaloes.

TABLE 4B

LACTATION LENGTHS OF VARIOUS BREEDS OF MILCH ANIMALS.

Sl. no.	Category of milk producers	Local cows		Crossbred cows		Buffaloes	
		Minimum days	Maximum days	Minimum days	Maximum days	Minimum days	Maximum days
1	Landless	242.00	310.33	280.81	310.33	259.81	314.81
2	Marginal	248.00	307.85	278.25	293.17	260.58	320.48
3	Small	275.73	305.25	288.87	297.55	260.83	324.71
4	Semi-medium	280.5	313.01	274.23	308.01	261.12	325.36
5	Medium	287.67	317.93	277.94	317.18	254.83	328.75
6	Large	296.17	345.00	272.15	320.25	257.64	323.25
	Total	**271.68**	**316.56**	**278.71**	**307.75**	**259.14**	**322.89**

Dry days: Overall, the average minimum number of dry days was 60.38 in case of crossbred cows. Across various categories of milk producers, the landless producers reported the shortest duration of dry days (50 days) for crossbred cows. In cases of local cows and buffaloes, the overall average duration of dry days varied from 70 days to 98.25 days and from 87.86 days to 127.50 days, respectively (see Table 4B1).

TABLE 4B1

DRY DAYS IN VARIOUS BREEDS OF MILCH ANIMALS.

Sl. no.	Category of milk producers	Local cows		Crossbred cows		Buffaloes	
		Minimum days	Maximum days	Minimum days	Maximum days	Minimum days	Maximum days
1	Landless	70.00	91.33	50.00	71.33	87.86	112.86
2	Marginal	78.50	98.25	58.50	78.25	92.77	115.77
3	Small	84.95	93.65	64.95	73.65	94.67	119.67
4	Semi-medium	85.24	98.00	65.24	86.35	98.14	124.14
5	Medium	83.57	97.58	63.57	77.58	102.50	127.50
6	Large	70.00	91.33	60.00	79.35	110.25	112.86
	Total	**78.71**	**95.02**	**60.38**	**77.75**	**97.70**	**118.80**

Inter-calving period: The category wise information on inter-calving period for different milch animals has been compiled and presented in Table 4B2. The table reveals that the overall average inter-calving period ranged from 366.70 days to 395.27 days for local cows; from 356.46 days to 368.13 days for crossbred cows; and from 377.94 days to 420.59 days for buffaloes. The minimum inter-calving period in case of local cows was reported as 333.33 days by landless farmers. For crossbred cows and buffaloes, the average minimum inter-calving period reported was 352.14 days by landless farmers and 370.50 days by large farmers.

TABLE 4B2

INTERCALVING PERIODS OF MILCH ANIMALS.

Sl. no.	Category of milk producers	Local cows		Crossbred cows		Buffaloes	
		Minimum days	Maximum days	Minimum days	Maximum days	Minimum days	Maximum days
1	Landless	333.33	380.33	352.14	360.33	372.67	402.67
2	Marginal	346.25	386.35	356.50	351.67	376.35	413.25
3	Small	369.38	390.20	362.52	362.50	380.50	419.38
4	Semi-medium	378.50	398.25	360.58	373.25	385.26	423.50
5	Medium	385.25	401.50	355.52	380.75	382.33	431.25
6	Large	387.50	415.00	351.50	380.25	370.50	433.50
	Total	**366.70**	**395.27**	**356.46**	**368.13**	**377.94**	**420.59**

Order of Lactation

The milk production potential of a milch animal increases with the increase in its physical maturity, which is normally attained between eight and nine years of age. The order of lactation is highly correlated with age, and therefore, has an indirect effect on the milk yield of the dairy cattle. It has generally been observed that milk yield of an animal increases from first lactation to third/fourth lactation and thereafter shows a declining trend. Animals in first four lactations are said to be in an increasing phase and animals from fifth lactation onward are said to be in a declining phase of productive life. The average lactation yields for different breeds of animals maintained by different categories of milk producers are given in Table 4C.

It can be seen from Table 4C that the overall lactation yield for local cows increased from first lactation to fourth lactation (from 1,510.37 liter to 1,839.40 liter) whereas in subsequent lactations it went down to 1,263.40 liter during seventh lactation. The highest first lactation yield (1,565.50 liter) for local cows was reported by the landless category of milk producers. It can be ascertained from this table that the highest yield for subsequent lactations was 1,720.60 liter during second lactation for the semi-medium category of milk producers; 1,880.45 liter during third lactation for the large category of milk producers; 1,890.95 liter during fourth lactation for the landless category of milk producers; 1,698.40 liter during fifth lactation also for the landless category of milk producers; 1,450.20 liter during sixth lactation for the medium category of dairy farmers; and 1,287.80 liter during seventh lactation in case of the landless category of milk producers.

TABLE 4C

ORDER OF LACTATION FOR LOCAL COWS.

Sl. no.	Category of milk producers	Lactation yields of local cows in liter						
		First	Second	Third	Fourth	Fifth	Sixth	Seventh
1	Landless	1,565.50	1,712.30	1,860.10	1,890.95	1,698.40	1,385.70	1,287.80
2	Marginal	1,425.25	1,656.68	1,810.25	1,829.23	1,638.68	1,305.76	1,240.00
3	Small	1,510.20	1,705.25	1,850.28	1,860.45	1,655.32	1,380.75	1,260.90
4	Semi-medium	1,535.40	1,720.60	1,865.36	1,859.23	1,675.33	1,435.26	1,280.45

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Sl. no.	Category of milk producers	Lactation yields of local cows in liter						
		First	Second	Third	Fourth	Fifth	Sixth	Seventh
5	Medium	1,480.50	1,665.35	1,720.85	1,810.90	1,660.23	1,450.20	1,260.52
6	Large	1,545.35	1,715.60	1,880.45	1,785.62	1,650.25	1,315.30	1,250.75
	Total	**1,510.37**	**1,695.96**	**1,831.22**	**1,839.40**	**1,663.04**	**1,378.83**	**1,263.40**

Table 4C1 presents the details of average lactation yield according to the order of lactation for crossbred cows. Here again, the overall lactation yield increased from first lactation to third lactation (4,852.03 liter to 5,313.87 liter). However, in subsequent lactations, it went down to the level of 4,166.85 liter in the seventh lactation. During the third lactation, the highest lactation yield of 5,481.56 liter was in case of the large category of milk producers. During the fourth lactation, the highest lactation yield (5,481.56 liter) was reported by the medium category of milk producers. However, fifth lactation onward, the highest yield was observed in case of the medium category of milk producers.

TABLE 4C1

ORDER OF LACTATION FOR CROSSBRED COWS.

Sl. no.	Category of milk producers	Lactation yields of crossbred cows in liter						
		First	Second	Third	Fourth	Fifth	Sixth	Seventh
1	Landless	4,520.00	4,902.04	5,138.88	5,208.21	4,785.41	4,452.46	4,106.66
2	Marginal	4,669.56	4,886.35	5,250.25	5,292.49	4,662.20	4,508.70	4,131.01
3	Small	4,928.35	5,066.84	5,380.00	5,307.08	4,830.21	4,389.14	4,151.28
4	Semi-medium	5,057.71	5,308.34	5,333.33	5,299.21	4,945.30	4,497.64	4,203.60
5	Medium	4,917.12	5,166.46	5,299.20	5,390.62	4,880.26	4,487.46	4,172.45
6	Large	5,019.42	5,250.35	5,481.56	5,292.36	4,915.08	4,424.78	4,236.12
	Total	**4,852.03**	**5,096.73**	**5,313.87**	**5,298.33**	**4,836.41**	**4,460.03**	**4,166.85**

In case of buffaloes, the overall increasing and decreasing trends for lactation yield for various orders of lactation were similar to those for local and crossbred cows. The overall lactation yield for buffaloes increased from 2,731.66 liter to 2,836.26 liter from the first lactation to the third lactation. For subsequent lactations, the yield went down to 2,121.94 liter (see Table 4C2). Nevertheless, it may be noted that the respondents have generally been found to be rearing comparatively better breeds of buffaloes.

TABLE 4C2

ORDER OF LACTATION FOR BUFFALOES.

Sl. no.	Category of milk producers	Lactation yield for buffaloes in liter						
		First	Second	Third	Fourth	Fifth	Sixth	Seventh
1	Landless	2,610.50	2,650.00	2,790.48	2,760.50	2,524.80	2,320.67	2,180.67
2	Marginal	2,690.20	2,705.40	2,785.23	2,775.15	2,540.16	2,305.18	2,085.93

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Sl. no.	Category of milk producers	Lactation yield for buffaloes in liter						
		First	Second	Third	Fourth	Fifth	Sixth	Seventh
3	Small	2,720.40	2,790.85	2,840.60	2,910.24	2,605.64	2,350.60	2,135.36
4	Semi-medium	2,790.21	2,850.34	2,920.25	2,890.33	2,660.21	2,229.77	2,069.06
5	Medium	2,818.21	2,709.77	2,765.83	2,815.28	2,575.35	2,440.15	2,110.25
6	Large	2,760.45	2,810.20	2,915.15	2,850.35	2,472.22	2,390.85	2,150.35
	Total	**2,731.66**	**2,752.76**	**2,836.26**	**2,833.64**	**2,563.06**	**2,339.54**	**2,121.94**

Productive Life of Milch Animals

Information on the productive lives of animals has also been gathered from the respondent milk producers and compiled and presented in Table 4D. The overall average maximum productive life of crossbred cows was 13.19 years, followed by buffaloes (12.94 years), and local cows (12.61 years).

TABLE 4D

PRODUCTIVE LIVES OF VARIOUS TYPES OF MILCH ANIMALS IN YEARS.

Sl. no.	Category of milk producers	Local cows		Crossbred cows		Buffaloes	
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1	Landless	11.63	12.74	10.05	13.38	12.89	13.35
2	Marginal	11.54	12.68	10.09	13.25	12.50	13.08
3	Small	11.47	12.63	10.12	13.21	12.37	13.02
4	Semi-medium	11.39	12.58	10.14	13.17	12.25	12.95
5	Medium	11.32	12.55	10.25	13.10	12.20	12.75
6	Large	11.26	12.5	10.32	13.05	12.22	12.50
	Total	**11.44**	**12.61**	**10.16**	**13.19**	**12.41**	**12.94**

Response of the Milk Producers on Availability of Required Infrastructure

The details related to the availability of the infrastructure facilities such as cattle shed, milking machine, chaff cutter, and veterinary hospital were obtained from the sample milk producers and are presented in Tables 5 through 5C.

TABLE 5

DETAILS ON CATTLE SHEDS.

Sl. no.	Category of milk producers	Number of milk producers	No. of farmers having cattle sheds	Average year of construction	Average cost of construction (INR)
1	Landless	3	–	–	–
2	Marginal	29	5 (17.24%)	6	122,650.84
3	Small	20	4 (20.00%)	9	143,375.50

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Sl. no.	Category of milk producers	Number of milk producers	No. of farmers having cattle sheds	Average year of construction	Average cost of construction (INR)
4	Semi-medium	13	5 (38.46%)	17	171,267.22
5	Medium	10	6 (60.00%)	16	195,415.75
6	Large	5	4 (80.00%)	18	210,834.25
	Total	**80**	**24 (30.00%)**	**11**	**148,708.51**

Availability of the Milking Machine and its Status

Milking machines are playing an important role not only in saving the labor time but also in enhancing the quality of milk. As can be seen from Table 5A, overall, 32.50% of the milk producers had milking machines. The percentage was the highest (80%) in case of the large category of milk producers and lowest (17.24%) in case of the landless category of milk producers. An increasing trend in this regard was observed among various categories of milk producers (it increased for the higher categories of milk producers). A similar trend was also observed in the price of the milking machine. The highest price of the machine (INR58,118.25) was reported by large milk producers while the lowest price (INR45,650.25) was found among the landless category of producers.

Further, overall, 88.46% of milk producers informed that their milking machines were functional while the remaining 11.54% informed that their machines were out of order. It is clear from Table 5A that all milk producers in medium and large categories were having relatively costlier and better-quality machines.

TABLE 5A

DETAILS OF MILKING MACHINES.

Sl. no.	Category of milk producers	Total number of milk producers	No. of farmers having milking machine and average cost in INR		Status of milking machines	
			No. of farmers	Average cost	Functional	Out of order
1	Landless	3	–	–	–	–
2	Marginal	29	5 (17.24%)	45,650.25	4 (80.00%)	1 (20.00%)
3	Small	20	4 (20.00%)	48,460.75	3 (75.00%)	1 (25.00%)
4	Semi-medium	13	7 (53.84%)	50,215.33	6 (85.71%)	1 (14.29%)
5	Medium	10	6 (60.00%)	52,455.67	6 (100.00%)	0 (0.00%)
6	Large	5	4 (80.00%)	58,118.25	4 (100.00%)	0 (0.00%)
	Total	**80**	**26 (32.50%)**	**50,979.60**	**23 (88.46%)**	**3 (11.54%)**

Details of Chaff Cutters

Most of the milk producers were having chaff cutters whether manual or power-operated to chaff both dry and green fodders for their animals. It is clear from Table 5B that overall, 80% of the milk producers had power-drawn chaff cutters while the remaining 20% had manually operated chaff cutters. Further, the overall average price of a power-operated chaff cutter was INR33,889.67 while that of a manually operated chaff cutter was INR12,720.82. The prices of both types of chaff cutters were comparatively lower in case of the landless category of milk producers.

TABLE 5B

DETAILS OF CHAFF CUTTERS.

Sl. no.	Category of milk producers	Total number of milk producers	No. of farmers having chaff cutters		Average purchase price of chaff cutter in INR	
			Manually operated	Power operated	Manually operated	Power operated
1	Landless	3	2 (66.67%)	1 (33.33%)	11,980.50	32,615.00
2	Marginal	29	18 (62.06%)	11 (37.94%)	12,610.33	33,210.67
3	Small	20	11 (55.00%)	9 (45.00%)	12,780.25	33,118.33
4	Semi-medium	13	4 (30.76%)	9 (69.24%)	12,950.75	33,622.67
5	Medium	10	2 (20.00%)	8 (80.00%)	12,890.50	35,208.25
6	Large	5	1 (20.00%)	4 (80.00%)	13,115.00	35,565.50
	Total	**80**	**38 (47.50%)**	**42 (52.50%)**	**12,720.82**	**33,889.67**

Veterinary Health Service

To obtain the desired results, efficient healthcare facilities are necessary for substantially reducing the incidence of diseases and thereby of production losses. Hence, an attempt was made to find out the status of infrastructural facilities in the study area. A category wise detailed analysis with respect to the availability of well-equipped veterinary hospitals; distance of veterinary hospitals from the selected villages; farmers getting veterinary services at their doorsteps; and timely availability of medicines, minerals, and recombinant bovine growth hormone (RBGH) is given in Table 5C. It can be seen from this table that the overall distance of veterinary hospitals from sample villages was found to be 9.06 km. Further, the availability of well-equipped infrastructure at veterinary hospitals was reported by only 15% of the milk producers. However, an overall 53.75% milk producers were getting the veterinary service at their doorsteps. The reason for the distance of veterinary hospitals from sample villages could probably be that veterinary aid was being provided by mobile veterinary dispensaries. The mobile units visited the allocated villages on a fixed route once a week and treated the milch animals maintained by different categories of milk producers.

The availability of medicines was confirmed by 75% of the milk producers while 45% dairy farmers confirmed the availability of minerals. The information related to utilization of RBGH was also obtained from the sample milk producers. It can be seen from Table 5C that only 8.75% of the milk producers were utilizing RBGH for enhancing milk production besides maintaining the health of their milch animals.

TABLE 5C

DETAILS ON AVAILABILITY OF VETERINARY HEALTH SERVICES.

Sl. no.	Category of milk producers	Total number of milk producers	Response of farmers on various parameters					
			Average distance in km	Availability of well-equipped veterinary hospitals	Farmers getting veterinary services at their doorsteps	Timely availability of medicines	Timely availability of minerals	Utilization of RBGH
1	Landless	3	9.25	Not aware	1 (33.33%)	2 (66.67%)	1 (33.33%)	Not aware
2	Marginal	29	8.87	4 (13.79%)	12 (41.38%)	21 (72.41%)	12 (41.38%)	1 (3.45%)

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Sl. no.	Category of milk producers	Total number of milk producers	Response of farmers on various parameters					
			Average distance in km	Availability of well-equipped veterinary hospitals	Farmers getting veterinary services at their doorsteps	Timely availability of medicines	Timely availability of minerals	Utilization of RBGH
3	Small	20	9.01	3 (15.00%)	10 (50.00%)	15 (75.00%)	9 (45.00%)	1 (5.00%)
4	Semi-medium	13	10.20	2 (15.38%)	9 (69.24%)	10 (76.92%)	6 (46.16%)	2 (15.39%)
5	Medium	10	9.65	2 (20.00%)	7 (70.00%)	8 (80.00%)	5 (50.00%)	2 (20.00%)
6	Large	5	10.35	1 (20.00%)	4 (80.00%)	4 (80.00%)	3 (60.00%)	1 (20.00%)
	Total	**80**	**9.06**	**12 (15.00%)**	**43 (53.75%)**	**60 (75.00%)**	**36 (45.00%)**	**7 (8.75%)**

Number of Farmers Getting Assistance from Various Agencies

The sample milk producers got assistance from various agencies for different purposes such as purchase of milch animals, feed, and fodders; construction of cattle sheds; and insurance of animals and their healthcare. This has been analyzed and presented in Table 5D. This table reveals that overall 86.25% of the milk producers received assistance from dairy plants for purchasing feed at subsidized rates; 63.75% milk producers received assistance for purchasing milch animals either from their dairy plants or from their respective lead banks under the Dairy Entrepreneur Development Scheme (DEDS); 63.75% dairy farmers got support for insuring their animals (part payment of the insurance premium came from the government and part payment from the dairy plant); and 53.75% milk producers received veterinary services from dairy plants as well as from the government for vaccinating their animals.

Further, it may be observed from Table 5D that 30% of the milk producers received assistance for construction of cattle sheds. The highest percentage (80%) was found among large milk producers while the lowest percentage (17.24%) was reported for the medium category of milk producers. An increase in the proportion of cattle-shed construction was observed from lower to higher categories of milk producers.

TABLE 5D

NUMBER OF FARMERS GETTING ASSISTANCE FROM VARIOUS AGENCIES.

Sl. no.	Category of milk producers	Number of respondents	Number of farmers getting assistance from government/ dairy plants toward:				
			Purchase of animals	Purchase of feed	Construction of cattle sheds	Insurance of animals	Animal healthcare
1	Landless	3	2 (66.67%)	2 (66.67%)	–	2 (66.67%)	1(33.33%)
2	Marginal	29	18 (62.07%)	26 (89.66%)	5 (17.24%)	18 (62.07%)	12(41.38%)
3	Small	20	13 (65.00%)	18 (90.00%)	4 (20.00%)	13 (65.00%)	10(50.00%)
4	Semi-medium	13	8 (61.54%)	11 (84.61%)	5 (38.46%)	8 (61.54%)	9(69.24%)

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Sl. no.	Category of milk producers	Number of respondents	Number of farmers getting assistance from government/ dairy plants toward:				
			Purchase of animals	Purchase of feed	Construction of cattle sheds	Insurance of animals	Animal healthcare
5	Medium	10	7 (70.00%)	8 (80.00%)	6 (60.00%)	7 (70.00%)	7(70.00%)
6	Large	5	3 (60.00%)	4 (80.00%)	4 (80.00%)	3 (60.00%)	4(80.00%)
	Total	**80**	**51 (63.75%)**	**69 (86.25%)**	**24 (30.00%)**	**51 (63.75%)**	**43 (53.75%)**

Availability of Water for Various Activities in Dairy Farming

Water is very important for performing dairy farming activities. It is required for watering the animals and cleaning them and the cattle sheds. The information pertaining to water requirement has been collected from the sample milk producers and illustrated in Table 5E. As may be seen from the table, all sample farmers of various categories use it for watering their animals; 90% use water for washing the animals; and 87.50% farmers who are having cattle sheds, use it for cleaning the sheds.

TABLE 5E

AVAILABILITY OF WATER USED FOR VARIOUS DAIRY FARMING ACTIVITIES.

Sl. no.	Category of milk producers	Total number of milk producers	Watering of animals	Washing/ Cleaning of animals	Cleaning of cattle sheds (in cases where milk producers have sheds)	
					Number of the milk producers having cattle sheds	Number of milk producers having water for cleaning of cattle sheds
1	Landless	3	3 (100%)	2 (66.67%)	–	–
2	Marginal	29	29 (100%)	25 (86.21%)	5	4 (80%)
3	Small	20	20 (100%)	18 (90%)	4	3 (75%)
4	Semi-medium	13	13 (100%)	12 (92.31%)	5	4 (80%)
5	Medium	10	10 (100%)	10 (100%)	6	6 (100%)
6	Large	5	5 (100%)	5 (100%)	4	4 (100%)
	Total	**80**	**80 (100%)**	**72 (90%)**	**24**	**21 (87.50%)**

Feedback of Milk Producers on the Prevalence of Diseases among Animals

With a view to having firsthand information on the prevalence of different types of animal diseases in the sample region, respondent feedback was gathered and compiled in Table 6. Animal diseases such as foot and mouth, *gurrua, surara,* contagious bovine pleuropneumonia (CBPP), and rinderpest were generally found to be prevalent in the study area. The most commonly reported disease by almost 75% respondents was foot and mouth disease, followed by mastitis (53.75%); rinderpest (16.25%); *gurrua* (15%); *surra* (12.50%); and CBPP (8.75%). The landless milk producers were not aware about the prevalence of *gurrua, surra,* and CBBP diseases.

TABLE 6

RESPONSES OF MILK PRODUCERS ON PREVALENCE OF DISEASES AMONG THEIR ANIMALS.

Sl. no.	Category of milk producers	Total number of milk producers	Response of the milk producers on various diseases					
			Foot and mouth	Gurrua	Surara	CBPP	Rinderpest	Mastitis
1	Landless	3	2 (66.67%)	Not aware	Not aware	Not aware	Not aware	1 (33.33%)
2	Marginal	29	21 (72.41%)	4 (13.79%)	3 (10.35%)	1 (3.45%)	4 (13.79%)	12 (41.38%)
3	Small	20	15 (75.00%)	3 (15.00%)	2 (10.00%)	1 (5.00%)	3 (15.00%)	10 (50.00%)
4	Semi-medium	13	10 (76.92%)	2 (15.38%)	3 (23.08%)	2 (15.39%)	3 (23.08%)	9 (69.24%)
5	Medium	10	8 (80.00%)	2 (20.00%)	1 (10.00%)	2 (20.00%)	2 (20.00%)	7 (70.00%)
6	Large	5	4 (80.00%)	1 (20.00%)	1 (20.00%)	1 (20.00%)	1 (20.00%)	4 (80.00%)
	Total	**80**	**60 (75.00)**	**12 (15.00)**	**10 (12.50)**	**7 (8.75)**	**13 (16.25)**	**43 (53.75)**

Feedback on Existing Animal Disease Surveillance Scheme

Under the animal disease surveillance scheme, a computerized information system has been commissioned by the central government to constantly monitor the status of animal diseases in every region. The respondents' feedback on the coverage of their respective villages under the surveillance scheme toward disease control of their livestock has been obtained and presented in Table 6A. It can be seen from the table that overall, just 38.75% of respondents reported the existence of animal surveillance schemes in their regions.

TABLE 6A

AWARENESS AMONG SAMPLE MILK PRODUCERS ON ANIMAL DISEASE SURVEILLANCE SCHEME.

Sl. no.	Category of milk producers	Total number of milk producers	Awareness on animal disease surveillance scheme	
			Yes	No
1	Landless	3	1 (33.33%)	2 (66.67%)
2	Marginal	29	8 (27.59%)	21 (72.41%)
3	Small	20	6 (30.00%)	14 (70.00%)
4	Semi-medium	13	7 (53.85%)	6 (46.15%)
5	Medium	10	6 (60.00%)	4 (40.00%)
6	Large	5	3 (60.00%)	2 (40.00%)
	Total	**80**	**31(38.75%)**	**49 (61.25%)**

Responses of Milk Producers on Health Facilities Availed

Various types of health facilities are made available to milk producers through different dairy development schemes. The respondent milk producers have availed one or more of such facilities.

The details have been presented in Table 6B. It can be seen from the table that overall, around 86.67% of the respondents had availed the vaccination facility to prevent the foot and mouth disease. Other health facilities such as brucellosis and deworming had been availed by 63.33% and 28.33% of the overall respondents, respectively.

TABLE 6B

ASSISTANCE RECEIVED FROM THE GOVERNMENT OR DAIRY PLANTS FOR ANIMAL DISEASES.

Sl. no.	Category of milk producers	Total number of sample milk producers	Assistance received from government/dairy plants for different animal diseases		
			Foot and mouth	Brucellosis	Deworming
1	Landless	2	2 (100.00%)	1 (50.00%)	1 (50.00%)
2	Marginal	21	18 (85.71%)	13 (72.41%)	6 (28.57%)
3	Small	15	13 (86.67%)	10 (66.67%)	5 (33.33%)
4	Semi-medium	10	8 (80.00%)	6 (60.00%)	2 (20.00%)
5	Medium	8	7 (87.50%)	5 (62.50%)	2 (25.00%)
6	Large	4	4 (100.00%)	3 (75.00%)	1 (25.00%)
	Total	**60**	**52 (86.67%)**	**38 (63.33%)**	**17 (28.33%)**

Milk Producers Confirming Visits of Veterinary Doctors, Para-vets, LDOs in Case of Emergency

The respondents' feedback on visits of veterinary doctors, paravets, or livestock development officers (LDOs) in case of emergency was gathered and is presented in Table 6C. Of the overall milk producers, 76.25% confirmed visits of doctors/paravets/LDOs in case of emergency. Dairy plants of both cooperative and private sectors provided this facility to their milk producers.

TABLE 6C

VISITS OF VETERINARY DOCTORS, PARAVETS, OR LDOs TO DAIRY FARMS IN CASES OF EMERGENCY.

Sl. no.	Category of milk producers	Total number of milk producers	Yes (%)	No (%)
1	Landless	3	2 (66.67)	1 (33.33)
2	Marginal	29	22 (75.86)	7 (24.14)
3	Small	20	15 (75.00)	5 (25.00)
4	Semi-medium	13	10 (76.92)	3 (23.08)
5	Medium	10	8 (80.00)	2 (20.00)
6	Large	5	4 (80.00)	1 (20.00)
	Total	**80**	**61 (76.25)**	**19 (23.75)**

Facilities Availed by Sample Milk Producers toward Animal Breeding:

The information pertaining to breeding facilities availed by milk producers has been collected, compiled, and presented in Table 6D. It can be seen from the table that an overall 35% of the milk producers availed the facility of natural insemination while 60% availed artificial insemination services for their animals.

TABLE 6D

ANIMAL BREEDING FACILITIES AVAILED BY SAMPLE MILK PRODUCERS.

Sl. no.	Category of milk producers	Total number of milk producers	Facilities availed by the milk producers toward animal breeding	
			Natural insemination	Artificial insemination
1	Landless	3	1 (33.33%)	2 (66.67%)
2	Marginal	29	11 (37.93%)	18 (62.07%)
3	Small	20	7 (35.00%)	13 (65.00%)
4	Semi-medium	13	4 (30.77%)	9 (69.23%)
5	Medium	10	3 (30.00%)	7 (70.00%)
6	Large	5	2 (40.00%)	3 (60.00%)
	Total	**80**	**28 (35.00%)**	**52 (65.00%)**

Response of Sample Milk Producers on Availability of Fodder

Since the success of a dairy farm depends to a large extent on the availability of both types of fodder (dry and green) throughout the year, the information related to the availability of fodder was obtained from milk producers and has been presented in Table 7. It may be seen from the table that overall, 90% of the milk producers could ensure the availability of dry fodder and 68.75% reported the availability of green fodder. All respondents from the large and medium categories could ensure the availability of dry fodder throughout the year but in case of green fodder, the percentage figures as reported by them were 80% and 70%, respectively.

TABLE 7

RESPONSES OF MILK PRODUCERS ON AVAILABILITY OF SUFFICIENT FODDER THROUGHOUT THE YEAR.

Sl. no.	Category of milk producers	Total number of milk producers	Dry fodder		Green fodder	
			Yes	No	Yes	No
1	Landless	3	2 (66.67%)	1 (33.33%)	2 (66.67%)	1 (33.33%)
2	Marginal	29	25 (86.21%)	4 (13.79%)	19 (65.52%)	10 (34.48%)
3	Small	20	18 (90.00%)	2 (10.00%)	14 (70.00%)	6 (30.00%)
4	Semi-medium	13	12 (92.31%)	1 (7.69%)	9 (69.23%)	4 (30.77%)
5	Medium	10	10 (100.00%)	–	7 (70.00%)	3 (30.00%)
6	Large	5	5 (100.00%)	–	4 (80.00%)	1 (20.00%)
	Total	**80**	**72 (90.00%)**	**8 (10.00%)**	**55 (68.75%)**	**25 (31.25%)**

Source and Cost of Procurement of Feed and Fodder

Feed and fodder constitute a major part of the cost incurred on rearing dairy animals. The information related to source of procurement was gathered from the milk producers and is presented in Table 7A. It may be observed from the table that overall, just 13.75% of the respondents formulated their own feed (concentrate) while 86.25% met their requirements through feed purchased either from the open market or from dairy plants/manufacturing units located in the vicinity. The overall average purchase cost of feeds was INR2,556.15 per quintal.

Further, the majority of sample milk producers (96.25%) reported meeting their fodder requirements from their own sources while a few (3.75%) among landless and marginal categories of milk producers purchased fodder from fellow farmers. The average per-quintal costs of dry fodder as reported by landless and marginal categories of milk producers were INR1,165 and INR1,162, respectively; while the costs of green fodder reported by them were INR165.50 and INR172.75, respectively.

TABLE 7A

SOURCES AND COSTS OF PROCUREMENT OF FEED AND FODDER.

Sl. no.	Category of milk producers	Total number of milk producers	Source of procurement of feed and its cost			Source of procurement of fodder and its cost			
			Own	Purchased	Average cost per quintal in INR	Own	Purchased	Average cost of dry fodder per quintal in INR	Average cost of green fodder per quintal in INR
1	Landless	3	1 (33.33%)	2 (66.67%)	2,560.80	2 (66.67%)	1 (33.33%)	1,165.00	165.50
2	Marginal	29	3 (10.34%)	26 (89.66%)	2,565.66	27 (93.10%)	2 (6.90%)	1,162.00	172.75
3	Small	20	2 (10.00%)	18 (90.00%)	2,570.75	20 (100.00%)	–	–	–
4	Semi-medium	13	2 (15.39%)	11 (84.61%)	2,568.33	13 (100.00%)	–	–	–
5	Medium	10	2 (20.00%)	8 (80.00%)	2,572.50	10 (100.00%)	–	–	–
6	Large	5	1 (20.00%)	4 (80.00%)	2,562.75	5 (100.00%)	–	–	–
	Total	**80**	**11 (13.75%)**	**69 (86.25%)**	**2,566.16**	**77 (96.25%)**	**3 (3.75%)**	**1,163.50**	**169.12**

Awareness among Milk Producers on Quality of Feed

The responses of sample milk producers with respect to the quality of feed have been complied and presented in Table 7B. It can be seen from the table that overall, 86.25% of the milk producers were well aware about the quality of feeds, while a significant proportion (13.75%) of respondents were not aware about the quality. The milk producers who had awareness about the quality of feed were further interviewed to know about the procurement system of feed, which is summarized in Table 7C. It may be observed from this table that the maximum percentage of milk producers (57.97%) had purchased feed from dairy societies; 36.23% had purchased only branded feed; and 5.79% had purchased directly from the manufacturing units located in their vicinity.

TABLE 7B

CATEGORY WISE RESPONSES OF MILK PRODUCERS HAVING AWARENESS ABOUT THE QUALITY OF FEED.

Sl. no.	Category of milk producers	Total number of milk producers	Yes (%)	No (%)
1	Landless	3	2 (66.67%)	1 (33.33%)
2	Marginal	29	26 (89.66%)	3 (10.34%)

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Sl. no.	Category of milk producers	Total number of milk producers	Yes (%)	No (%)
3	Small	20	18 (90.00%)	2 (10.00%)
4	Semi-medium	13	11 (84.62%)	2 (15.38%)
5	Medium	10	8 (80.00%)	2 (20.00%)
6	Large	5	4 (80.00%)	1 (20.00%)
	Total	**80**	**69 (86.25%)**	**11 (13.75%)**

TABLE 7C

SYSTEM FOR ENSURING THE QUALITY OF FEED.

Sl. no.	Category of milk producers	Total number of milk producers	Procured feed from societies	Purchased only standard brand feeds	Procured feed from manufacturing units
1	Landless	2	1 (50.00%)	1 (50.00%)	–
2	Marginal	26	15 (57.69%)	9 (34.62%)	2 (7.69%)
3	Small	18	11 (61.11%)	6 (33.33%)	1 (5.56%)
4	Semi-medium	11	6 (54.55%)	4 (36.36%)	1 (9.09%)
5	Medium	8	5 (62.50%)	3 (37.50%)	–
6	Large	4	2 (50.00%)	2 (50.00%)	–
	Total	**69**	**40 (57.97%)**	**25 (36.23%)**	**4 (5.79%)**

Awareness of Milk Producers on Recommended Feed and Fodder Doses

The awareness levels of respondent milk producers on recommended feed and fodder doses have been illustrated in Table 7D. It can be seen from this table that overall, around 65% of the respondents were well aware about the recommended feed and fodder doses. It can also be seen from this table that 80% of the milk producers from the large category were aware about the recommended feed and fodder doses for their animals, while in case of the landless category, only 33.33% of the milk producers had the knowledge about it. An increasing level of awareness was observed for the higher categories of milk producers.

TABLE 7D

AWARENESS STATUS OF RESPONDENTS ON RECOMMENDED FEED AND FODDER DOSES.

Sl. no.	Category of milk producers	Total number of milk producers	Feed and fodder	
			Aware	Not Aware
1	Landless	3	1 (33.33%)	2 (66.67%)
2	Marginal	29	18 (62.06%)	11 (37.94%)
3	Small	20	13 (65.00%)	7 (35.00%)
4	Semi-medium	13	9 (69.23%)	4 (30.74%)

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Sl. no.	Category of milk producers	Total number of milk producers	Feed and fodder	
			Aware	Not Aware
5	Medium	10	7 (70.00%)	3 (30.00%)
6	Large	5	4 (80.00%)	1 (20.00%)
	Total	**80**	**52 (65.00%)**	**28 (35.00%)**

Feeding System

Two types of feeding systems were reportedly prevalent in the study areas. Respondents were reported to be following stall feeding and a combination of stall feeding and grazing. It can be seen from Table 7E that overall, 87.50% of the milk producers were adopting stall feeding while the remaining 12.50% were adopting a combination of stall feeding and grazing. All the milk producers of medium and large categories were adopting only stall feeding. The corresponding figures were 92.31% for semi medium, 85.00% for small, 82.76% for marginal, and 66.67% for landless categories.

TABLE 7E

RESPONSES OF MILK PRODUCERS ON ADOPTION OF FEEDING SYSTEMS.

Sl. no.	Category of milk producers	Total number of milk producers	Feeding system adopted	
			Stall feeding	Stall feeding and grazing
1	Landless	3	2 (66.67%)	1 (33.33%)
2	Marginal	29	24 (82.76%)	5 (17.24%)
3	Small	20	17 (85.00%)	3 (15.00%)
4	Semi-medium	13	12 (92.31%)	1 (7.69%)
5	Medium	10	10 (100.00%)	–
6	Large	5	5 (100.00%)	–
	Total	**80**	**70 (87.50%)**	**10 (12.50%)**

Quantity of Fodder and Feed Fed to Milch Animals

The information pertaining to the quantity of fodder and feed fed to milch animals was collected from milk producers from various categories and has been illustrated in Table 7F and Table 7G. It can be observed from Table 7F that overall, 10.86 kg of dry fodder was given to a buffalo per day, 8.58 kg to a crossbred cow, and 7.80 kg to a local cow. Similarly, in case of green fodder, 13.80 kg per day was given to the buffalo, 12.49 kg to the crossbred cow, and 10.88 kg to the local cow.

Further, as may be seen from Table 7G, the per-day quantity of feed (concentrate) fed to the crossbred cow was the highest in both milking and dry days (4.70 kg and 2.14 kg), followed by the buffalo (3.17 kg and 1.42 kg), and the local cow (2.56 kg and 1.13 kg). Although the quantity of feed being given to various breeds of animals is based on their milk production, it varied from category to category depending on the economic condition of the milk producers. It was found to be the lowest in cases of local cows, crossbred cows, and buffaloes maintained by the landless category of milk producers.

TABLE 7F

QUANTITY OF FODDER AND FEED FED TO MILCH ANIMALS IN KG PER DAY.

Sl. no.	Category of milk producers	Total number of milk producers	Quantity of dry fodder			Quantity of green fodder		
			Local cows	Crossbred cows	Buffaloes	Local cows	Crossbred cows	Buffaloes
1	Landless	3	7.50	8.33	10.65	10.75	12.20	13.75
2	Marginal	29	7.68	8.45	10.80	10.90	12.35	13.80
3	Small	20	7.60	8.50	10.75	10.85	12.50	13.70
4	Semi-medium	13	7.75	8.70	10.90	10.95	12.60	13.90
5	Medium	10	7.80	8.65	10.85	10.88	12.75	13.85
6	Large	5	7.70	8.85	10.70	10.80	12.55	13.82
	Total	**80**	**7.67**	**8.58**	**10.78**	**10.86**	**12.49**	**13.80**

TABLE 7G

QUANTITY OF FEED FED TO MILCH ANIMALS IN KG PER DAY PER ANIMAL.

Sl. no.	Category of milk producers	Total number of milk producers	During lactation period			During dry period		
			Local cows	Crossbred cows	Buffaloes	Local cows	Crossbred cows	Buffaloes
1	Landless	3	2.20	4.30	2.90	1.00	2.00	1.30
2	Marginal	29	2.35	4.45	3.00	1.10	2.10	1.35
3	Small	20	2.55	4.60	3.15	1.12	2.15	1.40
4	Semi-medium	13	2.68	4.85	3.23	1.09	2.12	1.43
5	Medium	10	2.75	4.98	3.30	1.20	2.20	1.50
6	Large	5	2.85	5.00	3.45	1.25	2.25	1.55
	Total	**80**	**2.56**	**4.70**	**3.17**	**1.13**	**2.14**	**1.42**

Breed-wise Estimation of Annual Milk Production per Animal

To estimate the milk yield, information on average lactation yield for each milch animal was collected from milk producers. Lactation yield is one of the important economic indicators since it is milk production that brings returns to milk producers. Lactation yield of different types of milch animals for various categories of milk producers has been estimated to judge productivity of animals and has been presented in Table 7H. It may be observed from the table that the overall average lactation yield per animal was the highest (5,318.33 liter) for a crossbred cow followed by the buffalo (2,871.08 liter), and the local cow (1,870.82 liter).

Further, among the different categories of milk producers, the lactation yield of crossbred cows was lowest (5,228.22 liter) in case of landless milk producers compared with other categories of dairy farmers. The lower lactation yield in case of landless milk producers could be due to poor genetic potential of crossbred cows and poor feeding and management practices followed by this category of cattle keepers.

Similarly, among different categories of milk producers, the lactation yield of buffaloes was the highest (2,955.10 liter) for the category of large milk producers. This may be due to the fact that this category of milk producers had better resources and good quality of animals and was also providing quality fodder and feeds to their animals. Further, in case of local cows, the highest lactation yield (1,899.23 liter) was reported by the marginal category of milk producers (see Table 7H).

TABLE 7H

BREED WISE ANNUAL MILK PRODUCTION PER ANIMAL IN LITER.

Sl. no.	Category of milk producers	Local cows	Crossbred cows	Buffaloes
1	Landless	1,885.35	5,228.22	2,795.45
2	Marginal	1,899.23	5,282.40	2,789.25
3	Small	1,868.25	5,327.15	2,840.60
4	Semi-medium	1,879.20	5,329.21	2,910.25
5	Medium	1,860.29	5,360.65	2,935.80
6	Large	1,832.62	5,382.36	2,955.10
	Total	**1,870.82**	**5,318.33**	**2,871.08**

Proportion of Fat in Different Breeds of Milch Animals

The average percentage of fat in different types of milk as reported by the respondent milk producers has been calculated category wise and the outcome is presented in Table 7I. It may be observed from the table that the highest overall percentage of fat was reported by the sample milk producers in case of buffalo milk (6.88%); followed by local cow milk (4.88%); and crossbred cow milk (4.23%).

TABLE 7I

PERCENTAGE OF FAT IN MILK OF DIFFERENT BREEDS OF MILCH ANIMALS.

Sl. no.	Category of milk producers	Local cows	Crossbred cows	Buffaloes
1	Landless	4.75	3.98	6.60
2	Marginal	4.80	4.10	6.78
3	Small	4.89	4.18	6.85
4	Semi-medium	4.92	4.33	6.92
5	Medium	4.96	4.38	7.00
6	Large	4.98	4.40	7.15
	Total	**4.88**	**4.23**	**6.88**

Marketing of Milk

The success of dairy farming depends on the marketing facilities available to milk producers. Since milk is a highly perishable commodity, it requires quick sale or conversion into milk products at the farm level. The sample milk producers use different marketing channels to sell milk. They sell their milk either through primary-level milk producers' cooperative societies (PMPCS) or through private vendors as well as village-level commission agents. A few milk producers who were located in the vicinity of a dairy plant, sold their milk directly to the plant. It was observed that cooperative-sector dairy plants form the PMPCS at the village level to facilitate the milk producers in selling their milk as per their by-laws while private-sector dairy plants do not generally constitute such societies and instead procure milk through village-level commission agents or private vendors. Earlier, the private venders purchased milk from the doorsteps of milk producers, but now they also have single collection points where milk producers have to reach for pouring their milk.

From each identified dairy, 10 milk producers were selected randomly for in-depth study. Of the total milk producers that were selected from five cooperative dairy plants, 62.50% were selling milk though their respective PMPCS. However, the remaining 37.50% milk producers who were associated with the three private dairy plants, were selling their milk through village-level commission agents at designated places. Further, it was also informed by the sample milk producers that they were selling their milk based on fat and SNF parameters.

Time Taken in Supplying Milk

The time taken by milk producers in supplying milk to the next link in the chain, which can be a milk collection center, private vender/village-level commission agent, or dairy plant, varied from less than 15 minutes to up to 30 minutes. Accordingly, the time taken to supply milk as reported by milk producers has been compiled and presented in Table 7K. It can be seen from the table that 88.75% of the respondents reportedly took less than 15 minutes to supply milk to the next link in the chain. The remaining 11.25% respondents were reportedly supplying milk to the next chain within 30 minutes.

TABLE 7K

TIME TAKEN BY MILK PRODUCERS IN SUPPLYING MILK TO THE NEXT LINK IN THE CHAIN.

Sl. no.	Category of milk producers	Number of respondents	Less than 15 minutes	15 to 30 minutes
1	Landless	3	2 (66.67%)	1(33.33%)
2	Marginal	29	26 (89.66%)	3 (10.34%)
3	Small	20	18 (90.00%)	2 (20.00%)
4	Semi-medium	13	12 (92.30%)	1 (7.70%)
5	Medium	10	9 (90.00%)	1 (10.00%)
6	Large	5	4 (80.00%)	1 (20.00%)
	Total	**80**	**71 (88.75%)**	**9 (11.25%)**

Sales Price of Milk

Most of the dairy plants, in both cooperative and private sectors, were procuring milk from farmers through PMPCS/village-level commission agents based on the fat and SNF available in milks of different types of animals. Information in this regard was collected from the farmers and has been presented in Table 7L. It can be seen from the table that the overall sales price of milk was the highest (INR46.86 per liter) in case of buffaloes and lowest (INR36.21 per liter) in case of crossbred cows. Further, among the various categories of milk producers, it was higher in the category of large producers for all types of milch animals.

TABLE 7L

SALES PRICE OF MILK IN INR PER LITER.

Sl. no.	Category of milk producers	Local cows	Crossbred cows	Buffaloes
1	Landless	44.25	35.88	46.60
2	Marginal	44.30	36.12	46.73
3	Small	44.39	36.18	46.75
4	Semi-medium	44.52	36.32	46.98
5	Medium	44.69	36.38	47.00
6	Large	44.74	36.40	47.10
	Total	**44.48**	**36.21**	**46.86**

Frequency of Payment

Various payment cycles have been reported by the sample respondents. The responses have been compiled for durations up to 10 days and for 11 to 20 days. It can be seen from Table 7M that the majority of overall respondents (83.75%) reportedly realized payments within 10 days while the remaining 16.25% received payments within 11 to 20 days. None of the respondents from any of the categories reported to have received payments after 20 days. Further, it was informed by the milk producers who are pouring milk at the cooperative societies that they were getting payments in their respective accounts while those who were selling milk to private dairies were getting payments in cash through village-level commission agents.

TABLE 7M

FREQUENCY OF PAYMENTS.

Sl. no.	Category of milk producers	Number of respon-dents	Up to 10 days	11 to 20 days
1	Landless	3	2 (66.67%)	1(33.33%)
2	Marginal	29	23 (79.31%)	6 (20.69%)
3	Small	20	18 (90.00%)	2 (20.00%)
4	Semi-medium	13	11(84.62%)	2 (15.38%)
5	Medium	10	9 (90.00%)	1 (10.00%)
6	Large	5	4 (80.00%)	1 (20.00%)
	Total	**80**	**67 (83.75%)**	**13 (16.25%)**

Annual Income from Dung

The information related to the production of dung and its sales value was obtained from the milk producers, and is presented in Table 7N. It can be seen from this table that the overall production of dung and its value were the highest (64.17 quintal and INR1,4398.46) in case of buffaloes, followed by crossbred cows (37.11 quintal and INR7,892.16) and local cows (35.15 quintal and INR7,477.61). A similar trend may be observed among various categories of milk producers.

TABLE 7N

ANNUAL INCOME FROM DUNG.

Sl. no.	Category of milk producers	Local cows			Crossbred cows			Buffaloes		
		Production in quintal	Rate in INR	Total cost in INR	Production in quintal	Rate in INR	Total cost in INR	Production in quintal	Rate in INR	Total cost in INR
1	Landless	33.85	208.12	7,044.86	36.30	209.25	7,595.78	61.70	215.20	13,277.84
2	Marginal	34.65	210.20	7,283.43	36.85	210.50	7,756.93	63.80	218.40	13,933.92
3	Small	35.15	212.35	7,464.10	36.98	212.28	7,850.11	62.56	222.35	13,910.22
4	Semi-medium	35.50	214.60	7,618.30	37.15	213.20	7,920.38	64.15	227.75	14,610.16
5	Medium	35.80	215.30	7,707.74	37.60	215.40	8,099.04	65.20	232.10	15,132.92
6	Large	35.95	215.50	7,747.23	37.80	215.10	8,130.78	67.65	230.50	15,593.33
	Total	**35.15**	**212.68**	**7,477.61**	**37.11**	**212.62**	**7,892.17**	**64.17**	**224.38**	**14,398.46**

Respondents Desirous of Expanding Dairy Activities

The information related to the respondents desirous for expanding their dairy activities has been collected and presented category wise in Table 8. It can be seen from the table that overall, 82.50% of the respondents have expressed their willingness to expand dairy farming activities. Among various categories, it can be seen from the table that 100% of landless milk producers have reported their desire for expanding their dairy farming activities. The least interest for expanding these activities was expressed by the category of large milk producers. It is observed that there is a trend of decreasing interest with the increase in the category level of milk producers.

TABLE 8

RESPONDENTS DESIROUS OF EXPANDING DAIRY ACTIVITIES.

Sl. no.	Category of milk producers	Total number of milk producers	Respondents desirous of expanding dairy activities	
			Yes	No
1	Landless	3	3 (100.00%)	0 (0.00%)
2	Marginal	29	25 (86.21%)	4 (13.79%)
3	Small	20	17 (85.00%)	3 (15.00%)
4	Semi-medium	13	11 (84.62%)	2 (15.38%)
5	Medium	10	7 (70.00%)	3 (30.00%)
6	Large	5	3 (60.00%)	2 (40.00%)
	Total	**80**	**66 (82.50%)**	**14 (17.50%)**

Reasons Explained by Milk Producers to Expand Dairy Activities

The responses received from milk producers to expand dairy farming have been compiled and presented in Table 8A. It can be seen from the table that overall, 81.82% of the respondents said that dairy farming being a profitable venture was the prime reason for their willingness to expand dairy activities. The other most important reasons cited by the respondents were better utilization of spare time (78.79%); better utilization of crop residues (77.27%); and difficulty in sustaining on land alone (58.75%).

TABLE 8A

REASONS STATED BY MILK PRODUCERS FOR EXPANDING DAIRY FARMING.

Sl. no.	Category of milk producers	Total no. of milk producers	Number of respondents wanting to expand dairy activities	Reasons cited for expanding dairy activities			
				Dairy farming is profitable	Difficult to sustain on land alone	Better utilization of available spare time	Better utilization of crop residues
1	Landless	3	3	3 (100.00%)	–	3 (100.00%)	–
2	Marginal	29	25	22 (88.00%)	24 (96.00%)	20 (80.00%)	17 (58.62%)
3	Small	20	17	14 (82.35%)	14 (82.35%)	16 (94.12%)	15 (88.24%)
4	Semi-medium	13	11	8 (72.73%)	9 (81.82%)	7 (63.63%)	10 (90.91%)
5	Medium	10	7	5 (71.43%)	–	5 (71.43%)	6 (85.71%)
6	Large	5	3	2 (66.67%)	–	1 (33.33%)	3 (100.00%)
	Total	**80**	**66**	**54 (81.82%)**	**47 (58.75%)**	**52 (78.79%)**	**51 (77.27%)**

Reasons for not Expanding Dairy Activities

The reasons for not expanding dairy activities as expressed by those milk producers who were not interested have been summarized in Table 8B. It can be seen from the table that out of 14 milk producers who were not interested in expanding dairy activities, 10 (71.43%) respondents attributed the reason of non-availability of fodder, especially green fodder, throughout the year. The second-most important reason as expressed by eight (57.14%) milk producers was inadequate availability of veterinary service, followed by lack of time for dairy farming stated by six producers (42.86%); and crop production being enough to sustain as cited by five respondents (35.71%).

TABLE 8B

REASONS STATED BY MILK PRODUCERS FOR NOT EXPANDING DAIRY FARMING.

Sl. no.	Category of milk producers	Total no. of milk producers	Number of respondents who were not interested to expand dairy activities	Reasons for not expanding dairy activities			
				Inadequate availability of fodder	Crop production is enough to sustain	Lack of time for dairy farming	Inadequate availability of veterinary services
1	Landless	3	NA	NA	NA	NA	NA
2	Marginal	29	4	4 (100%)	–	1 (25%)	3 (75%)
3	Small	20	3	3 (100%)	–	1 (33.33%)	2 (66.67%)
4	Semi-medium	13	2	2 (100%)	1 (50%)	1 (50%)	1 (50%)

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Sl. no.	Category of milk producers	Total no. of milk producers	Number of respondents who were not interested to expand dairy activities	Reasons for not expanding dairy activities			
				Inadequate availability of fodder	Crop production is enough to sustain	Lack of time for dairy farming	Inadequate availability of veterinary services
5	Medium	10	3	1 (33.33%)	2 (66.67%)	1 (33.33%)	1 (33.33%)
6	Large	5	2	–	2 (100%)	2 (100%)	1 (50%)
	Total	**80**	**14**	**10 (71.43%)**	**5 (35.71%)**	**6 (42.86%)**	**8 (57.14%)**

Facilities Expected to Expand Dairy Farming

Various facilities have been demanded by the milk producers to expand their dairy farming activities. The details in this regard have been presented in Table 8C. It can be seen from the table that 72.73% of the milk producers expressed the availability of easy loan facility as the prerequisite for expanding dairy activities; 75.76% demanded availability of crossbred cows; 54.55% desired an ensured supply of fodder; 66.67% wanted veterinary and AI facilities; 83.33% wanted to have disease diagnostic facilities at their doorsteps; and 69.70% required insurance of their animals.

TABLE 8C

FACILITIES EXPECTED FOR EXPANDING DAIRY FARMING.

Sl. no.	Category of milk producers	No. of respondents desirous for expanding dairy activities	Facilities expected by respondents					
			Easy loan facility	Availability of crossbred animals	Ensured availability of fodder	Veterinary and AI facilities	Disease diagnostic facilities at doorsteps	Insurance of animals
1	Landless	3	3 (100.00%)	2 (66.67%)	3 (100.00%)	3 (100.00%)	2 (66.67%)	3 (100.00%)
2	Marginal	25	22 (88.00%)	19 (76.00%)	17 (68.00%)	15 (60.00%)	20 (80.00%)	20 (80.00%)
3	Small	17	12 (70.59%)	14 (82.35%)	10 (58.82%)	11 (64.71%)	15 (88.24%)	13 (76.47%)
4	Semi-medium	11	7 (63.64%)	9 (81.82%)	6 (54.55%)	8 (72.73%)	9 (81.82%)	7 (63.64%)
5	Medium	7	3 (42.86%)	5 (71.43%)	–	5 (71.43%)	6 (85.71%)	2 (28.57%)
6	Large	3	1 (33.33%)	1 (33.33%)	–	2 (66.67%)	3 (100.00%)	1 (33.33%)
	Total	**66**	**48 (72.73%)**	**50 (75.76%)**	**36 (54.55%)**	**44 (66.67%)**	**55 (83.33%)**	**46 (69.70%)**

Extension Programs Attended by Sample Milk Producers

Extension programs in the dairy sector are being organized by various organizations such as the Department of Dairy Development; dairy plants; and manufacturers of animal feed (*pashu aahar*), minerals, veterinary medicines, and hormones. The information pertaining to the extension program attended by respondents has been presented in Table 8D. It may be observed from the table that the majority of the milk producers (75.00%) have reportedly attended these extension programs.

TABLE 8D

MILK PRODUCERS ATTENDING EXTENSION PROGRAMS.

Sl. no.	Category of milk producers	Total number of milk producers	No. of milk producers that attended the extension programs	
			Yes	No
1	Landless	3	2 (66.67%)	1 (33.33%)
2	Marginal	29	21 (72.41%)	8 (27.59%)
3	Small	20	15 (75.00%)	5 (25.00%)
4	Semi-medium	13	10 (76.92%)	3 (23.08%)
5	Medium	10	8 (80.00%)	2 (20.00%)
6	Large	5	4 (80.00%)	1 (20.00%)
	Total	**80**	**60 (75.00%)**	**20 (25.00%)**

Milk Production, Consumption, and Marketed Surplus

Milk, unlike most other farm products, is highly perishable, and as such requires quick disposal or conversion into milk products. Therefore, it becomes imperative to examine the production and marketing of milk. The assessment of this parameter is important not only from the producer's viewpoint but is of greater importance to the dairy plants that plan their milk procurement strategies on the basis of such information in their respective areas.

In addition to the type of milch animals, the total production of milk in a household depends on the proportion of animals in milk. Higher milk production does not necessarily mean higher marketed surplus of milk. However, increase in milk production would definitely be more beneficial from the consumer's point of view. The average production vis-à-vis availability of marketed surplus per household has been worked out for different categories of households and presented in Table 8E. The marketed surplus has been computed by deducting the consumption per household from the production figures arrived for different categories of households. It can be seen from the table that overall, highest marketed surplus is available for crossbred cow milk (5,223.96 kg), followed by buffalo milk (2,813.59 kg), and local cow milk (1,738.66 kg). The reason can be attributed to the fact that milk yield in case of crossbred cows is higher and the consumer preference is comparatively lower due to the lower percentage of fat available in milk.

TABLE 8E

BREED-WISE ANNUAL MILK PRODUCTION, CONSUMPTION. AND MARKETED SURPLUS PER ANIMAL IN LITER.

Sl. no	Category of milk producers	Local cows			Crossbred cows			Buffaloes		
		Production	Consumption	Marketed surplus	Production	Consumption	Marketed surplus	Production	Consumption	Marketed surplus
1	Landless	1,885.35	98.50	1,786.85	5,228.22	65.33	5,162.89	2,795.45	45.33	2,750.12
2	Marginal	1,899.23	112.25	1,786.98	5,282.40	82.15	5,200.25	2,789.25	50.29	2,738.96

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Sl. no	Category of milk producers	Local cows			Crossbred cows			Buffaloes		
		Production	Consump-tion	Marketed surplus	Production	Consump-tion	Marketed surplus	Production	Consump-tion	Marketed surplus
3	Small	1,868.25	128.62	1,739.63	5,327.15	94.20	5,232.95	2,840.60	52.50	2,788.10
4	Semi-medium	1,879.20	145.21	1,733.99	5,329.21	105.65	5,223.56	2,910.25	58.60	2,851.65
5	Medium	1,860.29	152.60	1,707.69	5,360.65	108.40	5,252.25	2,935.80	65.40	2,870.40
6	Large	1,832.62	155.80	1,676.82	5,382.36	110.50	5,271.86	2,955.10	72.80	2,882.30
	Total	**1,870.82**	**132.16**	**1,738.66**	**5,318.33**	**94.37**	**5,223.96**	**2,871.08**	**57.49**	**2,813.59**

Parameters for Computation of Cost of Milk Production

The cost of milk production is one of the most important parameters having a direct bearing on the economics of a dairy enterprise. The cost of milk production can be the only reliable basis for price fixation. Income from dairy farming can be enhanced either by increasing the milk yield and/or by reducing the cost of milk production. The second alternative can be achieved through judicious use of various inputs employed in dairying. The cost of milk production is a function of milk yield and maintenance cost of milch animals. Various expenditures were reportedly incurred on different resources necessary for milk production by milk producers. The details on various cost components, i.e., fixed costs and variable costs that add to the per unit cost of milk production have been discussed below.

- **Variable cost:** The variable cost comprises expenses on dry fodder, green fodder, concentrate, human labor, and veterinary expenses. The variable expenses incurred on fodder and feed, besides labor and veterinary costs, were estimated per milch animal.

- **Feed and fodder cost:** The value of purchased feed and fodder, besides that of own feed and fodder, were valued at the prevailing market price as reported by the respondents and computed for the quantity fed per milch animal.

- **Labor cost:** The value of hired labor was recorded as reported by the milk producers, while family labor was valued at average wage rate of permanent labor prevalent in the area and computed per milch animal. Everyday time devoted by men, women, and children in dairy activities was converted into standard man hours.

- **Veterinary expenses:** The actual expenses incurred on healthcare, veterinary medicines, and vaccination of animals was recorded using personal enquiry method and computed per milch animal.

- **Other expenses:** Although the other expenses reported by milk producers were almost dismal and insignificant when computed on per milch animal basis, they were also included as miscellaneous expenses under the variable cost.

- **Fixed cost:** Fixed cost refers to those costs that remain unchanged over a short period of time. Cost components included here for computing fixed costs include depreciation on fixed assets like animals, cattle sheds and stores, dairy equipment, and interest on fixed capital.

The depreciation on animals, cattle sheds, and dairy equipment was worked out using the straight line method. Annual depreciation on cattle shed and stores was calculated at the rate 2% for *pucca* sheds and at the rate of 5% for *katcha* sheds, assuming useful life of the shed buildings to be 50 years and 20 years, respectively. In case of milch animals, 10% depreciation was charged annually separately for different milch animals. The depreciation on equipment and machinery was computed individually depending on the respective useful life. The average productive life of local cows as well as of crossbred cows was considered 10 years and that of buffaloes 12 years.

Estimation of Cost of Milk Production

In order to estimate the cost of producing one liter of milk, the total annual maintenance cost per milch animal was computed and divided by total lactation yield per milch animal for the respective breed.

Fodder and Feeds

The success of dairy farms depends to a large extent on the various cost components and shares of those components in the total cost. Feeds and fodders have major shares in the total input costs, therefore the fodder and feed consumption and the expenses incurred on feeding are essential components from a cost point of view. The feeding practices did not vary with season, because dry fodder, green fodder, and concentrate were fed in all the seasons throughout the year. Only slight variations were visible in their consumption patterns during lactation and dry days.

The milk producers/dairy farmers who were members of PMPCS mostly received the compound feed or *pashu aahar* of different brands through their respective societies. Similarly, private dairy plants were also supplying the compound feed to their milk producers through village-level commission agents.

The importance of adequate quantity of quality fodders and feed for achieving substantial increase in milk production can hardly be overemphasized. Milch animals can exhibit their full genetic potential only under adequate and balanced feeding and management conditions. The study of feeding practices is thus of utmost importance before embarking upon the economic analysis of the dairy enterprise.

The quantity of fodder and feed per day per animal depends on the milk production and financial position of the farmer. The cattle keepers or milk producers in the study generally fed relatively more dry fodder, green fodder, and concentrate during the milking period compared with the dry periods. Small quantities of concentrates were reportedly given by only a few farmers in the dry period. In order to arrive at the total expenditure on feeding dry fodder, green fodder, and concentrate mixture/compound to various breeds of cows and buffaloes by famers category wise, the quantities have been converted into equivalent values depending on the prevailing market prices of individual constituents. The average expenditures incurred on dry fodder, green fodder, and concentrate as reported by sample respondents is presented in Table 9A.

It can be seen from this table that the overall annual costs of dry fodder and green fodder were the highest per animal (INR45,760.56 and INR8,311.05, respectively) in case of buffaloes while they were the lowest (INR32,558.77 and INR6,540.44, respectively) in case of local cows. Further, the overall annual feed cost for all categories of milk producers in the reference year was the highest for crossbred cows (INR30,748.18 per animal) and the lowest for local cows (INR21,840.71 per animal). The annual feed cost for buffaloes was in between at INR27,617.85.

It can also be seen from this table that the contribution of concentrates in the total feed cost was the highest across all categories of milch animals. The reason can be attributed to the availability of insufficient and poor quality of green fodder, which is generally compensated by higher doses of concentrates by milk producers. Dry fodder constitutes the second major ingredient in the feed of milch animals.

TABLE 9A

EXPENDITURE INCURRED ON DRY FODDER, GREEN FODDER, AND CONCENTRATE IN INR PER YEAR.

Sl. no.	Category of milk producers	Local cows			Crossbred cows			Buffaloes		
		Dry Fodder	Green Fodder	Feed	Dry Fodder	Green Fodder	Feed	Dry Fodder	Green Fodder	Feed
1	Landless	31,837.13	6,474.19	17,624.14	35,360.43	7,347.45	35,653.53	45,208.72	8,280.94	24,677.58
2	Marginal	32,601.22	6,564.53	19,251.08	35,869.83	7,437.79	36,304.01	45,845.46	8,311.05	25,973.57
3	Small	32,261.62	6,534.41	21,613.98	36,082.08	7,528.13	38,503.69	45,633.21	8,250.83	27,565.21
4	Semi-medium	32,898.36	6,594.64	22,990.90	36,931.07	7,588.35	40,390.00	46,269.96	8,371.28	28,408.18
5	Medium	33,110.61	6,552.48	24,217.26	36,718.82	7,678.69	42,114.75	46,057.71	8,341.16	29,208.35
6	Large	32,686.12	6,504.30	25,999.06	37,567.81	7,558.24	41,971.92	45,420.97	8,323.10	30,110.92
	Total	**32,558.77**	**6,540.44**	**21,840.71**	**36,421.67**	**7,522.10**	**39,156.65**	**45,760.56**	**8,311.05**	**27,617.85**

Labor Cost

Labor is another important component of cost in the maintenance of animals. Dairying is a labor-intensive enterprise under Indian conditions. Labor is required for feeding, cleaning, milking, and looking after the animal. Dairying provides regular employment throughout the year. Here, the hired labor was valued as per the prevailing wage rate in the locality while family labor was valued as per the average wage of permanent labor.

It may be observed from Table 9B that the overall average annual labor cost per milch animal was the highest (INR6,418.34) in case of crossbred cows, followed by buffaloes (INR6,302.63) and local cows (INR5,466.93). This is attributed to the fact that local cows do not need constant care and attention when compared with crossbreds and buffaloes. Rather, in practice, local cows are generally ignored.

TABLE 9B

CATEGORY-WISE LABOR COST INCURRED FOR MAINTAINING THE MILCH ANIMALS IN INR PER YEAR.

Sl. no.	Category of milk producers	Local cows	Crossbred cows	Buffaloes
1	Landless	5,595.61	6,615.73	6,423.83
2	Marginal	5,587.54	6,518.97	6,370.35
3	Small	5,528.93	6,488.78	6,387.76
4	Semi-medium	5,436.60	6,355.96	6,274.96

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Sl. no.	Category of milk producers	Local cows	Crossbred cows	Buffaloes
5	Medium	5,435.35	6,294.99	6,185.18
6	Large	5,217.52	6,235.59	6,173.70
	Total	**5,466.93**	**6,418.34**	**6,302.63**

Veterinary Cost

Veterinary aid for animals is essential to prevent production losses and maintain precious animal health to obtain the desired results. Milk production could be increased by rejuvenating livestock health through systematic and scientific methods of breeding, upkeep of animals, and disease control. By and large, milk producers have been getting veterinary aids from veterinary hospitals, dispensaries, and livestock centers situated either in villages or in the vicinity. Some milk producers associated with the cooperative sector have also been availing veterinary aid from mobile veterinary dispensaries. Each mobile unit covers certain villages on a fixed route once a week and treats the milch animals belonging to members of the respective dairy cooperative society. Emergency treatment is also reportedly arranged for animals by these units as and when required on the request of milk producers. On a similar pattern, private dairy plants also provide veterinary services to their milk producers. Both cooperative and private dairy plants are creating awareness among the milk producers on breeding, feeding, and proper management of animals.

It can be seen from Table 9C that the overall expenditure incurred on medicines and veterinary charges was the highest (INR858.27) in case of crossbred cows and the lowest (INR390.06) in case of local cows. Among the various categories of milk producers, the highest amount on medicines/ veterinary cost was spent by the category of large milk producers for all types of milch animals. This suggests that large milk producers took more care of their animals compared with other categories of milk producers. It also indicates that dairy farmers of this category were more conscious about the need for veterinary and healthcare services.

TABLE 9C

CATEGORY-WISE MEDICINE COSTS INCLUDING VETERINARY CHARGES IN INR PER YEAR.

Sl. no.	Category of milk producers	Local cows	Crossbred cows	Buffaloes
1	Landless	350.60	820.67	450.33
2	Marginal	365.80	835.45	472.67
3	Small	390.45	852.20	485.22
4	Semi-medium	405.62	868.60	512.55
5	Medium	412.15	880.25	504.70
6	Large	415.75	892.50	525.80
	Total	**390.06**	**858.27**	**491.88**

Category-wise Costs of Minerals and RGBH

Minerals and RGBH have played an important role in enhancing milk production as well as growth of the milch animals. The information related to the use of minerals and RGBH was gathered from the milk producers and has been presented in Table 9D. It can be seen from the table that overall, the highest expenditure of INR424.73 was incurred in case of crossbred cows and the lowest (INR404.21) in case of local cows.

TABLE 9D

CATEGORY-WISE EXPENDITURE ON MINERALS AND RGBH IN INR.

Sl. no.	Category of milk producers	Local cows	Crossbred cows	Buffaloes
1	Landless	–	–	–
2	Marginal	398.20	820.35	408.30
3	Small	395.40	817.64	412.45
4	Semi-medium	405.80	822.50	415.60
5	Medium	408.45	825.60	418.40
6	Large	413.22	837.55	432.80
	Total	**404.21**	**824.73**	**417.51**

Annual Premium Paid by Milk Producers toward Insurance

The information related to the premium amount paid toward insurance was obtained from the milk producers from various categories and is presented in Table 9E. It can be seen from this table that overall, the maximum premium amount (INR1,744.70) was paid by the milk producers for buffaloes while the minimum amount (INR793.33) was paid for local cows.

TABLE 9E

ANNUAL PREMIUM AMOUNT PAID BY MILK PRODUCERS TOWARD INSURANCE IN INR.

Sl. no.	Category of milk producers	Local cows	Crossbred cows	Buffaloes
1	Landless	718.75	1,037.50	1,663.12
2	Marginal	737.50	1,049.37	1,917.00
3	Small	781.25	1,058.75	1,722.50
4	Semi-medium	820.00	1,086.75	1,756.25
5	Medium	840.00	1,109.37	1,812.00
6	Large	862.50	1,131.25	1,843.75
	Total	**793.33**	**1,078.75**	**1,744.70**

Annual Miscellaneous Cost per Animal

The information related to miscellaneous expenditure incurred on electricity charges, ropes/chains, water charges (if any), etc. was ascertained from milk producers of various categories and presented in Table 9F. It can be seen from this table that overall, the maximum annual expenditure (INR781.13) was incurred in case of crossbred cows while the minimum expenditure (INR454.61) was in case of local cows.

TABLE 9F

ANNUAL MISCELLANEOUS COST PER ANIMAL IN INR.

Sl. no.	Category of milk producers	Local cows	Crossbred cows	Buffaloes
1	Landless	442.60	775.50	453.25
2	Marginal	448.15	765.40	458.80
3	Small	452.40	780.30	465.56
4	Semi-medium	460.75	785.65	468.20
5	Medium	458.20	790.68	470.60
6	Large	465.54	789.22	468.30
	Total	**454.61**	**781.13**	**464.12**

Estimation of Fixed Costs

Depreciation

Depreciation can be understood as the loss of an asset's value due to its use over time. The detailed analysis of depreciation with respect to the categories of dairy farmers and types of milch animals has been calculated and given in Table 10A. It can be seen from the table that overall depreciation per animal was the highest in case of buffaloes (INR5,913.37), followed by crossbred cows (INR4,315.00) and local cows (INR3,173.33).

TABLE 10A

DEPRECIATION COSTS ON VARIOUS ITEMS IN INR.

Sl. no.	Category of milk producers	Milch animals			Cattle sheds and dairy equipment		
		Local cows at the rate of 10%	Crossbred cows at the rate of 10%	Buffaloes at the rate of 8.33%	Cattle sheds	Chaff cutters	Milking machines
1	Landless	2,875.00	4,150.00	5,541.53	–	371.63	–
2	Marginal	2,950.00	4,197.50	5,564.44	613.25	286.38	1,141.26
3	Small	3,125.00	4,235.00	5,739.37	573.50	229.49	969.22
4	Semi-medium	3,280.00	4,345.00	5,853.91	489.33	166.33	717.36
5	Medium	3,360.00	4,437.50	6,037.58	651.39	200.41	874.26
6	Large	3,450.00	4,525.00	6,143.38	1,405.56	405.67	1,937.28
	Total	**3,173.33**	**4,315.00**	**5,813.37**	**746.61**	**276.65**	**1,127.87**

Total Annual Depreciation Cost Per Animal

The total deprecation cost per animal was calculated by adding the depreciation costs of cattle shed, chaff cutter, and milking machine to the depreciation cost of the given type of animal. A detailed analysis of total depreciation cost with respect to various categories of dairy farmers has been given in Table 10B. It can be seen from Table 10B that overall, the depreciation cost was the highest in case of buffaloes (INR7,964.50), followed by crossbred cows (INR6,466.13) and local cows (INR5,324.46).

TABLE 10B

TOTAL ANNUAL DEPRECIATION COST PER ANIMAL.

Sl. no.	Category of milk producers	Local cows	Crossbred cows	Buffaloes
1	Landless	3,246.63	4,521.63	5,913.16
2	Marginal	4,990.89	6,238.39	7,605.33
3	Small	4,897.21	6,007.21	7,511.58
4	Semi-medium	4,653.02	5,718.02	7,226.93
5	Medium	5,086.06	6,163.56	7,763.64
6	Large	7,198.51	8,273.51	9,891.89
	Total	**5,324.46**	**6,466.13**	**7,964.50**

Interest on Fixed Capital

Interest on fixed capital was calculated at the rate of 10% for different types of milch animals, cattle sheds, chaff cutters, and milking machines, and has been presented in Table 10C. It can be seen from this table that overall, interest per animal was the highest in case of buffaloes (INR6,978.83), followed by crossbred cows (INR4,315.00) and local cows (INR3,173.33). In case of cattle shed, chaff cutter, and milking machine, the interest amounts were INR3,733.03, INR553.31, and INR1,127.87, respectively. The corresponding figures were the highest (INR7,027.81, INR811.34, and INR1,937.28, respectively) for the category of large milk producers.

TABLE 10C

INTEREST ON FIXED CAPITAL.

Sl. no.	Category of milk producers	Milch animals			Cattle sheds and dairy equipment		
		Local cows	Crossbred cows	Buffaloes	Cattle shed	Chaff cutter	Milking machine
1	Landless	2,875.00	4,150.00	6,652.50	–	743.26	–
2	Marginal	2,950.00	4,197.50	6,680.00	3,066.27	572.76	1,141.26
3	Small	3,125.00	4,235.00	6,890.00	2,867.51	458.99	969.22
4	Semi-medium	3,280.00	4,345.00	7,027.50	2,446.67	332.67	717.36
5	Medium	3,360.00	4,437.50	7,248.00	3,256.93	400.82	874.26
6	Large	3,450.00	4,525.00	7,375.00	7,027.81	811.34	1,937.28
	Total	**3,173.33**	**4,315.00**	**6,978.83**	**3,733.03**	**553.31**	**1,127.87**

Category-wise Total Interest for Different Types of Milch Animals

The total interest on fixed capital with respect to different types of animals was calculated and illustrated in Table 10D. It can be seen from the table that overall, the interest per animal was the highest in case of buffaloes (INR12,393.04) followed by crossbred cows (INR9,729.21) and local cows (INR8,587.54). Among the various categories of milk producers, it was higher in case of the category of large farmers due to the reason that large farmers were maintaining costly and quality breeds of animals and equipment.

TABLE 10D

CATEGORY-WISE TOTAL INTEREST WITH REGARD TO DIFFERENT TYPES OF MILCH ANIMALS.

Sl. no.	Category of milk producers	Local cows	Crossbred cows	Buffaloes
1	Landless	3,618.26	4,893.26	7,395.76
2	Marginal	7,730.29	8,977.79	11,460.29
3	Small	7,420.72	8,530.72	11,185.72
4	Semi-medium	6,776.70	7,841.70	10,524.20
5	Medium	7,892.01	8,969.51	11,780.01
6	Large	13,226.43	14,301.43	17,151.43
	Total	**8,587.54**	**9,729.21**	**12,393.04**

Total Maintenance Cost

The total maintenance cost includes annual fixed costs and variable costs. Fixed-cost expenditure comprises the depreciation on fixed assets like milch animals, cattle sheds, dairy equipment and machinery, and interest on fixed capital; while variable costs include expenditures on dry fodder, green fodder, concentrate, labor, and miscellaneous expenses such as actual amount paid for electricity, repair cost of equipment, expenditure on ropes, etc. Besides, actual expenditures incurred on veterinary aid like medicines, healthcare, vaccination of milch animals, along with other routine expenses, have been considered while computing the total maintenance cost.

Costs of Milk Production for Different Types of Milch Animals

The average cost of milk production per liter has also been worked out for various breeds of milch animals maintained by different categories of milk producers. A close observation of Table 11 reveals that overall, the average cost of milk production per liter was the lowest (INR20.54) for crossbred cows, followed by buffaloes (INR38.82) and local cows (INR44.02).

Returns from Different types of Milch Animals

The details pertaining to cost of milk production have been discussed in detail in the foregoing paragraphs. However, with a view to draw a comparative outline of the economic aspects of milk production for different types of milch animals as well as category of milk producers, the return per liter of milk produced has been worked out on the basis of cost of milk production and amount realized through sale of milk by milk producers. The return through sale of dung has also been considered while computing the net return on sale of milk per liter. The result related to the overall return has been presented in Table 11. It can be seen from the table that overall, the maximum (INR46.86 per liter) sale price was reportedly for buffalo milk followed by local cow milk (INR44.48 per liter) and crossbred cow milk (INR36.21 per liter), whereas the overall per liter return as reported by milk producers was the highest (INR17.15) in case of crossbred cows followed by buffaloes (INR13.05) and local cows (INR4.45).

The above trend is attributed to higher productivity of crossbred cows and higher returns realized by their milk producers. The lower gain from local cows may be due to the poor productivity of local cows maintained by sample households as well as lower price realized for cow milk.

TABLE 11

DETAILS OF EXPENDITURE AND INCOME DURING 2021–22 IN INR PER ANIMAL PER ANNUM.

Details of inputs used	Local cows	Crossbred cows	Buffaloes
(1) Total variable cost A) Dry fodder	32,558.00	36,423.35	45,760.05
B) Green fodder	6,540.80	7,522.65	8,311.05
C) Feed cost	21,841.60	39,156.65	27,619.55
D) Cost of medicines	390.06	858.27	491.88
E) Cost of minerals and RBGH	404.21	824.73	417.51
F) Total labor cost	5,466.93	6,418.34	6,302.63
G) Premium amount of insurance	793.33	1,078.75	1,744.70
H) Miscellaneous costs	454.61	781.13	464.12
Total variable cost (A to H)	**68,449.54**	**93,063.87**	**91,111.49**
(2) Fixed costs A) Depreciation on fixed assets	5,324.46	6,466.13	7,964.50
B) Interest on fixed assets	8,587.54	9,729.21	12,393.04
Total fixed cost	**13,912.00**	**16,195.34**	**20,357.54**
Total annual expenditure includes variable cost + fixed cost (INR)	**82,361.54**	**109,259.21**	**111,469.03**
(3) Annual milk production (liter per animal)	1,870.82	5,318.33	2,871.08
(4) Actual sales of milk (liter per animal)	1,738.66	5,223.96	2,813.59
Sales price of milk (INR per liter)	44.48	36.21	46.86
(5) Annual income from sales of milk (INR per animal)	77,335.59	189,159.59	131,844.83
(6) Annual income from dung (INR)	7,477.61	7,892.17	14,398.46
Annual gross income per animal (5+6) in INR	84,813.20	197,051.76	146,243.29
Net income of the milk producer (gross income- total expenditure)	24,51.66	87,792.55	34,774.26
Net income from dairy farming (gross income from milk (if total quantity of milk sold) + dung value – total expenditure)	8,330.14	91,209.69	37,468.24
Cost of milk production (INR per liter)	44.02	20.54	38.82
Net return (INR per liter per day)	4.45	17.15	13.05

Social Impact of Dairy Farming

With a view to knowing the social impact of dairy farming, the information related to the expenditure incurred on children's education, food and clothing, healthcare, social events, and nutritional levels were collected from the milk producers, and have been presented in Table 12. It may be seen from this table that overall, 90% of the milk producers spent money on children's education, 87.50% spend on health care, 83.75% on food and clothing, 81.25% on social events, and 78.75% spent more money for maintaining the nutritional level.

TABLE 12

SOCIAL IMPACT OF DAIRY FARMING.

(PART A)

Sl. no.	Category of milk producers	Total number of milk producers	Expenditure on children's education		Expenditure on food and clothing	
			Increased	No change	Increased	No change
1	Landless	3	2 (66.67%)	1 (33.33%)	2 (66.67%)	1 (33.33%)
2	Marginal	29	26 (89.66%)	3 (10.34%)	25 (86.21%)	4 (13.79%)
3	Small	20	18 (90.00%)	2 (10.00%)	17 (85.00%)	3 (15.00%)
4	Semi-medium	13	12 (92.31%)	1 (7.69%)	11 (84.62%)	2 (15.38%)
5	Medium	10	9 (90.00%)	1 (10.00%)	8 (80.00%)	2 (20.00%)
6	Large	5	5 (100.00%)	–	4 (80.00%)	1 (20.00%)
	Total	**80**	**72 (90.00%)**	**8 (10.00%)**	**67 (83.75%)**	**13 (16.25%)**

(PART B)

Sl. no.	Category of milk producers	Total number of milk producers	Expenditure on healthcare		Expenses on social events		Expenditure on maintaining nutritional level	
			Increased	No change	Increased	No change	Increased	No change
1	Landless	3	2 (66.67%)	1 (33.33%)	2 (66.67%)	1 (33.33%)	2 (66.67%)	1 (33.33%)
2	Marginal	29	26 (89.66%)	3 (10.34%)	24 (82.76%)	5 (17.24%)	23 (79.31%)	6 (20.69%)
3	Small	20	17 (85.00%)	3 (15.00%)	16 (80.00%)	4 (20.00%)	16 (80.00%)	4 (20.00%)
4	Semi-medium	13	11 (84.62%)	2 (15.38%)	11 (84.62%)	2 (15.38%)	10 (76.92%)	3 (23.08%)
5	Medium	10	9 (90.00%)	1 (10.00%)	8 (80.00%)	2 (20.00%)	8 (80.00%)	2 (20.00%)
6	Large	5	5 (100.00%)	–	4 (80.00%)	1 (20.00%)	4 (80.00%)	1 (20.00%)
	Total	**80**	**70 (87.50%)**	**10 (12.50%)**	**65 (81.25%)**	**15 (18.75%)**	**63 (78.75%)**	**17 (21.25%)**

Major Constraints Impeding Performance of Dairy Farming

The information related to major constraints impeding performance of dairy farming has been ascertained from the various categories of milk producers and presented in Table 13. It can be seen from this table that overall, 95% of the milk producers reported about the non-availability of green fodder throughout the year, 91.25% said that they were not having the marketing facility for dung in and around their villages, 88.75% dairy farmers reported about the non-availability of sort sex semen and not having received the remunerative price of milk. High price of dry fodder as well as inadequate knowledge about the prevalence of diseases was reported by 86.25% milk producers, while non-availability of quality breed in local markets was reported by 67.50% milk producers and inadequate knowledge about good hygiene practices was reported by 58.75% producers. Among various categories of milk producers, the reporting percentages were higher in cases of landless, marginal, and small farmers.

TABLE 13

MAJOR CONSTRAINTS IMPEDING PERFORMANCE OF DAIRY FARMING.

Sl. no.	Category of milk producers	Total number of milk producers	High price of dry fodder	Non-availability of green fodder throughout the year	Non-availability of quality breed in local market	Inadequate knowledge about prevalence of diseases	Inadequate availability of sort sex semen	Inadequate marketing facility of dung	Inadequate knowledge about good hygiene practices	Receiving less price of cow milk
1	Landless	3	3 (100.00%)	3 (100.00%)	2 (66.67%)	3 (100.00%)	3 (100.00%)	3 (100.00%)	2 (66.67%)	3 (100.00%)
2	Marginal	29	25 (86.21%)	28 (96.55%)	20 (68.97%)	27 (93.10%)	27 (93.10%)	28 (96.55%)	19 (65.52%)	28 (96.55%)
3	Small	20	18 (90.00%)	19 (95.00%)	13 (65.00%)	17 (85.00%)	18 (90.00%)	18 (90.00%)	12 (60.00%)	17 (85.00%)
4	Semi-medium	13	11 (84.62%)	12 (92.31%)	9 (69.23%)	10 (76.92%)	11 (84.62%)	12 (92.31%)	7 (53.85%)	12 (92.31%)
5	Medium	10	9 (90.00%)	10 (100.00%)	7 (70.00%)	8 (80.00%)	8 (80.00%)	8 (80.00%)	4 (40.00%)	8 (80.00%)
6	Large	5	3 (60.00%)	4 (80.00%)	3 (60.00%)	4 (80.00%)	4 (80.00%)	4 (80.00%)	1 (20.00%)	3 (60.00%)
	Total	**80**	**69 (86.25%)**	**76 (95.00%)**	**54 (67.50%)**	**69 (86.25%)**	**71 (88.75%)**	**73 (91.25%)**	**45 (58.75%)**	**71 (88.75%)**

Constraints in Getting Loans

The information pertaining to constraints in getting loans was collected from those respondent milk producers who had taken loans, and has been illustrated in Table 14. It can be seen from this table that overall, 76.47% of the milk producers reported that the loan procedure was very cumbersome,74.51% milk producers said they were unable to deposit collateral security, 58.82% respondents reported that loan amount was not sufficient to purchase quality breeds of animals, 50.98% milk producers informed that banks were not willing to provide loans for dairy farming, and 39.22% milk producers noted that the rate of interest was high.

TABLE 14

CONSTRAINTS IN GETTING LOANS FOR DAIRY FARMING.

Sl. no.	Category of milk producers	Total number of milk producers taken loans	Cumbersome loan procedure	Inadequate amount of loan	High interest rate	Banks not encouraging/ helpful	Unable to deposit collateral security
1	Landless	2	2 (100.00%)	2 (100.00%)	1 (50.00%)	1 (50.00%)	2 (100.00%)
2	Marginal	18	14 (77.78%)	10 (55.56%)	8 (44.44%)	10 (55.56%)	15 (83.33%)
3	Small	13	10 (76.92%)	7 (53.85%)	5 (38.46%)	7 (53.85%)	11 (84.62%)
4	Semi-medium	8	6 (75.00%)	5 (62.50%)	3 (37.50%)	4 (50.00%)	6 (75.00%)
5	Medium	7	5 (71.43%)	4 (57.14%)	2 (28.57%)	3 (42.86%)	3 (42.86%)
6	Large	3	2 (66.67%)	2 (66.67%)	1 (33.33%)	1 (33.33%)	1 (33.33%)
	Total	**51**	**39 (76.47%)**	**30 (58.82%)**	**20 (39.22%)**	**26 (50.98%)**	**38 (74.51%)**

Adoption of Modern Technology, Equipment, and Machines

The information related to adoption of modern technology/milking machines has been obtained from various categories of milk producers and presented in Table 15. It can be seen from this table that overall, 63.75% of the milk producers had adopted clean milk production practices, 53.75% had adopted automatic watering system, 43.75% were maintaining hygienic conditions, 32.50% milk producers were using the milking machine, 13.75% had adopted preventive measures for disease control, 11.25% believed in artificial insemination, and 8.75% milk producers were well aware of making silage.

TABLE 15

ADOPTION OF MODERN TECHNOLOGY, EQUIPMENT, AND MACHINES.

Sl. no.	Category of milk producers	Total number of milk producers	Silage making	Automatic watering system	Adoption of milking machine	Adoption of clean milk production practices	Maintaining hygienic conditions	Acceptability of AI with sort sex seamen	Adoption of modern preventive measures for disease control
1	Landless	3	–	1 (33.33%)	–	1 (33.33%)	1 (33.33%)	–	–
2	Marginal	29	1 (3.45%)	14 (48.28%)	5 (17.24%)	15 (51.72%)	10 (34.48%)	2 (6.90%)	2 (6.90%)
3	Small	20	2 (10.00%)	10 (50.00%)	4 (20.00%)	13 (65.00%)	8 (40.00%)	2 (10.00%)	3 (15.00%)
4	Semi-medium	13	2 (15.38%)	7 (53.85%)	7 (53.84%)	10 (76.92%)	6 (46.15%)	2 (15.38%)	3 (23.08%)
5	Medium	10	1 (10.00%)	7 (70.00%)	6 (60.00%)	8 (80.00%)	6 (60.00%)	2 (20.00%)	2 (20.00%)
6	Large	5	1 (20.00%)	4 (80.00%)	4 (80.00%)	4 (80.00%)	4 (80.00%)	1 (20.00%)	1 (20.00%)
	Total	**80**	**7 (8.75%)**	**43 (53.75%)**	**26 (32.50%)**	**51 (63.75%)**	**35 (43.75%)**	**9 (11.25%)**	**11 (13.75%)**

Productivity Assessment in Dairy Processing Industry

Sample Profile

With a view to assessing the productivity of dairy plants, eight plants (five from the cooperative sector and three from the private sector) were selected on the basis of ownership and capacity of the unit. The sample profiles of these plants are presented in Table 16. The required information was sought from these dairy plants for the purpose of this study. It was endeavored to select a greater number of dairy plants from the cooperative sector because the government has reinforced this sector by providing funds toward development of infrastructure through National Dairy Development Board. The sample dairy plants were categorized based on the ownership.

On the basis of the year of commissioning of a dairy plant, the age of the plant has been computed. It may be observed from Table 16 that the overall average age of cooperative dairy plants was 44 years (varying from 29 years to 71 years) while it was about 35 years in case of private-sector dairy plants (varying from 22 years to 59 years). This indicates that private-sector dairy plants are relatively new as compared with cooperative-sector dairy plants and have adopted modern technology. In other words, we can say that the adoption of modern technology is becoming visible in the private sector faster. The latest technology that depends on full automation where milk is untouched by humans is yet to make a significant dent in India (i.e., more hygienic and larger milk quantities can be processed in lesser time). Such plants are now being commissioned in India on a sporadic basis. Similarly, the average per day capacity of the dairy units varied from 0.4 million liter to 1.8 million liter in cooperative dairy plants while it varied from 0.4 million liter to 2 million liter in private-sector dairy plants.

TABLE 16

OWNERSHIP AND CAPACITY-WISE DETAILS OF DAIRY PLANTS.

Sl. no	Name of the dairy plant	Ownership	Year of establishment (age of the dairy plant as on March 2022)	Year of renovation	Capacity (million liter per day)
1	Bhilwara Zila Dugdh Utpadak Sahkari Sangh Ltd. Bhilwara, Rajasthan	Cooperative	1983 (29 years)	2021–22	0.5
2	Valsad District Cooperative Milk Producers' Union Ltd., Vasudhara, Dairy, Alipur 396409, Gujarat	Cooperative	1981 (41years)	1993/2002/ 2011/2018	0.4
3	Kolhapur Zilla Sahakari Dudh Utpadak Sangh Ltd., Kolhapur, B-1, MIDC, Gokul Shirgaon, Tal. Karvir, Dist. Kolhapur, Maharashtra	Cooperative	1978 (44 years)	1978–86	1.7
4	Mega Dairy complex Bannur Road, Alanahalli post, Mysuru 570028, Karnataka	Cooperative	1987 (35 years)	2019	0.8
5	Surat District Cooperative Milk Producers' Union Limited. Sumul Dairy Road, Gujarat	Cooperative	1951 (71 years)	2015–20	1.8
6	M/s. B.G. Chitale, A/p: Bhilawadi Station, Tal. Palus, Dist. Sangli, 416303, Maharashtra	Private	1963 (59 years)	2014	0.8
7	Dodla Dairy Ltd, 8-2-293/82/A, 270/Q, Road No 10-C, Jubilee Hills, Hyderabad 500033, Telangana, India	Private	1997 (25years)	2022	2.0
8	S.R. Thorat Milk Products Pvt Ltd, Sangamner, Maharashtra	Private	2000 (22 years)	NA	0.4
			Average age 44 years (cooperative) and 35.33 years (private)		

Procurement Area of the Dairy Plants

Under the Milk and Milk Product Order 1992, specific milk shed areas for milk procurement were demarcated for dairy plants, but in April 2002, the concept of milk shed area was abolished by the GoI and the plants became free to procure milk from anywhere across the country. However, the operational area of a dairy plant depends on the intensity of dairy farming activities in its vicinity. Higher intensity leads to a lower radius of operation. The ownership-wise average radius of operation for the period from 2018–19 to 2021–22, along with the number of villages covered, is presented in Table 17. It can be seen from this table that the overall average radius of operation of dairy plants varied from 6 km to 144.50 km in case of cooperative-sector dairy plants and from 37.50 km to 185 km in case of private-sector dairy plants during the years from 2018–19 to 2021–22.

Further, it can also be seen from this table that the overall average number of villages covered by cooperative dairy plants during the reference period varied from 1,114.40 to 1,187.60, while for private-sector plants it varied from 3,443.67 to 4,280. As may be seen from Table 17, the coverage of villages by the cooperative sector was lower than that by the private sector, while an increasing trend was observed in both cases. This implies that the private sector is putting more efforts toward enhancing its milk procurement, keeping in view the economic considerations. The infrastructural facilities related to procurement are higher in case of the cooperative sector compared with the private sector. No doubt, the cooperative sector is more service oriented toward farmers than the private sector, which operates dairy units as a profitable venture. By and large, all cooperative-sector dairy plants are providing veterinary services to animals of their milk producers (who are PMPCS members located in their respective villages and pouring milk twice a day at these societies). Besides, the cooperative sector is also providing utensils, chaff cutters, emergency services, and financial support for insuring their animals.

TABLE 17

OPERATIONAL DISTANCE AND NUMBERS OF VILLAGES COVERED.

Sl. no.	Years	Operational distance (km)				No. of villages covered	
		Cooperative		Private			
		Minimum	Maximum	Minimum	Maximum	Cooperative	Private
1	2018–19	6	140.00	37.50	185	1,114.40	3,443.00
2	2019–20	6	137.50	37.50	185	1,174.00	3,457.50
3	2020–21	6	138.00	37.50	185	1,178.20	3,726.50
4	2021–22	6	144.50	37.50	185	1,187.60	4,280.00
Overall average		**6**	**140.00**	**37.50**	**185**	**1,163.55**	**3,726.75**

Milk Procurement System:

Procurement of milk by cooperative-sector dairy plants is done through village-level milk producers' cooperative societies (MPCS) whereas the private sector has designated commission agents who directly collect the milk from farmers and supply to the dairy plants. Table 18 outlines the details on the number of registered MPCS as well as village-level commission agents vis-à-vis those who are supplying milk to dairy plants.

TABLE 18

NUMBER OF MPCS/REGISTERED AGENTS.

Sl. no.	Years	MPCS/registered commission agents		MPCS/commission agents supplying milk to dairy plants	
		Cooperative	Private	Cooperative	Private
1	2018–19	2,140.60	249.00	2,082.20 (97.27%)	238.67 (95.85%)
2	2019–20	2,152.40	331.00	2,085.60 (96.90%)	313.00 (94.56%)
3	2020–21	2,208.20	326.00	2,148.00 (97.27%)	310.00 (95.09%)
4	2021–22	2,331.20	294.00	2,269.40 (97.35%)	281.33 (95.69%)
Overall average		**2,208.10**	**300.00**	**2,146.30 (97.20%)**	**285.75 (95.30%)**

It can be seen from Table 18 that in case of cooperative dairy plants, there was generally a steady growth in the number of functional MPCS from 2018–19 to 2021–22. In case of private-sector plants too, a similar trend was observed except during the year 2021–22. It has also been observed during the plant visit that in certain cases, a few large milk producers in the vicinity of the dairy plants were also supplying milk directly to private dairy plants on the pattern of commission agents.

Availability of Chilling Centers

In situations where milk procurement is from distant places or in places where ambient temperatures are higher, the dairy plants experience the problems of soured milk as well as high cost of transportation. As an alternative, chilling centers are established at intermediate locations where milk is chilled immediately after collection. The chilled milk is then transported to dairy plants for further processing. The ownership and category wise average number of chilling centers, their average radius of operation, chilling capacity, and proximity to dairy plants have been computed based on data for the four years from 2018–19 to 2021–22 and presented in Table 19.

It can be seen from the table that on an average 259.15 bulk milk coolers (BMCs) were found in the cooperative sector with a total capacity of 721,932.50 liter per day. In the private sector, on an average, 7.88 BMCs were reported with a total capacity of 27,000 liter per day.

As can be seen from Table 19A, on an average, the highest number of chilling centers (34.25) was reported in private-sector dairy plants with an average total capacity of 7,85,000 liter per day, while in the case of cooperative-sector dairy plants, the total number of chilling centers was only 2.40. However, the average total capacity was 290,000 liter per day. As reported, most of the chilling centers attached to private plants were working on custom hiring basis whereas cooperative plants had their own chilling centers.

TABLE 19

TOTAL NUMBER OF BMCs AND THEIR CAPACITIES.

Sl. no.	Years	Average		Total capacity of BMCs (liter per day)	
		Cooperative	Private	Cooperative	Private
1	2018–19	206.20	5.00	551,506	16,000
2	2019–20	264.00	7.50	716,908	25,500

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Sl. no.	Years	Average		Total capacity of BMCs (liter per day)	
		Cooperative	Private	Cooperative	Private
3	2020–21	277.60	9.00	794,396	31,500
4	2021–22	288.80	10.00	824,920	35,000
Overall average		**259.15**	**7.88**	**721,933**	**27,000**

TABLE 19A

TOTAL NUMBER OF CHILLING CENTERS AND THEIR CAPACITIES.

Sl. no.	Years	Average number of chilling centers		Average total capacity ('000 liter/day)	
		Cooperative	Private	Cooperative	Private
1	2018–19	2.60	28.50	321.25	625.00
2	2019–20	2.60	31.50	321.25	700.00
3	2020–21	2.20	36.50	258.75	850.00
4	2021–22	2.20	40.50	258.75	965.00
Overall average		**2.40**	**34.25**	**290.00**	**785.00**

Operational Details of Dairy Plants

Dairy plants usually remain operational on all days throughout the year. However, their working depends on the availability of milk. In the lean season, when the availability of milk is low and milk collection is relatively less, the plants have to be closed down intermittently, especially in case of the private sector. Nevertheless, the dairy plants remain fully operational during the flush season due to abundant milk supply. The season-wise operational details of respondent dairy units in the context of number of working days per hour are presented in Table 20.

TABLE 20

NUMBER OF WORKING DAYS IN FLUSH AND LEAN SEASONS AND WORKING HOURS PER DAY OF DAIRY PLANTS.

Sl. no.	Years	Flush (working days)		Lean (working days)		Flush (working hours)		Lean (working hours)	
		Cooperative	Private	Cooperative	Private	Cooperative	Private	Cooperative	Private
1	2018–19	182.6	182.5	182.6	182.5	23.2	20	22.4	20
2	2019–20	182.8	183	182.6	182.5	23.2	20	22.4	20
3	2020–21	182.4	183	182.6	182.5	23.2	20	22.4	20
4	2021–22	182.4	183	182.6	182.5	23.2	20	22.4	20
Overall average		**182.55**	**182.87**	**182.6**	**182.5**	**23.2**	**20**	**22.4**	**20**

It may be seen from Table 20 that no major seasonal variation was reported in working days in both cooperative- and private-sector dairy plants during the study period. On an average, they were reportedly working throughout the year. However, a noticeable variation was reported in the overall working days computed separately for each season, i.e., for lean and flush seasons for the period from 2018–19 to 2021–22. As may be seen from the table, an average of 23.20 working hours per day were reported during the flush season and 22.40 hours were reported in the lean season by cooperative-sector dairy plants, while 20 working hours per day on an average were reported for both flush and lean seasons by private-sector dairy plants. It may be observed that the dairy plants of both cooperative and private sectors worked consistently in both the seasons during the study period.

Season-wise Procurement Details

The details of milk procured during flush and lean seasons are presented in Table 21. As may be seen from the table that overall milk procurement by cooperative dairy plants was slightly higher in both flush and lean seasons compared with private dairy plants. This is due to the fact that cooperative dairy plants have a well-established procurement system through primary milk producers' cooperative societies, thereby procuring milk throughout the year without wide variations in different seasons. It is slightly higher in the flush season in comparison with the lean season in case of both cooperative- and private-sector dairy plants.

TABLE 21

MILK PROCUREMENT DURING FLUSH AND LEAN SEASONS IN METRIC TON PER YEAR.

Sl. no.	Years	Total procurement (flush period)		Total procurement (lean period)	
		Cooperative	Private	Cooperative	Private
1	2018–19	167,724.10	168,938.50	154,895.93	116,493.00
2	2019–20	165,251.48	164,704.00	143,200.91	148,175.00
3	2020–21	171,038.87	162,156.50	157,386.83	134,617.00
4	2021–22	179,394.36	179,158.00	162,761.54	148,697.50
Overall average		**170,852.20**	**168,739.25**	**154,561.30**	**136,995.63**

Percentage Share of Sour Milk in Total Milk Procured

It can be seen from Table 22 that the overall percentage of sour milk in total milk procured is higher (0.58%) in case of cooperative-sector dairy plants than private-sector plants (0.05%). The reason for higher percentage of sour milk in cooperative dairy plants may be due to stricter supervision at the reception dock while receiving the milk. On the other hand, private-sector dairy plants may have taken a lenient view in this regard because of which the percentage of sour milk in the total milk procured was very minimal.

TABLE 22

TOTAL QUANTITY OF MILK PROCURED AND PERCENTAGE SHARE OF SOUR MILK IN TOTAL MILK.

Sl. no.	Years	Total procurement (quantity in metric ton per year)		Share of sour milk in total milk procured (%)	
		Cooperative	Private	Cooperative	Private
1	2018–19	322,620.03	285,431.50	0.45	0.03
2	2019–20	308,452.38	312,879.00	0.79	0.07
3	2020–21	328,425.70	296,773.50	0.60	0.04
4	2021–22	342,155.90	327,855.50	0.47	0.05
Overall average		**325,413.50**	**305,734.88**	**0.58**	**0.05**

Percentage Shares of Different Types of Milk in Total Milk Procured

The proportions of various types of milk (buffalo milk, cow milk, and mixed milk) in the total milk procured by various dairy plants of both cooperative and private sectors have been compiled and presented in Table 23. It is observed from the table that the overall shares of buffalo milk, cow milk, and mixed milk were 25.58%, 38.70%, and 35.72%, respectively, in the total milk procured by the cooperative sector. In the private sector, the share of buffalo milk was 16.43% while the share of cow milk was 83.57% during the study period. The private sector was not procuring mixed milk due to higher demand for cow milk in the market than buffalo milk. Also, most of the private dairy plants are product plants and hence require cow and buffalo milk separately for making various products.

TABLE 23

PERCENTAGE SHARES OF DIFFERENT TYPES OF MILK PROCURED BY COOPERATIVE AND PRIVATE DAIRIES.

Sl. no.	Years	Buffaloe milk (in %)		Cow milk (in %)		Mixed milk (in %)	
		Cooperative	Private	Cooperative	Private	Cooperative	Private
1	2018–19	26.24	19.08	41.45	80.92	32.31	0.00
2	2019–20	26.84	16.54	35.23	83.46	37.93	0.00
3	2020–21	24.86	15.34	38.70	84.66	36.44	0.00
4	2021–22	24.64	14.95	39.10	85.05	36.26	0.00
Overall average		**25.58**	**16.43**	**38.70**	**83.57**	**35.72**	**0.00**

Composition of Milk

The proportion of fat and SNF in the milk procured by dairy plants is presented in Table 24. The overall average fat percentage in the milk procured by cooperative dairy plants was 5.96% and 5.75% in case of private dairies (slightly lower than cooperative dairies). The higher fat percentage is directly attributable to larger proportion of buffalo milk in the total milk procured. This may be due to the specific buffalo breed being fed on high fat containing feed like cottonseed. Similarly, it may also be observed from this table that cooperative dairy plants procured milk with high SNF compared with private dairy plants. The overall SNF percentage was 8.68% in milk procured by cooperative-sector dairies and 8.53% in case of private-sector milk. The reason for higher SNF percentage in milk procured by cooperative dairies was due to maintaining quality standards from production stage to processing stage besides procuring milk from quality breeds of animals.

TABLE 24

AVERAGE FAT AND SNF IN MIXED MILK.

Sl. no.	Years	Average fat in %		Average SNF in %	
		Cooperative	Private	Cooperative	Private
1	2018–19	5.93	5.69	8.67	8.51
2	2019–20	5.95	5.74	8.68	8.57
3	2020–21	5.98	5.75	8.67	8.51
4	2021–22	5.96	5.75	8.71	8.53
Overall average		**5.96**	**5.73**	**8.68**	**8.53**

Milk Procurement Price Paid by Dairy Plants

The proportion of fat and SNF in milk forms the basis for price fixation, particularly in case of cooperative dairies where the procurement price varies with the season. Private-sector dairies, in particular, fix procurement prices at prevalent market rates (with minimum fat percentage of 6%) usually higher as compared with procurement prices of the cooperative sector. With this in view, the average price of milk has been computed on the basis of total amount paid in a year toward procurement excluding other costs (e.g., transportation) and presented in Table 25.

It can be seen from this table that the overall milk price per kg fat in case of cooperative-sector dairy plants was INR559.13, while in case of private-sector plants, it was INR607.50. The corresponding figures varied from INR512.66 to INR583.80 in case of cooperative-sector dairy units, whereas for private-sector units, these varied from INR560.00 to INR690.00 for the period from 2018–19 to 2021–22. An increasing trend in the milk price paid by dairy plants was observed for both cooperative- and private-sector dairies during the study period.

TABLE 25

AVERAGE MILK PRICE PAID BY DAIRY PLANTS BASED ON PER KG FAT IN INR.

Sl. no.	Years	Average milk price per kg fat	
		Cooperative	Private
1	2018–19	512.66	560.00
2	2019–20	569.51	580.00
3	2020–21	570.54	600.00
4	2021–22	583.80	690.00
Overall average		**559.13**	**607.50**

Capacity Utilization

Capacity utilization (CU) has been calculated with respect to the installed capacity of the plant and presented in Table 26. As may be seen from this table, the overall CU was slightly higher in case of cooperative dairy plants (97.23%) compared with private dairy plants (87.41%).

TABLE 26

CAPACITY UTILIZATION OF DAIRY PLANTS.

Sl. no.	Years	Capacity utilization					
		Cooperative			Private		
		Total capacity	Milk processed	Capacity utilization in %	Total capacity	Milk processed	Capacity utilization in %
1	2018–19	940,000	917,843.89	97.64	1,066,000	926,331.51	86.9
2	2019–20	940,000	871,402.41	92.70	1,066,000	973,857.53	91.36
3	2020–21	940,000	904,042.60	96.17	1,066,000	868,172.60	81.44
4	2021–22	940,000	962,667.34	102.41	1,066,000	958,668.49	89.93
Overall average		**940,000**	**913,989.06**	**97.23**	**1,066,000**	**931,757.53**	**87.41**

Capacity Utilization of Milk Powder

As may be seen from Table 27, the overall capacity utilization for manufacturing of milk powder (CU-MP) in case of cooperative dairy plants was 35.66% and in case of private-sector dairy plants, it was 21.25%. This means there is a large scope to utilize the available capacity for manufacturing milk powder in both cooperative and private sectors. In case of rising milk yields and increased milk surplus, the dairy industry may be in a position to convert the excess liquid milk into milk powder.

TABLE 27

CAPACITY UTILIZATION OF MILK POWDER.

Sl. no.	Years	Capacity utilization of milk powder in %	
		Cooperative	Private
1	2018–19	34.00	17.50
2	2019–20	34.00	22.50
3	2020–21	37.33	22.50
4	2021–22	37.33	22.50
Overall average		**35.66**	**21.25**

The major obstacle in this process was the higher cost of conversion of milk into skimmed milk powder compared with the cost of imported milk powder. The imported milk powder was available at a much cheaper rate compared with the cost of indigenous milk powder. This is one reason why this segment of dairy industry was doing poorly. Another reason was nearly stable or lower demand for milk powder because of its lower offtake by baby-food manufacturers. Intensive promotion of breast milk has resulted in this situation. Further, due to higher availability of fresh milk, reconstituted milk was not preferred by consumers. In view of the controlled milk prices at the consumer's end, the recombined milk production was not viable. Nonetheless, with concerted cost reduction efforts, this industry segment would again become viable and exhibit higher CU-MP.

Capacity Utilization of Ghee

The overall capacity utilization of *ghee* (CU-G) manufacturing units was about 12.50% the of total plant capacity in cooperative-sector plants and 14.25% in private-sector plants (see Table 28). It was slightly higher in case of the private sector because the sale of liquid milk was higher in the cooperative-sector dairy units compared with that in the private sector.

TABLE 28

CAPACITY OF GHEE UNITS.

Sl. no.	Years	Capacity of ghee plants in %	
		Cooperative	Private
1	2018–19	13.40	14.00
2	2019–20	11.80	14.50
3	2020–21	12.40	14.50
4	2021–22	12.40	14.50
Overall average		**12.50**	**14.25**

Capacity Utilization of Paneer

During the course of the study, it has been observed that the dairy plants of both cooperative and private sectors were manufacturing various products like butter, *dahi, paneer,* icecream, and UHT milk, but the production of such products was less. So, the capacity for manufacturing of *paneer* (common for most of the units) was calculated for only those dairy plants that were engaged in this activity. The overall capacity for manufacturing of *paneer* (CU-Paneer) was 4.32% in case of cooperative dairy plants and 5.37% in case of private-sector dairy plants (see Table 29).

This was because only a handful of players were manufacturing products other than milk powder and *ghee* in the private sector. However, many cooperative and private liquid plants located in and around urban conglomerates and state capitals were manufacturing *dahi* and *paneer*. It was also seen that at the direction of state dairy federations, some of the milk unions/dairy plants were diverting their excess milk to one of their constituent plants (feeder balancing dairy) having adequate facilities for manufacturing various dairy products.

TABLE 29

CAPACITY UTILIZATION OF PANEER.

Sl. no.	Years	CU-Paneer in %	
		Cooperative	Private
1	2018–19	4.53	5.00
2	2019–20	4.20	5.50
3	2020–21	4.20	5.50
4	2021–22	4.37	5.50
Overall average		**4.32**	**5.37**

Processing Cost per Ton of Milk

The processing cost per ton (PCPT) of milk in INR gives a fair indication of the productivity of a dairy plant. The overall average processing cost per ton of milk was INR510.08 in case of cooperative-sector dairy plants, while it was INR414.43 for private-sector dairy plants (see Table 30). This may be attributed to a wide variation in the technology employed. Although the overall PCPT was fairly reasonable in both sectors, the PCPT for cooperative plants was higher than that for private plants. The main reason for this is that the cooperative dairy plants are old while most of the private-sector plants are comparatively new and are adopting latest technologies. Further, as can be seen from this table, the PCPT varied from INR482.11 to INR546.16 in case of cooperative dairies and from INR371.27 to INR462.50 in case of private dairies. It increases over the years commensurate with the rise in inflation and the overall increase in cost of inputs such as energy, labor, and material.

TABLE 30

PROCESSING COST PER TON OF MILK.

Sl. no.	Years	PCPT in INR	
		Cooperative	Private
1	2018–19	504.66	376.57
2	2019–20	482.11	371.27
3	2020–21	507.42	447.39
4	2021–22	546.16	462.50
Overall average		**510.08**	**414.43**

Energy Cost per Ton of Milk

Energy is the second-largest cost in dairy plants' operations. Dairy plants use various forms of energy such as electricity, diesel, furnace oil, biogas, and paddy husk. Instead of calculating indices for each such fuel (type of fuel used varied from plant to plant depending on its availability and technology employed), it was assumed more logical to convert the absolute quantities of different fuels into calorific value (K cal) that gave a common index for comparison. However, some dairy plants did not furnish the details of their fuel consumption and provided only the expenditure details. Hence, due to nonavailability of required information, the energy cost per ton (ECPT) of milk has been calculated only in value terms, which gives an idea of how energy intensive dairy operations are. It is an index of energy efficiency.

As many fuels used are nonrenewable in nature, they need to be conserved. Hence, lower the ECPT, more energy-efficient the plant would be. As of now, no standard energy consumption norms are available either at national or international level for dairy plants. Moreover, specific energy consumption levels for several dairy products are available but not widely known. Different dairy plants have different product mixes, which makes it complicated to arrive at unit-level norms. This is an attempt to arrive at an indicative norm based on Indian situations.

The ECPT of milk in INR is the productivity index that gives a benchmark value of energy consumption in processing of milk. The value of ECPT is fairly constant across various capacities of plants, whether cooperative or private. The overall average value of ECPT was found to be INR555.23 for cooperative-sector plants and INR664.47 for private-sector dairy plants. Even over the past four years, the ECPT varied from INR522.12 to 630.38 in cooperative dairy plants and from INR622.73 to INR727.47 in private dairy plants. The overall ECPT was lower in case of cooperative dairy plants compared with private dairy plants (see Table 31). This may be reflective of the management and mindset on the cost-control front. On the other hand, private-sector dairy plants are product plants and hence require more energy while most of the cooperative-sector dairy plants are liquid plants and require less energy. Since milk is a highly perishable commodity, the cost of maintaining the right temperatures at various levels should not be compromised in both cooperative- and private-sector dairies in the guise of energy conservation.

The trend of ECPT over the past four years was found to be quite stable. This is because many plants have come up with highly efficient energy systems. Being a focus area of corporate management, a few of the plants have taken several energy conservation measures that have led to stable ECPT. However, this is only indicative, and plants should make all efforts to lower the ECPT, at least within their own categories, by studying and benchmarking the best practices.

TABLE 31

ENERGY COST PER TON OF MILK.

Sl. no.	Years	ECPT in INR	
		Cooperative	Private
1	2018–19	530.78	622.73
2	2019–20	537.64	626.68
3	2020–21	522.12	680.99
4	2021–22	630.38	727.47
Overall average		**555.23**	**664.47**

Labor Cost per Ton of Milk

The labor cost per ton (LCPT) of milk in INR is indicative of labor intensity and labor productivity in dairy units. On one hand, the labor intensity may be decreasing as new technologies for dairy products suggest that they should not be handled by hand at all. On the other hand, the cost of labor is increasing not because of a greater number of people being put on the job but because of high-skilled people being employed. The sophistication of new plants requires lesser number but highly qualified people, which leads to higher labor cost. However, in India, many operations are still handled by labor rather than machines because of an abundant availability of labor as well as due to underemployment.

As can be seen from Table 32, the overall value of LCPT was INR1.91 in cooperative dairy plants and INR1.50 in private dairy plants. An increasing trend in LCPT has been observed in case of private dairy plants while no definite trend was discernable in cooperative-sector dairy plants.

TABLE 32

LABOR COST PER TON OF MILK.

Sl. no.	Years	LCPT in INR	
		Cooperative	Private
1	2018–19	1.65	1.30
2	2019–20	2.00	1.46
3	2020–21	1.96	1.58
4	2021–22	2.03	1.68
Overall average		**1.91**	**1.50**

Total Expenditure to Total Labor Cost

As can be seen from Table 32A, the overall value of total expenditure to total labor cost (TETLC) was 3.41% in case of cooperative dairy plants and 5.63% in private dairy plants. The corresponding figure varied from 3.34% to 3.51% in case of cooperative dairies and from 5.19% to 5.92% in private dairies.

TABLE 32A

TOTAL EXPENDITURE TO TOTAL LABOR COST IN %.

Sl. no.	Years	Total expenditure to total labor cost	
		Cooperative	Private
1	2018–19	3.34	5.55
2	2019–20	3.51	5.19
3	2020–21	3.43	5.84
4	2021–22	3.36	5.92
Overall average		**3.41**	**5.63**

Milk Handled per Employee

Milk handled per employee (MHPE) is another labor productivity index that speaks for itself. The larger the value, the better it is. It indicates labor productivity that is dependent on the plant capacity and the technology employed. As can be seen from Table 33, the overall average milk handled per employee per annum in case of cooperative dairy plants was 385.21 ton, while in case of private dairy plants, it was 198.02 ton.

Obviously, private plants handled less quantity of milk compared with cooperative-sector dairy plants. Besides, most of the private dairy plants are products plants, and therefore, low MHPE in such plants is an obvious result. The milk handled per employee in case of cooperative dairies is higher as they are mostly liquid plants. The difference in MHPE was just double between private plants and cooperative plants. This is amply suggestive of employee productivity and its scope for improvement.

TABLE 33

MILK HANDLED IN METRIC TON PER EMPLOYEE.

Sl. no.	Years	MHPE in metric ton	
		Cooperative	Private
1	2018–19	391.55	212.11
2	2019–20	376.32	199.42
3	2020–21	367.49	183.54
4	2021–22	405.46	197.02
Overall average		**385.21**	**198.02**

Average Cost per Employee

The annual average cost per employee (ACPE) is the complementary index of labor productivity. As such it may not be of much relevance except for keeping an eye on the total employee cost. The rising wage rate, inflation, and the associated compensation packages would necessarily explain the increasing trend of average annual cost per employee from INR5.17 lakh to INR6.64 lakh during the years from 2018–19 to 2021–22 in case of cooperative-sector dairy plants. In case of private-sector dairy plants, the corresponding figures were INR2.69 lakh and INR3.05 lakh, respectively (see Table 34). This means that even if the total number of employees got reduced, the total employee cost would be nullifying the positive effect on total expenditure of dairy plants. Hence, as far as possible, employees should be multi-skilled and interchangeable except for highly specialized and technical jobs. This would provide the required versatility and keep the employee costs under check.

A significant difference between private-plant employees and cooperative employees is visible. The overall ACPE was higher in cooperative-sector dairy plants (INR5.89 lakh) compared with that in private-sector dairy plants (INR2.85 lakh). This may be due to higher number of technically qualified people being employed in the cooperative sector. Further, the ACPE here was calculated based on direct costs of employees and did not include other facilities and perks given to them such as housing, electricity, and subsidized product supplies, particularly in the cooperative sector.

The ACPE also indicates the general quality of life (living standards of an employee) compared with other industrial units. The ACPE values for dairy industry are placed higher compared with many other manufacturing industries (other than the hazardous products industries) because of the nature of the product handled. Milk supply is considered an essential service. On one hand, milk being perishable can easily get spoiled and lead to losses not only for dairy plants but for dairy farmers as well. Also, it will affect the consumers who require milk intake as a daily routine.

TABLE 34

AVERAGE COST PER EMPLOYEE PER ANNUM.

Sl. no.	Years	ACPE per annum in INR lakh	
		Cooperative	Private
1	2018–19	5.17	2.69
2	2019–20	6.03	2.80
3	2020–21	5.73	3.05
4	2021–22	6.64	2.87
Overall average		**5.89**	**2.85**

Average Profit per Liter of Milk

The average profit per liter (APPL) of milk is a measure of overall operational efficiency of dairy plants. As such, the APPL should be high enough to sustain the current operations and future growth of the industry. However, it cannot be very high as milk is a fast-moving consumable product. The high profitability cannot be sustained for long in such items. Milk being highly perishable with very limited shelf life, its business should generate enough to cover such risks adequately, otherwise the dairy plants may not be able to sustain and may become unviable.

A glance at Table 35 and Table 35A reveals that the overall APPL during the study period (2018–19 to 2021–22) ranged from INR0.22 to INR0.32 in case of the cooperative sector and from INR0.88 to INR2.60 for private dairy plants. The profitability of dairy plants was purely determined by their turnover, quantum, and margins as well as the quality (hygienic hazards controlled at critical points). If these two factors were ensured, the APPL would remain on the higher side.

A lower APPL is a warning signal and should trigger the management to look for the reasons and possible solutions. Low APPL could be a sum product of several reasons of both operational and financial nature and could certainly lead to similar associated problems. Generally, private dairy plants (mostly product plants) have shown higher APPL than the cooperative dairy plants (mostly liquid plants). Once the milk is converted into a high-value-added product, the entire nature of the product and its related business tactics undergo a massive change. It leads to higher profit realizations than selling only liquid milk. Earlier, cooperative plants were not entering product manufacturing, but with increased milk availability, more and more cooperative plants are now entering the product business. It is only product plants that could realize higher APPL. Nowadays, some plants have come up with innovative packaging for longer shelf lives and lower inventory risks. Such plants are also showing higher APPLs.

TABLE 35

AVERAGE PROFIT PER LITER OF MILK PROCURED.

Sl. no.	Years	APPL in INR	
		Cooperative	Private
1	2018–19	0.22	1.17
2	2019–20	0.25	0.88
3	2020–21	0.23	2.34
4	2021–22	0.32	2.60
Overall average		**0.25**	**1.75**

TABLE 35A

AVERAGE PROFIT PER LITER OF MILK PROCESSED.

Sl. no.	Years	APPL in INR	
		Cooperative	Private
1	2018–19	2.70	9.84
2	2019–20	2.98	7.73
3	2020–21	3.00	11.95
4	2021–22	4.10	12.41
Overall average		**3.20**	**10.48**

Milk Processed to Procured Ratio

Milk processed to procured ratio (MPPR), in percentage, reflects the efficiency of procurement efforts. It means how much effort has been put into procuring the raw milk that is being processed at the dairy plant. It also indicates the level of dependency on other suppliers to run the plant at full capacity. Ideally, it should not vary by 15% (on either side), meaning that for cutting the production costs, a plant may process the milk procured by other agencies (usually other plants under similar ownership) or even do job work (such as liquid milk packaging by small and medium plants for other dairies), but its survival should not become dependent on the procurement surplus of other plants. The overall MPP ratio was found to be 1:0.97 in case of cooperative dairy plants and 1:0.90 for private dairy plants. The corresponding ratio varied from 1:0.96 to 1:1 in case of cooperative-sector plants, while for private dairy plants it ranged from 1:0.84 to 1:0.94 (see Table 36). A lower MPP ratio means that milk has been procured by some other plants (maybe from far-off places) and supplied in bulk to the specific dairy plant (feeder balancing dairy). This is quite prevalent in private product plants of smaller capacities where they do not develop a well-knit milk procurement system due to a low level of operation or operational ease.

TABLE 36

MILK PROCESSED TO PROCURED RATIO.

Sl. no.	Years	Milk processed to procured ratio (MPPR)	
		Cooperative	Private
1	2018–19	1:0.96	1:0.84
2	2019–20	1:0.97	1:0.88
3	2020–21	1:1.00	1:0.94
4	2021–22	1:0.97	1:0.94
Overall average		**1:0.97**	**1:0.90**

Packaging Cost per Liter of Milk

The packaging cost per liter (PPCL) of milk in INR constitutes a major portion of the marketing cost of milk. This is an indicator of the add-on cost before reaching the end consumer. The type of pack (e.g., polypack or tetrapack); method of packaging (bulk, can, or bottle); type of distribution network (retailer/distributor or own network); market proximity (near, far, or export); type of consumer (low end, high end, bulk, or retail); and product value (e.g., toned or full cream) all have significant impacts on the PCPL value. However, dairy plants in general aim to keep the PCPL low for reasons of sound business tactics.

Table 37 reveals a lot in this indicative value. The overall PCPL value was lower in case of private dairy plants (INR1.26) but higher for cooperative plants (INR1.55) during the study period. This could happen only on one premise that the extreme capacity plants on either sides were not putting enough effort to contain PCPL due to a "have to sell" mindset, mainly as a result of financial and operational compulsions. The other reason is that these large-capacity cooperative plants were involved in product manufacturing activities that increased the PCPL. Milk-based products being high-value-added and having longer shelf-lives required more stable and attractive packaging, thereby keeping the PCPL higher.

Further, an increasing trend was observed in PCPL over the past four years. It clearly indicates the significance of PCPL and its rising value and hence the need to contain it for higher profitability and productivity. The rising consumption of milk, especially in urban areas; the consumer preference and ease (pouches instead of bulk or bottles); innovative packaging such as tetra packs and aseptic packs; and aggressive marketing due to competition have led to a rising PCPL. Of course, milk selling prices have also risen, but PCPL has risen proportionately faster. In any case, the entire cost is borne by end consumers and if they are ready to absorb such costs, dairy plants would like to incur it. The other aspect is that this is an era of packaging, which leads to higher turnover and incremental profitability. Hence, dairy plants need to choose an appropriate cost-effective packaging while focusing on the consumers they serve.

TABLE 37

PACKAGING COST PER LITER OF MILK.

Sl. no.	Years	PCPL in INR	
		Cooperative	Private
1	2018–19	1.33	1.17
2	2019–20	1.49	1.14
3	2020–21	1.54	1.20
4	2021–22	1.84	1.54
Overall average		**1.55**	**1.26**

Selling and Promotional Cost per Liter of Milk

Selling and promotional cost per liter (SPCL) of milk in INR gives an indication of costs associated with such marketing efforts. It comprises purely distribution and sales promotion costs and is an indicator of the efficiency of marketing efforts. Normally, for commodities like milk, sales promotion expenses are not very comparable with other branded food products. The major cost constituents are distribution costs, network maintenance costs, and transportation and storage costs. The plants may either have their own network, outlets, and transport arrangement or may outsource it. Dairy plants may also choose to channelize milk through distributors and retailers and may have different working arrangements for sharing the costs. Normally, in the cooperative sector, milk is distributed through milk booths and supplemented by another retailer network (which charges a bit extra). The private plants generally prefer the distributor–retailer network because it takes time and funds to build own outlets. In such a case, a larger percentage share of distributor margin is provided.

As may be seen from Table 38, the overall SPCL in case of cooperative dairy plants was INR0.51 per liter while in case of private-sector dairy plants it was INR0.14 per liter. This is quite comparable with other similar food products. However, one good thing in milk marketing is that milk does not change hands frequently (market intermediaries are less) and SPCL can be contained to a lower value. In case of cooperative plants, SPCL has shown consistency because of the plants' inherent strength in collection and distribution of milk. Most of these plants have their own transport facilities and even their own distribution outlets. Private operators (usually ex-servicemen from defense and handicapped persons) manage the distribution outlets of cooperative dairies on commission basis. They keep a better check on the quality of milk. Also, the outlets do not require to make any extra selling efforts as the cooperative-sector dairy plants have indulged in brand building and spent large amounts on advertisement, publicity, and sales promotion in their initial few years. Slowly and steadily, consumerism has grown even in milk selling, with brand loyalties becoming stronger and paying back early expenses in the long run. On the other hand, private dairy plants do not have their own facilities and depend on marketing channels and distributor networks. Due to the high degree of competition now prevailing in the market, these smaller plants find it difficult to absorb such costs, but are forced to spend money for retaining their market shares.

TABLE 38

SELLING AND PROMOTIONAL COST PER LITER OF MILK.

Sl. no.	Years	SPCL in INR	
		Cooperative	Private
1	2018–19	0.44	0.15
2	2019–20	0.53	0.14
3	2020–21	0.51	0.12
4	2021–22	0.54	0.14
Overall average		**0.51**	**0.14**

Water Use Ratio

Water is extensively used in dairy plants. It is mostly used for maintaining cleanliness and hygiene besides steam generation. The water use ratio (WUR) is the indicator of the quantum of water used and is defined as the quantity of water used per liter of milk processed. As may be seen from Table 39, the milk–water ratio varied from 1:1.24 to 1:1.33 in the cooperative sector and from 1:1.72 to 1:1.80 in the private sector, depending on the technology available at the dairy plants, frequency of cleaning, type of flooring, and size of dairy plant.

It is clear from the table that WUR was higher in private dairy plants compared with cooperative-sector dairy plants during the period from 2018–19 to 2021–22. This may be because of the fact that private-sector dairy plants are mostly product plants and require more water for cleaning plant equipment and machinery compared with cooperative dairy plants. It has been observed during the visit that most of the sample dairy plants were using treated water for cleaning floor, crates, etc. Although dairy plants have increasingly emphasized on plant cleanliness and general hygiene, including improvised floorings and plugging leakages, and are more concerned with the maintenance of general cleanliness and hygienic awareness among plant operators, there still seems to be a good scope for lowering WUR in both cooperative and private-sector plants. WUR could be brought down to 1:1 without compromising the quality by adopting steam cleaning, recycling hot water through milk lines, and continuous floor cleaning techniques.

TABLE 39

WATER USE RATIO.

Sl. no.	Years	Water use ratio (WUR)	
		Cooperative	Private
1	2018–19	1:1.33	1:1.80
2	2019–20	1:1.33	1:1.76
3	2020–21	1:1.28	1:1.72
4	2021–22	1:1.24	1:1.75
Overall average		**1:1.30**	**1:1.76**

Profitability Ratio

Profitability ratio (PR) indicates the relationship between gross profit and net sales. In dairy industry, this ratio cannot be very high because of the nature of the products. Milk and milk products can best be compared with fast moving consumer goods. This is a high-turnover, low-margin, low-value-addition (especially in liquid milk), and low shelf-life business, coupled with the risk of perishability, which calls for appropriately compensating the profit margin. Somehow, dairy plants covered under the study have not shown high profitability (see Table 40). The PR was found to be slightly higher in case of private-sector dairy plants (1:1.43 to 1:1.62) compared with cooperative-sector dairy plants (1:0.98 to 1:1.03) during the period from 2018–19 to 2021–22. The main reason for low PR in cooperative-sector dairy plants may be higher overhead costs in this sector, thereby affecting the profitability adversely. Cooperative-sector plants had also incurred higher expenditure on infrastructure; farmer support services such as veterinary services, subsidy in cattle insurance premium, and various extension activities to educate the milk producers for running their business; and balance feed and clean milk production. The overall PR showed uniformity during the study period in both cooperative- and private-sector dairy plants.

TABLE 40

PROFITABILITY RATIO.

Sl. no.	Years	Profitability ratio (PR)	
		Cooperative	Private
1	2018–19	1:0.98	1:1.62
2	2019–20	1:1.03	1:1.43
3	2020–21	1:0.99	1:1.58
4	2021–22	1:1.01	1:1.54
Overall average		**1:1.00**	**1:1.55**

Packaging Cost to Total Expenditure

Packaging cost is one of the main constituents of the total cost of dairy products. The overall packaging cost as a percentage of total expenditure was observed to vary from 0.03% to 0.05% in various dairy plants during the study period (see Table 41). As observed during the course of the study, liquid milk packaging had lower cost when packed in LDPE film pouches compared with tetra packs or any other special packs to enhance the shelf life. The overall packaging cost to total expenditure (PCTE) was higher in case of private dairy plants compared with cooperative dairy plants that showed a uniform trend. There has been a remarkable change in packaging milk and milk products due to the availability of various types of flexible films. The demand for packaged milk and milk products is increasing due to ease of handling, higher shelf life, and wider consumer awareness regarding quality.

TABLE 41

PACKAGING COST TO TOTAL EXPENDITURE.

Sl. no.	Years	Packaging cost to total expenditure	
		Cooperative	Private
1	2018–19	0.03	0.05
2	2019–20	0.03	0.04
3	2020–21	0.03	0.04
4	2021–22	0.03	0.05
Overall average		**0.03**	**0.04**

Selling Cost to Total Expenditure

This ratio in percentage gives an indication of selling efficiency. The lower the ratio, lower is the selling cost. The overall selling cost to total expenditure (SCTE) ratio for cooperative dairy plants was 1:0.0089 while in case of private-sector plants it was 1:0.0049 (see Table 42). The reason for this may be that private plants have established a well-knit selling network compared with cooperative plants that still use the distributor channel method which requires high selling margins. Besides, the SCTE also depends on the selling methods, proximity to markets, and nature of products. It may also be seen from the table that the overall trend in SCTE is also broadly stable in both cooperative and private dairy plants. This is a good sign of the industry becoming mature.

TABLE 42

SELLING COST TO TOTAL EXPENDITURE.

Sl. no.	Years	Selling cost to total expenditure (SCTE)	
		Cooperative	Private
1	2018–19	1:0.0089	1:0.0063
2	2019–20	1:0.0093	1:0.0049
3	2020–21	1:0.0089	1:0.0040
4	2021–22	1:0.0089	1:0.0046
Overall average		**1:0.0089**	**1:0.0049**

Working Capital to Total Capital Employed

Working capital management is very important in the dairy industry. Due to the nature of product, the ratio of working capital to total capital employed (WCTCE) is very high compared with other industrial products. Generally, all agri and food processing industries are working as capital-intensive industries as they deal in perishable, seasonal products. The dairy industry is no exception. Its overall WCTCE varied from 1:0.04 to 1:0.05 in case of the cooperative sector and from 1:0.15 to 1:0.51 in case of the private sector (see Table 43).

Although it may look high, it is still toward the lower side in the food industry segment. The major reason for this is the fast cash realization. Also, working capital locked in inventories is low and so is the product shelf life. Such products require capital-intensive network buildup for both procurement and distribution. A quick sales realization and high turnover makes this industry more competitive. It may be observed from Table 43 that private plants have higher WCTCE than cooperative plants, mainly because of quicker payments made by them for the milk procured. By and large, the overall WCTCE ratio during the study period was stable in cooperative-sector dairy plants, which is good for the industry.

TABLE 43

WORKING CAPITAL TO TOTAL CAPITAL EMPLOYED RATIO.

Sl. no.	Years	WCTCE ratio	
		Cooperative	Private
1	2018–19	1:0.04	1:0.36
2	2019–20	1:0.05	1:0.51
3	2020–21	1:0.04	1:0.19
4	2021–22	1:0.04	1:0.15
Overall average		**1:0.04**	**1:0.30**

Fixed Assets Turnover Ratio

As can be seen from Table 44, the overall fixed asset turnover (FAT) ratio is quite attractive compared with other industries. The industries that could achieve a FAT ratio of more than 10 are doing much better in the market and may look for expansion opportunities. The overall FAT ratio during the study period was 1:4.32 to 1:5.04 in the cooperative sector and 1:4.58 to 1:5.29 in the private sector. The dairy industry requires a sizable investment in plants and machinery as well as land and buildings; and the new technology plants (fully automatic) are very costly (as high as INR2,000 million for a 2 lakh liter per day plant).

TABLE 44

FIXED ASSET TURNOVER RATIO.

Sl. no.	Years	FAT ratio	
		Cooperative	Private
1	2018–19	1:4.32	1: 4.58
2	2019–20	1:4.69	1:4.96
3	2020–21	1:4.67	1:4.72
4	2021–22	1:5.04	1:5.29
Overall average		**1:4.68**	**1:4.89**

Inventory Turnover Ratio

The inventory turnover ratio establishes the relationship between the cost of goods sold during a given period and the average amount of inventory carried during that period. It indicates whether the investment in stock/inventory has been efficiently used or not. The ratio signifies how fast inventories are rolled over within a year. The higher the ratio better it is. A higher ratio indicates that more sales are being produced by a unit of investment in stocks. Industries in which the inventory turnover ratio is high usually work on a comparatively low margin of profit. In the dairy industry, which is dealing with highly perishable commodities like milk, the inventory of raw material as well as finished goods (pasteurized milk) is usually not maintained beyond two days except for UHT milk. However, in case of product plants, inventory of finished goods such as *ghee,* cheese, butter, etc. could be held for several weeks.

The overall inventory turnover ratio in case of cooperative dairy plants was 1:0.25 while in case of private dairy plants it was 1:0.14 (see Table 45). It has been observed that cooperative plants had sufficient setup for storing milk and hence were in a position to collect higher quantities of milk than what they supplied to the market. The private plants have not made that kind of investment in milk silos and are forced to sell milk without keeping much inventory.

TABLE 45

INVENTORY TURNOVER RATIO.

Sl. no.	Years	Inventory turnover ratio	
		Cooperative	Private
1	2018–19	1:0.31	1:0.14
2	2019–20	1:0.18	1:0.18
3	2020–21	1:0.24	1:0.14
4	2021–22	1:0.26	1:0.12
Overall average		**1:0.25**	**1:0.14**

Employee Cost to Total Expenditure

The average employee cost to total expenditure ratio varied from 1:0.03 to 1:0.06 in case of cooperative dairy plants while in case of private-sector plants, it varied from 1:0.05 to 1:0.06, which is fairly constant (see Table 46). This implies that for the given technological set up and the corresponding capacities, the employee cost would remain stable. However, from an overall productivity point of view, this constitutes a major part of the total processing cost and hence needs to be looked at. Further, with emphasis on quality and hygienic production, the involvement of human beings is becoming less and less, especially in the processing area. There are instances of fully automatic plants where only a handful of people are required to manage the entire plants.

TABLE 46

EMPLOYEE COST TO TOTAL EXPENDITURE RATIO.

Sl. no.	Years	Employee cost to total expenditure ratio	
		Cooperative	Private
1	2018–19	1:0.06	1:0.06
2	2019–20	1:0.04	1:0.05
3	2020–21	1:0.03	1:0.06
4	2021–22	1:0.03	1:0.06
Overall average		**1:0.04**	**1:0.06**

Processing Cost to Total Expenditure

The processing cost to total expenditure (PCTE) ratio indicates the efficiency of a plant. The lower the PCTE ratio the higher the plant's efficiency is. As may be seen from Table 47, the overall PCTE ratio for cooperative dairy plants was 1:0.09 (varying from 1:0.08 to 1:0.10) while for private-sector plants it was 1:0.15 (ranging from 1:0.13 to 1:0.16). That it is higher in private-sector plants compared with cooperative sector plants means that the efficiency of private dairy plants is lower than that of cooperative-sector plants. Further, as can be seen from the table, for both cooperative and private dairy plants, the PCTE shows a stable trend.

TABLE 47

PROCESSING COST TO TOTAL EXPENDITURE RATIO.

Sl. no.	Years	PCTE ratio	
		Cooperative	Private
1	2018–19	1:0.10	1:0.16
2	2019–20	1:0.08	1:0.13
3	2020–21	1:0.09	1:0.16
4	2021–22	1:0.09	1:0.16
Overall average		**1:0.09**	**1:0.15**

Sales Per Employee

This is indicative of labor productivity, which has direct relation with the technology available at the plant level. The sophistication of new plants (automatic plants) requires a smaller number of qualified technical people. Sales per employee would increase if we put higher skilled manpower on job.

As may be seen from Table 48, the annual sales per employee was higher in case of cooperative-sector plants than in case of private-sector plants for the period under consideration. It varied from INR18.57 million to 23.76 million in cooperative dairies and from INR8.42 million to INR9.15 million in private dairy plants. More automation was observed in cooperative dairy plants where most of the dairy operations were being managed with limited manpower and proper/strict supervision, thereby resulting in higher sales per employee.

TABLE 48

SALES PER EMPLOYEE.

Sl. no.	Years	Sales per employee in INR million	
		Cooperative	Private
1	2018–19	18.57	8.42
2	2019–20	21.32	8.45
3	2020–21	19.89	8.38
4	2021–22	23.76	9.15
Overall average		**20.88**	**8.60**

Debt–equity Ratio

The debt–equity ratio is worked out to ascertain the long-term financial position and soundness of the financial policies of a dairy plant. This ratio expresses the relationship between debt and equity. A higher ratio indicates a risky financial position while a lower ratio indicates a safer financial position. In India, this ratio may be taken as acceptable if it is 2:1. Nowadays, leading institutions prefer it to be 1:1.

As may be seen from Table 49, the overall debt–equity ratio during the study period varied from 1:8.29 to 1:12.84 in case of cooperative-sector dairy plants while for private-sector plants it varied from 1:0.31 to 1:0.75 (much lower than that in the cooperative sector). Cooperative dairy plants have large amounts of loans from NDDB/lead banks. The interest payment on such large loans also affects their profitability. Thus, there is lot of scope for improvement on this front in cooperative dairy plants.

TABLE 49

DEBT–EQUITY RATIO.

Sl. no.	Years	Debt–equity ratio	
		Cooperative	Private
1	2018–19	1:12.84	1:0.75
2	2019–20	1:9.98	1:0.61
3	2020–21	1:8.29	1:0.31
4	2021–22	1:8.64	1:0.33
Overall average		**1:9.93**	**1:0.50**

Total Income to Total Expenditure Ratio

The total income to total expenditure (TITE) ratio should be high to enhance the future growth of the dairy industry, otherwise dairy plants may become unviable. It was high in value-added products plants but not in case of liquid plants (as milk is highly perishable with limited shelf life). The overall TITE ratio in case of cooperative-sector plants varied from 1:0.91 to 1:0.92 while in case of private-sector plants, it varied from 1:1.04 to1:1.12, which is higher than that in the cooperative sector. As can be seen from Table 50, in case of cooperative-sector plants, the TITE was almost constant during the study period while it varied in case of private-sector plants.

TABLE 50

TOTAL INCOME TO TOTAL EXPENDITURE RATIO.

Sl. no.	Years	TITE ratio	
		Cooperative	Private
1	2018–19	1:0.92	1:1.07
2	2019–20	1:0.92	1:1.04
3	2020–21	1:0.91	1:1.12
4	2021–22	1:0.91	1:1.10
Overall average		**1:0.91**	**1:1.08**

Working Capital Turnover Ratio

This ratio shows the number of times the working capital has been employed at various stages in the process of operation of a dairy plant. It indicates whether the working capital has been effectively utilized or not. The higher the ratio, better is the efficiency in the utilization of working capital.

It can be seen from Table 51 that the overall working capital turnover ratio varied from 1:0.48 to 1:0.66 in case of cooperative-sector plants and from 1:0.12 to 1:0.21 in private-sector dairy plants.

The reason for higher working capital turnover ratio in cooperative-sector dairy plants is mainly the faster cash realization from sales, which results in quicker payment made by them to milk producers for the milk procured. This shows that cooperative-sector dairy plants have utilized working capital more effectively compared with private-sector dairy plants.

TABLE 51

WORKING CAPITAL TO TOTAL CAPITAL TURNOVER RATIO.

Sl. no.	Years	Working capital turnover ratio	
		Cooperative	Private
1	2018–19	1:0.54	1:0.13
2	2019–20	1:0.48	1:0.12
3	2020–21	1:0.58	1:0.20
4	2021–22	1:0.66	1:0.21
Overall average		**1:0.56**	**1:0.17**

Net Current Assets Turnover Ratio

The net current assets turnover ratio indicates the number of times the current assets have been employed in the processing of milk and manufacturing of milk products for sales. The higher the ratio, the better the efficiency of utilization of current assets is. As can be seen from Table 52, the overall current assets turnover ratio during the study period (from 2018–19 to 2021–22) was higher (1:17.86) in private-sector dairy plants and varied from 1:12.04 to 1:28.29 compared with that in cooperative-sector dairy plants (1:5.11) where it ranged from 1:3.99 to 1:6.03.

TABLE 52

NET CURRENT ASSETS TURNOVER RATIO.

Sl. no.	Years	Net current assets turnover ratio	
		Cooperative	Private
1	2018–19	1:3.99	1:18.71
2	2019–20	1:6.03	1:28.19
3	2020–21	1:5.10	1:12.51
4	2021–22	1:5.32	1:12.04
Overall average		**1:5.11**	**1:17.86**

Return on Total Assets

This ratio indicates how effectively the total assets have been utilized in dairy plants. It measures the extent of utilization of assets for maximizing the return. The higher the ratio, the better the utilization of assets is. A close perusal of Table 53 reveals that the overall return on total assets varied from 1:1.95 to 1:2.35 in cooperative dairy plants and from 1:2.23 to 1:3.08 in private dairy plants. It is quite evident from the table that the return on total assets was generally found to be higher in private plants compared with cooperative dairy plants. This shows that cooperative-sector dairy plants had not utilized the available assets properly.

TABLE 53

RETURN ON TOTAL ASSETS.

Sl. no.	Years	Return on total assets	
		Cooperative	Private
1	2018–19	1:1.95	1:2.23
2	2019–20	1:2.35	1:3.08
3	2020–21	1:2.23	1:2.42
4	2021–22	1:2.23	1:2.63
Overall average		**1:2.22**	**1:2.64**

Productivity Norms

For an industry that is widely distributed across the country and has large variations in terms of management, technology, products, and customers, it is very difficult to arrive at some common norms that could be used as yardsticks to measure productivity performance. The productivity performance is basically a sum total of all factorial productivity (such as capital productivity, labor productivity, material productivity, machine productivity, and production methods) on one hand and quality of product and satisfaction of customers on the other hand.

The analytical attempt made in this report is only a small portion of the productivity measurement process, because the required data for many of the measurable parameters has not been maintained by the sample dairy plants. Several other parameters are still intangible and can only be measured indirectly. In majority of cases, productivity parameters receive low priority against day-to-day industry problems and unequitable sharing of gains of productivity. However, for the overall healthy growth of the dairy industry and for it to remain globally competitive, productivity parameters that are result based and not process based have been measured and made known widely in the dairy sector. With this in view and with the constraints of time, money, and data, a few of such parameters have been compiled and presented in Table 54.

These values may be taken as indicative for the reasons given above. Nevertheless, if the units make concerted efforts to improve and rise toward the best values, the dairy industry will find its place of pride in the world market.

TABLE 54

PRODUCTIVITY NORMS WITH INDICATIVE NORMATIVE VALUES FOR VARIOUS PRODUCTIVITY PARAMETERS.

Sl. no.	Parameter and unit/ratio	Cooperative		Private		Indicative normative value
		Minimum	Maximum	Minimum	Maximum	
1	Milk handled (ton) per employee (MHPE)	367.49	405.46	183.54	212.11	350
2	Average cost per employee (INR in lakhs)	5.17	6.64	2.69	3.05	4.50
3	Employee cost to total expenditure	1:0.03	1:0.06	1:0.05	1:0.06	1:0.06
4	Processing cost per ton of milk (PCPT) in INR	482.11	546.16	371.27	462.50	460

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Sl. no.	Parameter and unit/ratio	Cooperative		Private		Indicative normative value
		Minimum	Maximum	Minimum	Maximum	
5	Labor cost per ton of milk (LCPT) in INR	1,953.66	2,991.22	1,343.49	1,788.58	2,000
6	Employee cost to total expenditure	1:0.03	1:0.06	1:0.05	1:0.06	1:0.05
7	Energy cost per ton of milk (ECPT) in INR	522.12	630.38	622.73	727.47	600
8	Packaging cost per liter of milk (PCPL) in INR	1.33	1.84	1.14	1.54	1.40
9	Selling and promotional cost per liter of milk (SPCL) in INR	0.44	0.54	0.12	0.15	0.35
10	Packaging cost to total expenditure (%)	0.03	0.03	0.04	0.05	0.04
11	Selling cost to total expenditure	1:0.0089	1:0.0093	1:0.0040	1:0.0063	1:0.0080
12	Working capital to total capital employed	1: 0.04	1: 0.05	1: 0.15	1: 0.51	1:0.08
13	Fixed asset turnover	1:4.32	1:5.04	1: 4.58	1:5.29	1:4.75
14	Inventory turnover	1:0.18	1:0.31	1:0.12	1:0.18	1:0.15
15	Average profit per liter of milk (APPL) procured in INR	0.22	0.32	0.88	2.60	1.00
16	Average profit per liter of milk (APPL) processed in INR	2.70	4.10	7.73	14.41	7.00
17	Milk processed to procured ratio (MPPR)	1:0.96	1:1.00	1:0.84	1:0.94	1:0.98
18	Capacity utilization by working hours (CUWH) %	22.40	23.20	20.00	20.00	21.30
19	Capacity, milk powder %	34.00	37.33	17.50	22.50	33.00
20	Capacity, ghee (CUG) %	11.80	13.40	14.00	14.50	14.00
21	Capacity, paneer %	4.20	4.53	5.00	5.50	5.00
22	Water use ratio (WUR)	1:1.24	1:1.33	1:1.72	1:1.80	1:1.10
23	Capacity utilization of the dairy plant, milk procured (%)	92.70	102.41	81.44	91.36	95.00
24	Debt-equity ratio	1:8.29	1:12.84	1:0.31	1:0.75	1:1
	Total expenditure to total labor cost (TETLC) in %	3.36	3.51	5.19	5.92	4.00
25	Total income to total expenditure (TITE)	1:0.91	1:0.92	1:1.04	1:1.12	1:1.05
26	Return on total assets	1:1.95	1:2.35	1:2.23	1:3.08	1:2.25
27	Net current assets turnover ratio	1:3.99	1:6.03	1:12.04	1:28.19	1:8.00
28	Sales per employee in INR lakh	237.60	185.66	84.22	91.46	200

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Sl. no.	Parameter and unit/ratio	Cooperative		Private		Indicative normative value
		Minimum	Maximum	Minimum	Maximum	
29	Working capital turnover ratio	1:0.48	1:0.66	1:0.12	1:0.21	1:0.50
30	Processing cost to total expenditure	1:0.08	1:0.10	1:0.13	1:0.16	1:0.10
31	Profitability ratio	1:0.98	1:1.03	1:1.43	1:1.62	1:1.10

Qualitative Parameters

Due to increased awareness among consumers, everybody wants to purchase quality products. So, maintaining the quality of products by dairy plants is not a choice but compulsion. Keeping in view this fact, information on various parameters that affect the quality of products has been ascertained and presented in a self-explanatory manner.

Major Constraints in Dairy Processing Industry Achieving Higher Productivity Performance

Some of the major constraints that impede the dairy processing industry in achieving higher productivity performance are

- excess installed capacity versus total milk procured by dairy units;
- low capacity utilization for products manufacturing;
- inadequate logistics of procurement and distribution (inadequate infrastructure and transport facilities);
- low marketable milk surplus in certain pockets where dairy activities are low;
- low employee productivity;
- cost of inputs (labor, energy, and packaging material) increasing faster than the final milk price;
- higher awareness on quality and hygiene putting more pressure on dairy units;
- high cost of conversion in case of SMP not being internationally competitive;
- low margins, especially in case of the private sector;
- low consumption of milk per capita compared with the world average, resulting in low domestic demand;
- lower penetration of branded products at the national level due to high demand as well as preferences for local brands;
- stiff competition with MNCs but large demand for traditional milk products; and

- location consideration based on incentives rather than milk availability (more incentive declared by the government for hilly and northeastern regions).

Major Constraints in Dairy Industry Achieving Higher Productivity Performance

Despite its tremendous performance on the production front, Indian dairy sector is constrained by low yields. According to the Organization for Economic Co-operation and Development estimates (OECD), the average yield in India between 2017 and 2019 stood at a meagre 1.3 ton per in-milk animal, which was substantially lower than the yields recorded by some of the leading milk producers like the USA (10.5 ton per in-milk animal); European Union (7.2 ton per in-milk animal); and New Zealand (4.3 ton per in-milk animal). Low levels of yield can pose a major challenge for the sector to leverage the demand-side potential and meet the growing demand. Emergence of several dairy entrepreneurs with innovative and cost-effective interventions at different stages of the dairy supply chain infuses much optimism for the sector. They aim to tackle the challenges of low productivity arising from limited genetic potential and lack of nutrition due to a national shortage of feed and fodder.

As a key player in the global dairy market, India is positioned to be an industry leader. Although operational challenges still account for major losses, investments in technology and attention to changing consumer needs have already contributed to considerable improvements. With a strong exports forecast, the dairy industry in India remains one of the country's most lucrative sectors. During the visits to dairy units and discussions held with dairy farmers, the following challenges emerged:

- inadequate availability of fodder, especially green fodder, throughout the year;
- price of feed and fodder increasing very fast;
- most of the marginal and small farmers not having proper cattle sheds;
- lack of well-equipped veterinary hospitals nearby;
- insufficient number of veterinary doctors and paravets at most of the veterinary hospitals for attending to emergency services;
- by and large, dairy farmers not getting the veterinary services at their doorsteps;
- Indian cattle and buffaloes having lower productivity in comparison with developed countries;
- improving productivity of farm animals being a major challenge because milk producers are not able to get the quality breed of milch animals due to various reasons;
- crossbreeding of indigenous species with exotic stocks to enhance genetic potential of different species being successful only to a limited extent;
- limited availability of sort sex semen and low awareness about it among milk producers;

- shortage of organized dairy farms (hence the need for a high degree of investment to take dairy industry to global standards);
- the sector coming under significant adjustment pressure from emerging market forces (even though globalization will create avenues for increased participation in international trade, stringent food safety and quality norms would be required);
- access to markets critical to speed up commercialization (lack of access may act as a disincentive for farmers in adopting improved technologies and quality inputs);
- inadequate logistics of procurement and distribution (inadequate infrastructure and transport facilities);
- low marketable milk surplus in certain pockets where dairy activities are low;
- excess installed capacity versus total milk procured by dairy units;
- low capacity utilization for products manufacturing;
- higher employee productivity in the cooperative sector due to availability of required infrastructure;
- cost of inputs (labor, energy, and packaging) increasing faster than the final milk price;
- higher awareness for quality and hygiene among consumers putting more pressure on dairy units;
- high cost of conversion of milk to SMP (not internationally competitive);
- low margins in cooperative-sector dairy plants because most of the dairy plants are liquid plants (sale of milk being more than 66%);
- lower penetration of branded products due to local availability and preferences;
- more competition with MNCs but large demand for traditional milk products; and
- location consideration based on incentives rather than milk availability.

Strategies for Sustainable Modernization of Agriculture and Dairy Sector in India

The primary constraint in the dairy sector is low productivity across dominant species of cows and buffaloes. The population of high-yielding crossbred animals has seen slow growth in India, contributing only 28% of the total milk production, with the rest being contributed by indigenous breeds. Apart from productivity challenges, animal health monitoring, lack of quality fodder and feed and limited market access have been critical bottlenecks in this sector. Keeping in view the above constraints, precision dairy farming may be introduced to maximize animal performance and early detection of diseases in cows. Besides, following strategies may also be considered by the Government of India as well as various state governments:

- low interest loans for small- and medium-scale farmers for purchasing the cattle;
- encouraging cattle markets to provide quality breeds of animals;
- encouraging rural women to take up animal husbandry;
- providing education and training for small-and-medium-sized farmers toward breeding, feeding, and management of dairy farming at the *panchayat* level;
- nurturing dairy entrepreneurs through effective training of youth at the village level, coupled with dedicated leadership and professional management of farmers' institutions;
- promoting good agricultural practices, sanitation, and quality of drinking water and fodder, aligned with the goal of quality milk;
- improving veterinary facilities, especially artificial insemination of cattle with sex sorted semen;
- promoting use of chips and body sensors to prevent disease outbreaks and crucial large-scale livestock management (chips and body sensors measure vital parameters and indicators that could detect illness early and prevent herd infection);
- insurance of cattle against diseases like anthrax, foot and mouth, peste des ruminants, etc.;
- contract/corporate dairying and emerging global dairy trade to rope in dairy supply chains stakeholders in order to expand their outreach and on-the-go product positioning in target segments;
- digital technology-enabled dairy farms to identify their compatible partners and competitors for co-creation through product–process innovation via relationship/value-based marketing;
- bringing technology innovation to store milk or milk products for freshness in large dairy farms in association with startups;
- upgrading facility of logistics for produced milk;
- encouraging private-sector firms to procure dairy produced at the rural level;
- there being no authentic data source from where the procurement capacity of organized private dairies can be verified, there is an urgent need for the NDDB to step up and collect comprehensive data for organized private players in India systematically and make it available in the public domain;
- keeping in view that extension support is weak or non-existent in the case of animal husbandry in India and yet the contribution of dairy farming to farmer's income has increased during last three decades, there is an urgent need to strengthen the extension activities;
- with a view to providing food and nutrition security in the country, emphasis is being put on crop husbandry, but considering the growing importance and demand for livestock

products, the government needs to rethink and increase the allocation on R&E toward livestock sector (it has been observed that around 70% of the total agriculture R&E budget is allocated to crop husbandry, and only 10% is allocated to animal husbandry and dairy development. However, animal husbandry and dairy segment have grown in importance, and this is in contrast with the gradual transformation of the agriculture sector in India).

Besides, the following aspects may also be considered by the Government of India for enhancing the productivity of milch animals:

Availability of good genetic material: Due to import prohibition, the available exotic genetic material with the dairy industry could not be replenished. It is therefore required that the government liberalizes the import policy with respect to semen, embryos, and animals.

Scientific breeding policies: There is no strict scientific animal breeding policy in India, at least in practice. It is just free for all. A number of countries have incorporated Indian animals' blood in their breeds and developed distinct but stable breeds. Instead of crossbreeding, efforts should be made to develop stable productive breeds in India. Internationally, industry–private participations have done this successfully. In India too, there is a need to support private research initiatives (in partnership with academic institutes). It is therefore suggested that the government considers such policy changes (CSIR is supporting this concept).

Privatization of animal health and productivity services: The state governments are neither able to provide recurring grants to existing veterinary units nor the extension of services to new areas is possible. In this scenario, privatization of services is one possible option. This could be done either through milk producers' unions or veterinarians' societies. In order to ensure quality services to farmers at affordable costs, privatization will have to be regulated, like in any other service market. International experience suggests that for privatization of veterinary services, the government will have to play a proactive role and develop suitable model(s). Private partnership will bring quality to services (poultry is an example).

Regulation and accreditation of private service providers and R&D laboratories: In order to encourage private participation, it will be essential for the government to develop a system of accreditation and regulation. This is an international requirement to ensure uniform quality. Even for exports, there is a need to get health certifications from accredited laboratories. It is suggested to form of the following accreditation units:

- frozen semen and embryo banks;
- disease diagnostic laboratories;
- herd health and productivity management centers;
- private veterinary service providers;
- feed and mineral mixtures; and
- para-veterinarian/para-professional regulatory councils.

There is also a need to develop regulations for accreditations after a wider consultation. This will hasten the process of privatization, maintain uniformity, and create employment opportunities.

Private veterinary diagnostic laboratories: In order to avoid irrational use of drugs in animals, which ultimately result in residues, there is a need to encourage private diagnostic laboratories as part of herd health and productivity management (or rural veterinary business facility). The concept of team approach, i.e., 10–15 para veterinarians and one veterinarian providing protocol-based veterinary services to 10,000 to 15,000 animals spread in village clusters and keeping their records, which can be shared by the government, would be an economically feasible model. There is an urgent need to develop and validate suitable animal health service delivery models.

Development of rapid animal disease diagnostic kits with private industry participation: Animal health management involves testing and monitoring for various diseases. Brucellosis is one such disease for which the international requirement (for export) is ELISA testing. Earlier ADMAS (in Bangalore) had developed an ELISA reagent, which has been used for few years. Now this kit is not available as the production has been discontinued. It is proposed that this technology be transferred to the private industry at an affordable cost so that the kits are made available. Diagnostic kits developed as per internationally accepted norms are urgently needed to ensure quality animal products. As a matter of fact, as part of the regulation of animal and human health, testing of animals for important diseases should be made compulsory and the cost should be paid for by the government (as done internationally). If this policy decision is taken, many private industries will show interest in this venture. The imported kits are extremely expensive. There is also a need to develop 'animal-side' diagnostic kits for on-field diagnosis of health and reproduction problems. It is suggested that the government takes initiatives to bring private industries, veterinary institutes, and the dairy industry together to form a multidisciplinary team to develop these technologies for commercial exploitation. These kits would also have great export potential since many developing countries cannot afford western reagents.

Conclusion

Apart from enhanced availability of the newly released seeds of high yielding varieties recommended by the ICAR, strong field-level extension, government procurement at enhanced minimum support prices in case of glut in markets, and effective government programs like NFSM, APPP, and RKVY have helped in enhancing crops production in India. This needs to be up-scaled and out-scaled through appropriate technological support, favorable government policies, and remunerative pricing backed by an effective supply chain management.

Better price realization, efficient post-harvest management, improvement in irrigation facilities, competitive value chains, and adoption of allied activities can contribute to at least one-third increase in the farmer's income. Liberalization of the agricultural sector may be considered to attract private investment in production and market operations. The government may consider taking bold decisions with a vision of taking the sector forward and addressing the plaguing issues associated with it.

In principle, innovations and modernization of dairy farms can provide better productivity and profitability over the conventional system of dairy farming. They can provide greater flexibility in routine works of commercial dairy farming.

In order to solve the drawbacks of the traditional measurement model based on Cobb–Douglas (C–D) production function of statistics in the analysis of total factor productivity of agriculture, the analysis method based on stochastic block model (SBM) is proposed. With SBM-based agricultural total factor productivity algorithm and the obtained sample data, agricultural efficiency and agricultural total factor productivity would be analyzed. The production analysis will help in ascertaining how much yield would be enough.

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INDONESIA

Background

Commitments on SDGs and Emissions

Indonesia is faced with global challenges such as increasing productivity, eliminating hunger and poverty, managing climate change and greenhouse gas (GHG) emissions, addressing land degradation, maintaining energy sustainability, and sustaining environmental health [2, 7, 11].

Conventional agriculture, without the internet of things (IoT) technology, tends to apply more input energy to reach the productivity required for eliminating poverty and hunger [1, 7]. The application of more energy input contributes to excessive GHG emissions and accelerates global warming [1, 7, 21]. Global warming directly threatens the progress toward maintaining environmental sustainability as part of the Sustainable Development Goals (SDGs) and indirectly threatens the progress toward decreasing poverty and hunger [7].

Indonesia is committed to SDGs as a global action to end poverty, reduce inequality, and protect the environment [10, 12] by encompassing farming practices that sustainably increase productivity, enhance resilience/adaptation, reduce GHG emissions, and help achieve national food security and development goals [8].

The application of IoT can be a catalyst for increasing productivity and sustainability to reach the SDGs by mitigating GHG emissions [6, 21]. Ending poverty and hunger still remain on top of the agenda, being the first two of the 17 SDGs. And, given that the majority of global poor (smallholders) live in rural areas, agriculture is still the key target sector for efforts to reach these goals [7].

Finally, smallholders adopting IoT using low-cost technologies, is the key to achieving SDG targets in developing countries [1]. In addition, we need to understand how improving agricultural technology adoption for increasing agricultural productivity and incomes of smallholders as well as reducing poverty and hunger are the top SDGs [7]. We also need a measurement to monitor and evaluate the progress of the SDGs and to track the country's performance in achieving the 17 SDGs [12].

Various studies have been conducted in Indonesia to provide solutions on how to overcome climate change and GHG emissions without neglecting to increase productivity for achieving food security and decreasing poverty and hunger [5, 6, 11, 16, 22, 23, 24, 25, 29, 32, 34, 35].

Unsustainable and Unproductive Agriculture Based on SITASI

Persistently high levels of hunger, malnutrition, and unsustainable human activities present major challenges to agriculture. The indicators of SDGs for the agricultural sector can portray the extent to which a series of global action plans are applied to the sector through Indonesia's integrated agricultural pilot survey, known as SITASI, which is used as a data source for measuring indicators of sustainable agriculture [12] (see Table 1).

TABLE 1

SDG INDICATORS REFLECTING VARIOUS DIMENSIONS OF SUSTAINABILITY WITH 11 THEMES AND 11 SUBINDICATORS.

Dimensions	Themes	Subindicators
Economic (productivity)	(1) Land productivity	Land productivity
	(2) Profitability	Farm profit
	(3) Resilience	Mitigating risks
Environmental	(4) Soil health	Soil degradation prevalence
	(5) Water use	Availability of water for various uses
	(6) Fertilizer pollution risk	Fertilizers management
	(7) Pesticide risk	Pesticides management
	(8) Biodiversity	Implementation of practices supporting biodiversity
Social	(9) Decent employment	Agricultural wage rates
	(10) Food security	Food Insecurity Experience Index (FIES)
	(11) Land tenure	Ensured rights to land ownership

The measurement of SDGs encompasses three dimensions comprising 11 themes and 11 subindicators, as outlined in Table 1. By applying sustainability criteria and thresholds, the outcome for each subindicator is depicted across three spectrums: desirable, acceptable, and unsustainable.

The findings of SITASI in three provinces (West Java, East Java, and West Nusa Tenggara) in 2020 showed that 89.72% of the agricultural land utilized in these provinces fell in the substandard category in terms of productive management for ensuring sustainable agriculture. Based on the management of pesticide used, 98.49% of the agricultural land was categorized as sustainable land, consisting of 36.21% in the desirable category and 62.28% in the acceptable category. In East Java, farmers utilized fertilizers on 67.58% of agricultural land, yet none of the specific measures to mitigate the risks associated with fertilizer usage were implemented. As a result, this agricultural land was categorized as unsustainable. According to the subindicator of farm profit, 97.13% of the agricultural land was classified as sustainable. Within this, 32.05% was deemed desirable, 65.08% acceptable, and the remaining 2.87% categorized as unsustainable agricultural land.

Objectives

The achievement of these goals on sustainable agriculture will have a positive impact in supporting the achievement of other SDGs indicators [12]. So, this research has two main objectives:

(1) Compare total factor productivity (TFP) and total resource productivity (TRP) in Indonesian agriculture (macro approach with SITASI data and previous studies).

(2) Estimate the impact of soil health and pesticide reduction on farmers' productivity (micro approach in Nagekeo District of East Nusa Tenggara province).

Agricultural Productivity Indicators

Shifting TFP to TRP

TFP encompasses all individuals, companies, or systems within a specified scope. It primarily focuses on measuring output, marketable inputs, and costs [15, 27]. However, it has been emphasized that effective, efficient, and quality measures are incomplete without considering environmental aspects [18]. In contrast, TRP complements TFP by incorporating environmental factors into the measurement [10, 18, 19].

Proper measures of productivity growth serve as indicators of how efficiently the society allocates its limited resources. In this context, there is little distinction between traditional inputs like labor, capital, and materials; and natural resources such as air and water. Each resource is scarce, implying that consuming any of them incurs true opportunity costs. Productivity growth is a real, rather than nominal, concept. Therefore, there is a strong argument for expanding TFP into TRP [19].

TRP enhances the efficiency of TFP by considering how effectively the society transforms its scarce resources into outputs. This study follows the approach outlined by Gollop and Swinand [19] to calculate TRP, which incorporates environmental quality (S/Y) as given in Equation 1:

$$¥ = R\ (Y,\ S/Y,\ X',\ T) \tag{1}$$

Here, the maximum value of aggregate output (¥) is a function of output (*Y*), environmental quality (*S/Y*), resources (*X'*), and technology (*T*). Negative externality, represented by undesirable output (S), limits the economy's production (*Y*). The function R exhibits standard homogeneity properties.

The function *R* increases with *S/Y, X'*, and *T*, but decreases with constant quality output *Y*. Holding *Y* constant, an increase in *S/Y* releases resources to produce additional aggregate output (¥), whereas an increase in *Y* consumes resources and thus reduces aggregate output. There exists a positive rate of transformation between *Y* and *S/Y*.

Returning to the more general representation of *R*, the objective of the producing sector of the economy is to maximize production, given the supplies of primary factors of production (*X'*); sectoral production functions summarized in the technology variable (*T*); market equilibrium conditions for inputs (*X'*) and conventional outputs (*Y*); and existing societal restrictions, if any, on environmental quality (*S/Y*).

For instance, a firm utilizes resources (*X*) and technology (*T*) to produce two outputs: the marketable output (*Y*) and the regulation-mandated output (*S/Y*). This study will incorporate environmental indicators and resource accounting to develop TFP data. The value of TRP will likely be lower than TFP due to the negative externality value, as illustrated in Equation 2.

$$TRP^G = \left(\frac{M}{M-\eta S}\right)\left[\frac{d\ln Y}{dT} - \frac{\sum w_i}{M}\frac{d\ln X_i}{dT}\right] - \left(\frac{\eta S}{M-\eta S}\right)\frac{d\ln S}{dT} \tag{2}$$

or

$$TRP^G = \left(\frac{M}{M-\eta S}\right)\mathrm{TFP}^G - \left(\frac{\eta S}{M-\eta S}\right)\frac{d\ln S}{dT} \tag{3}$$

Here, TRP^G represents the growth of TRP, where w_i stands for input prices, and M represents money income. Additionally, η equals the absolute money value of the marginal disutility of S or represents the marginal abatement cost (shadow price) of S. On the other hand, if there is no externality or $\eta = 0$, TRP^G will be similar to the growth of TFP, i.e., TFP^G. Further explanations of the indicators of TFP and TRP will be provided.

Total Factor Productivity

Research Assumptions to Measure TFP

The assumptions utilized in this study to measure TFP are as follows:

(1) The production function follows the modified Solow Neoclassical Growth Model, where technology is treated as an exogenous factor.

(2) The inputs of production factors, including both labor and capital, operate under 'perfect competition' market conditions.

(3) Capital stock is approximated using the 2015 input-output table.

Data Types and Sources for Measuring TFP

Research on TFP measurement employs time series data from the agricultural sector spanning from 2010 to 2020. The necessary data includes:

(1) gross domestic product (GDP) at both constant and current prices (in billion rupiah);

(2) net capital stock (in billion rupiah);

(3) the area of managed land (in hectare);

(4) the number of workers (in persons);

(5) wages/salaries of workers (in rupiah); and

(6) the input-output table for the year 2015.

Data were obtained from various sources, such as BPS (Statistics Indonesia); Ministry of Agriculture of Republic of Indonesia; the World Bank; and various journals and literatures related to this research.

TFP Measurement

TFP measures agricultural efficiency by comparing total output (crops and livestock) to the combined amount of labor, capital, and other resources (intermediate inputs) used in production. Drawing from economic and index number theory, and under certain restrictive assumptions regarding the form of the underlying production function, TFP is defined as the ratio of the aggregate measures of outputs to the aggregate measures of inputs used in the production process [15].

TFP Growth Decomposition

Output is quantified as the value of everything farmers sell, keep for their own use, and have in stock, as obtained from BPS. This value encompasses government subsidies but excludes indirect taxes such as sales tax. The prices utilized are those received by farmers (producer prices). Furthermore, any production that cannot be delineated from farming activities, even if it falls outside strict agricultural boundaries (such as raising chickens for egg sales), is incorporated [14].

TFP calculation in this study uses the growth accounting model (GAM) following a previous study [14]. This method was chosen because it is relatively easier and widely used in various countries in calculating TFP growth.

The assumption of the theory of endogenous growth developed by David H. Romer in 1986, which is eliminating the exogenous assumption of technological progress [31], is used in this study. The theory overcame several problems in the neoclassical growth theory proposed by Robert M. Solow and basically follows the Cobb–Douglas production function. The scope of research for measuring TFP is growth of output, growth of capital, and growth of labor.

The steps for decomposing TFP growth using the GAM approach are outlined as follows:

(1) Calculate the growth rates of GDP, labor, and net capital stock in the agricultural sector. Net capital stock is derived from the difference between the purchase price of capital and its depreciation value, while the proportion of sectoral capital stock is obtained through the aggregation of sectoral capital stock in the 2015 Input-Output Table.

(2) Compute the labor income share (LIS) and capital income share (CIS) in the agricultural sector.

(3) Determine the weighted growth of labor and capital in the agricultural sector. This involves multiplying the labor income share and capital income share by the growth rates of labor and capital, respectively.

(4) Calculate the TFP growth by subtracting the weighted growth of both labor and capital from GDP growth.

(5) Determine the correlation between the growth rates of labor, capital, and TFP to economic growth, i.e., GDP.

(6) Analyze the decomposition of economic growth and the contribution of each factor of production to agricultural economic growth.

Input of Labor

Labor productivity in agriculture measures the output generated per unit of labor input utilized in the production process. It is calculated by dividing the volume of output by the total units of labor used:

$$\text{Labor productivity} = \frac{\text{Volume of output}}{\text{Units of labor used}}$$

Various methods can be employed to quantify labor input, including the number of active workers on the farm; the number of hours, days, or months worked; or full-time equivalent units based on average daily working hours according to specific country standards.

The agricultural workforce typically comprises individuals aged 15 years and above engaged in agriculture, forestry, hunting, and fishing. Labor cost encompasses wages and benefits paid to hired labor, as well as the imputed wage bill for unpaid family labor or own labor. The imputed compensation for unpaid labor is determined by referencing comparable compensation rates for paid labor with similar demographic characteristics. Adjustments for changes in labor quality are intricate and comprehensive.

In this study, labor input will be measured using the number of effectively worked hours. This approach accounts for variations between seasonal and nonseasonal workers and different working schedules (part-time versus full-time), enabling more accurate comparisons across production systems, regions, and countries. Metrics such as hours worked and compensation per hour will be developed for laborers categorized by gender, age, education, and employment class (employee, self-employed, or unpaid family labor) to establish quality-adjusted labor input.

Input of Capital

Capital productivity assesses the efficiency of capital utilization in the production process. Capital typically refers to assets owned by the farm that provides services over multiple years. This study will primarily focus on measuring capital invested in machinery and equipment, farm buildings, and stock/inventories. However, the area of land managed will be treated separately from capital input.

In this study, capital input will include the number of livestock kept, with livestock farm size quantified in terms of tropical livestock units (TLU). TLU serves as a standardized measure to compare the relative sizes of different livestock herds. It is calculated by converting the body weight of livestock to metabolic weight, providing an 'exchange ratio' among livestock species.

Capital productivity is computed using the following formula:

$$\text{Capital productivity} = \frac{\text{Volume of output}}{\text{Volume of capital input}}$$

This metric enables the assessment of how effectively capital resources contribute to production output.

Input of Land

The area of agricultural land encompasses rice fields, gardens, fields, aquaculture areas, and areas allocated to forest concession companies. This data includes fallow land, seasonal or annual crop land, and rented land, excluding conservation-forest land and abandoned areas. Information on rice fields, gardens, and fields is sourced from the Agricultural Land Area Statistics issued by the Ministry of Agriculture.

Land productivity measures the output generated by a given area of land. While primarily applicable to cropping activities, it can also extend to certain cases of livestock production. Various productivity measures can be calculated:

(1) A broad measure is the ratio between the value of all agricultural products (crops and livestock) and the total land used in agriculture.

(2) Other land productivity measures involve dividing crop production by the amount of planted land, expressed in hectare. This amounts to crop yield when expressed in physical output (e.g., tons of maize) or return on land when expressed in monetary terms.

$$\text{Land productivity} = \frac{\text{Volume of output}}{\text{Planted area}}$$

Planted area is preferred over other area concepts, such as harvested area, to measure effective yield or land productivity. Inputs are typically applied before harvest on the sown/planted area, not on the harvested area, which is often unknown at the preharvest phase. The disparity between harvested and planted areas may also indicate the efficiency and relevance of farming practices.

Intermediate Input

Intermediate inputs, also known as intermediate consumption, refer to goods and services utilized or entirely consumed in the production process during an accounting period or agricultural season. In agriculture, intermediate inputs encompass purchases made by farmers for raw and auxiliary materials utilized as inputs across various agricultural activities. In this study, intermediate inputs are synonymous with agricultural production costs, encompassing expenses such as seeds, fertilizers, pesticides, feed, rental costs, transportation, depreciation of capital goods, and other related expenditures.

Intermediate inputs are typically valued at the price actually paid by the farmer, which may include subsidies and taxes. Identifying and quantifying subsidies and taxes is recommended, as it provides valuable insights into the significance and impact of these incentives for farmers.

To gauge the productivity of intermediate inputs, the numerator of the productivity ratio should comprise gross agricultural output, encompassing final products and intermediate (agricultural) products used in agricultural production. When using value-added or net output as the numerator, the effect of intermediate consumption is already considered.

Total Resource Productivity

This study will measure TRP by using SITASI sourced from BPS (see Table 1). We will use various indicators to measure TFP and TRP in Indonesian agriculture. Themes 1 in Table 1 will be obtained through measurement of TFP. Furthermore, this study will reveal not only economic dimensions through TFP, but also environmental and social dimensions through further subindicators discussed below:

Farm profit: This essential metric for assessing the economic performance of agricultural enterprises is indicative of the total income generated from agricultural production. This subindicator delves into whether agricultural businesses have experienced growth or decline in profitability over the past three years. To facilitate meaningful comparisons across countries, revenues are expressed in purchasing power parity (PPP) dollars.

PPP serves as a valuable tool for comparing the purchasing powers of different countries, considering not only exchange rates but also the market prices of a standardized basket of goods when denominated in dollars. This approach ensures that disparities in currency valuation do not skew the comparison. Specifically, a decrease in the purchasing power of one currency will correspondingly decrease its valuation in the foreign exchange market, thereby maintaining parity in comparison with other currencies.

$$\text{Farm profit} = \frac{\text{Purchasing power parity (in rupiahs)}}{\text{Units of labor used}}$$

Mitigating risks: This is evaluated in this study by examining farmers' utilization of crop insurance to minimize their exposure to climate- and weather-related risks. Specifically, the study assesses the adoption of weather index-based insurance as a mechanism to mitigate risks associated with adverse weather conditions. A farm operation is deemed sustainable if it has either accessed or has the capacity to access such risk-mitigation measures.

$$\text{Resilience} = \frac{\text{Volume of output}}{\text{Access to credit and insurance}}$$

Soil degradation prevalence: A critical aspect of sustainability is evaluated through this subindicator, which gauges the degree to which agricultural practices impact soil health. Soil degradation may arise from various factors including erosion, salinization, excessive use of chemical fertilizers and pesticides, and other detrimental processes. Assessing the extent of soil degradation is essential for understanding and addressing its implications for agricultural sustainability.

$$\text{Soil health} = \frac{\text{Volume of output}}{\text{Area of degraded soil}}$$

Variation in water availability: This focuses on assessing the degree to which agricultural practices contribute to unsustainable patterns of water usage. It aims to quantify the level of unsustainability in water usage within a given context, typically measured at the scale of a river basin or groundwater aquifer. This approach considers the collective impact of all users sharing the same water resource, providing insights into the overall sustainability of water management practices.

$$\text{Water availability} = \frac{\text{Volume of output}}{\text{Water usage}}$$

Fertilizer management: This evaluates the management practices related to fertilizer usage among farmers. It encompasses an information-based approach to fertilizer utilization, assessing farmers' awareness of environmental risks associated with fertilizer application and their behaviors in managing fertilizers and manures. This subindicator provides insights into the level of knowledge, awareness, and implementation of sustainable fertilizer management practices within agricultural systems.

$$\text{Fertilizer risk} = \frac{\text{Volume of output}}{\text{Ecofriendly fertilizer usage}}$$

Pesticides management: This evaluates the management practices related to pesticide usage in agriculture. It involves collecting information on the use of pesticides, including the types of pesticides utilized, and the measures taken to mitigate associated risks. This subindicator provides insights into farmers' approaches to pesticide application and their efforts to minimize environmental and health impacts through appropriate risk management strategies.

$$\text{Pesticide risk} = \frac{\text{Volume of output}}{\text{Ecofriendly pesticide usage}}$$

Use of practices that support agrobiodiversity: Also termed agrobiodiversity practice, this assesses the adoption of farming practices that promote biodiversity across different levels: ecosystem, species, and genetic diversity. This subindicator evaluates the extent to which farmers integrate methods aimed at enhancing agrobiodiversity within their agricultural systems. It encompasses a range of practices aimed at preserving and enhancing biodiversity within agricultural landscapes, contributing to ecosystem resilience and sustainability.

$$\text{Agrobiodiversity practice} = \frac{\text{Volume of output}}{\text{Agrobiodiversity usage}}$$

Wage rate in agriculture: This subindicator of decent employment quantifies the daily wage rate of unskilled agricultural workers, typically expressed in the local currency of the region or the country under consideration. This metric offers insights into labor market dynamics within the agricultural sector, reflecting the prevailing wage levels for unskilled workers engaged in agricultural activities.

$$\text{Decent employment} = \frac{\text{Volume of output}}{\text{Wage rate of unskilled labor}}$$

The Food Insecurity Experience Scale (FIES): FIES is a subindicator that quantifies the severity of food insecurity experienced by individuals and households. This metric provides a comprehensive measure of the extent to which individuals and households lack reliable access to sufficient and nutritious food, thereby highlighting the severity of food insecurity within a population.

$$\text{FIES} = \frac{\text{Volume of output}}{\text{Amount food insecurity households}}$$

The Secure tenure rights to land (STRL): STRL assesses the extent to which individuals or entities possess ownership or legally recognized rights to use agricultural land. This metric provides insights into the security and stability of land tenure arrangements within the agricultural sector, reflecting the degree of protection afforded to landholders against arbitrary eviction, encroachment, or disputes over land ownership or use rights.

$$\text{STRL} = \frac{\text{Volume of output}}{\text{Amount household owning land}}$$

Sustainable Source of Food Security and Economic Growth

Information on agricultural productivity intersects with various SDG indicators, reflecting various impacts on sustainable development, specifically [7]:

(1) **Volume of production per labor unit by classes of farming/pastoral/forestry enterprise size:** This indicator relates to SDG 1 (No Poverty) by assessing the efficiency and effectiveness of agricultural labor in generating output. It also aligns with SDG 8 (Decent Work and Economic Growth) by measuring productivity and employment within the agricultural sector.

(2) **Average income of small-scale food producers by gender and indigenous status:** This indicator corresponds to SDG 1 (No Poverty) and SDG 5 (Gender Equality) by examining income disparities among small-scale food producers, including gender and indigenous groups. It also supports SDG 10 (Reduced Inequalities) by addressing income inequality within the agricultural sector.

(3) **Proportion of agricultural area under productive and sustainable agriculture:** This indicator contributes to SDG 2 (Zero Hunger) by promoting sustainable agricultural practices that enhance productivity while preserving natural resources. It also supports SDG 12 (Responsible Consumption and Production) by encouraging sustainable farming methods and reducing environmental degradation.

FIGURE 1

SDG INDEX OF INDONESIA AND ITS PROVINCES.

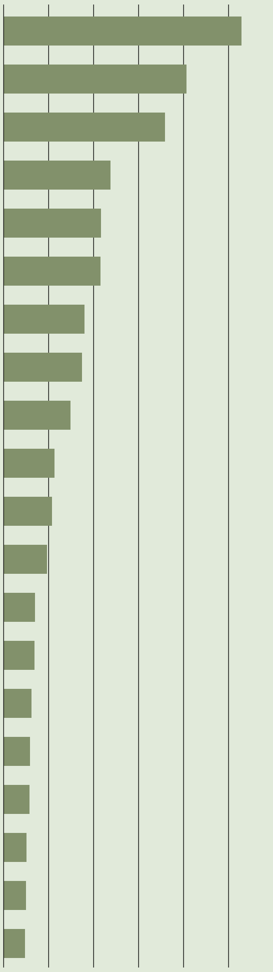
Source: BPS [12].

Indonesia has to invariably anticipate its SDG index reaching 70.0 (Figure 1), because there are still many challenges that lie ahead. Social inequality is still very pronounced, with only 50.8% of women being in the labor force compared with 82% of men; 8.84% of Indonesians still not having electricity, and 37% or 9 million children being stunted. In addition, other challenges faced are fires and forest destruction; violence against women (one in three women have experienced physical and/or sexual violence); plastic waste damaging the environment, with up to 8 million ton of plastic waste circulating annually in the oceans of the world; and unemployment of young people still being very high (around 7 million are unemployed, 4 million of whom are young people aged 15–24 years) [12].

Land in Indonesia covers an extensive area of 191.1 million hectare. Among 20 countries, Indonesia ranks fifteenth in terms of agricultural land area globally, with approximately 623,000 sq km (see Figure 2), constituting about 11.79% of the world's largest agricultural land area, which is in PR China. Indonesia's agricultural land resources encompass various types, including paddy fields covering 7.46 million hectare, and plantations comprising palm oil (14.9 million hectare), coconut (3.4 million hectare), rubber (3.7 million hectare), coffee (1.2 million hectare), cocoa (1.5 million hectare), sugarcane (0.42 million hectare), and tea (0.112 million hectare).

FIGURE 2

AGRICULTURAL LAND AREAS OF 20 COUNTRIES IN SQ KM.

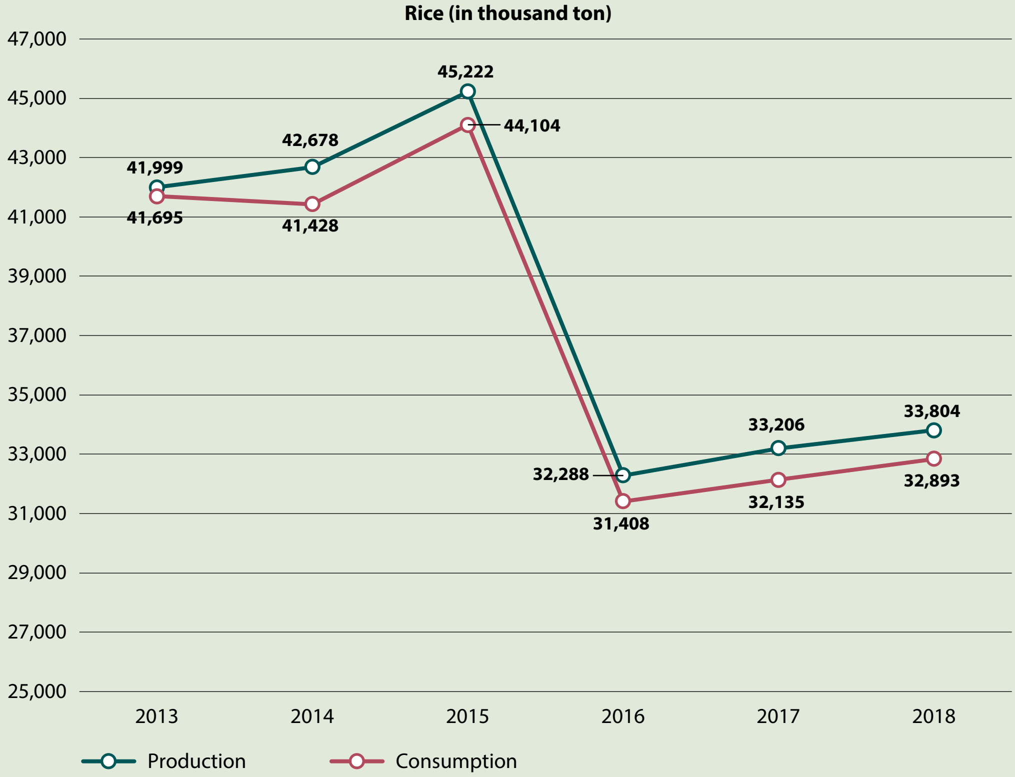


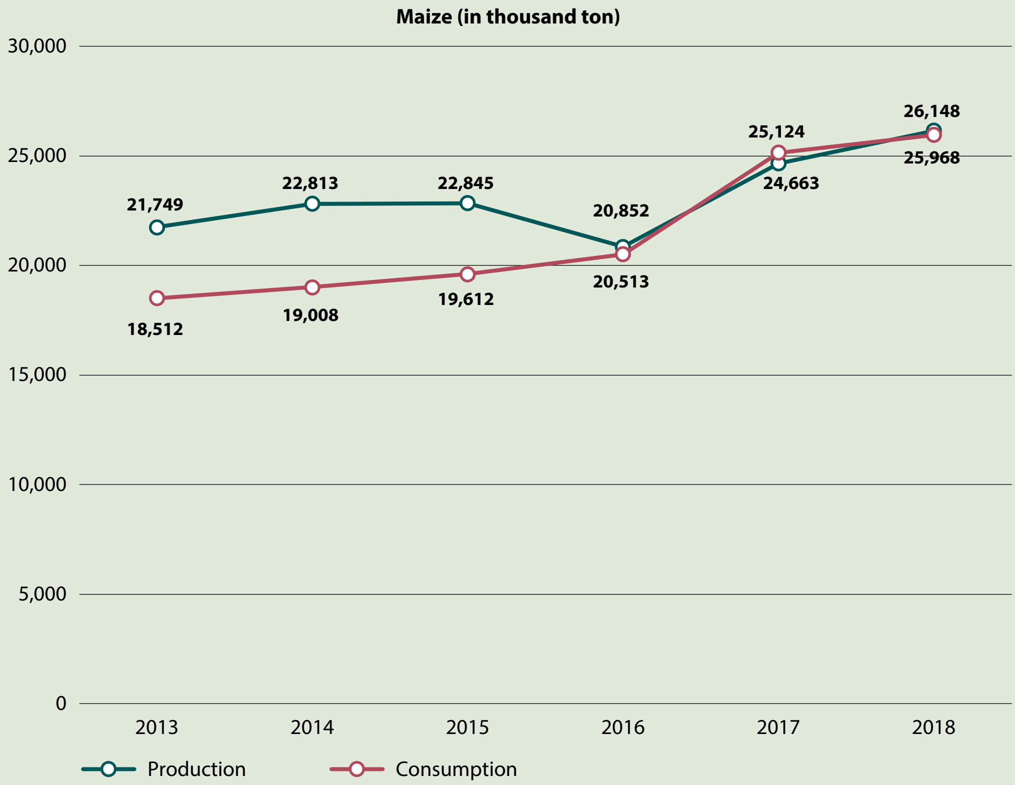
	2018	2017	2016	2015	2014	2013	2012
PR China	5,285,287	5,285,311	5,285,529	5,286,334	5,286,950	5,288,015	5,287,995
USA	4,058,104	4,058,104	4,052,646	4,047,187	4,041,729	4,036,270	4,030,811
Australia	3,588,950	3,718,370	3,426,020	3,481,190	3,744,230	3,717,750	3,870,760
Brazil	2,368,788	2,368,786	2,361,590	2,354,382	2,347,174	2,339,966	2,332,758
Kazakhastan	2,160,365	2,162,138	2,162,421	2,162,597	2,167,994	2,169,941	2,170,121
Russian Federation	2,154,940	2,154,940	2,154,940	2,154,940	2,154,940	2,154,940	2,154,940
India	1,796,740	1,796,740	1,796,740	1,796,740	1,797,210	1,796,980	1,796,420
Saudi Arabia	1,736,290	1,736,292	1,736,190	1,736,354	1,735,753	1,732,950	1,733,450
Argentina	1,487,680	1,487,000	1,487,000	1,487,000	1,487,000	1,491,990	1,492,540
Mongolia	1,134,330	1,134,672	1,135,608	1,136,644	1,136,820	1,140,303	1,140,679
Mexico	1,068,910	1,069,640	1,049,920	1,032,120	1,014,070	1,015,860	1,021,380
South Africa	963,410	963,410	963,410	963,410	963,410	963,410	963,410
Nigeria	691,235	689,602	687,969	686,336	684,702	683,069	681,436
Sudan	681,862	681,862	681,862	681,862	681,862	681,946	682,072
Indonesia	623,000	623,000	602,000	573,000	570,000	570,000	565,000
Canada	581,990	580,240	580,500	579,850	579,130	578,420	577,710
Angola	569,525	563,974	558,424	552,873	547,322	541,772	536,221
Chad	502,380	502,380	502,380	502,370	502,360	500,360	496,850
Columbia	494,920	494,990	447,230	447,539	447,847	448,156	426,176
Niger	466,000	466,000	463,970	456,970	456,820	456,820	447,820

Source: BPS [12].

FIGURE 3

PRODUCTION LEVELS OF CARBOHYDRATE AGRO COMMODITIES BELOW CONSUMPTION LEVELS.





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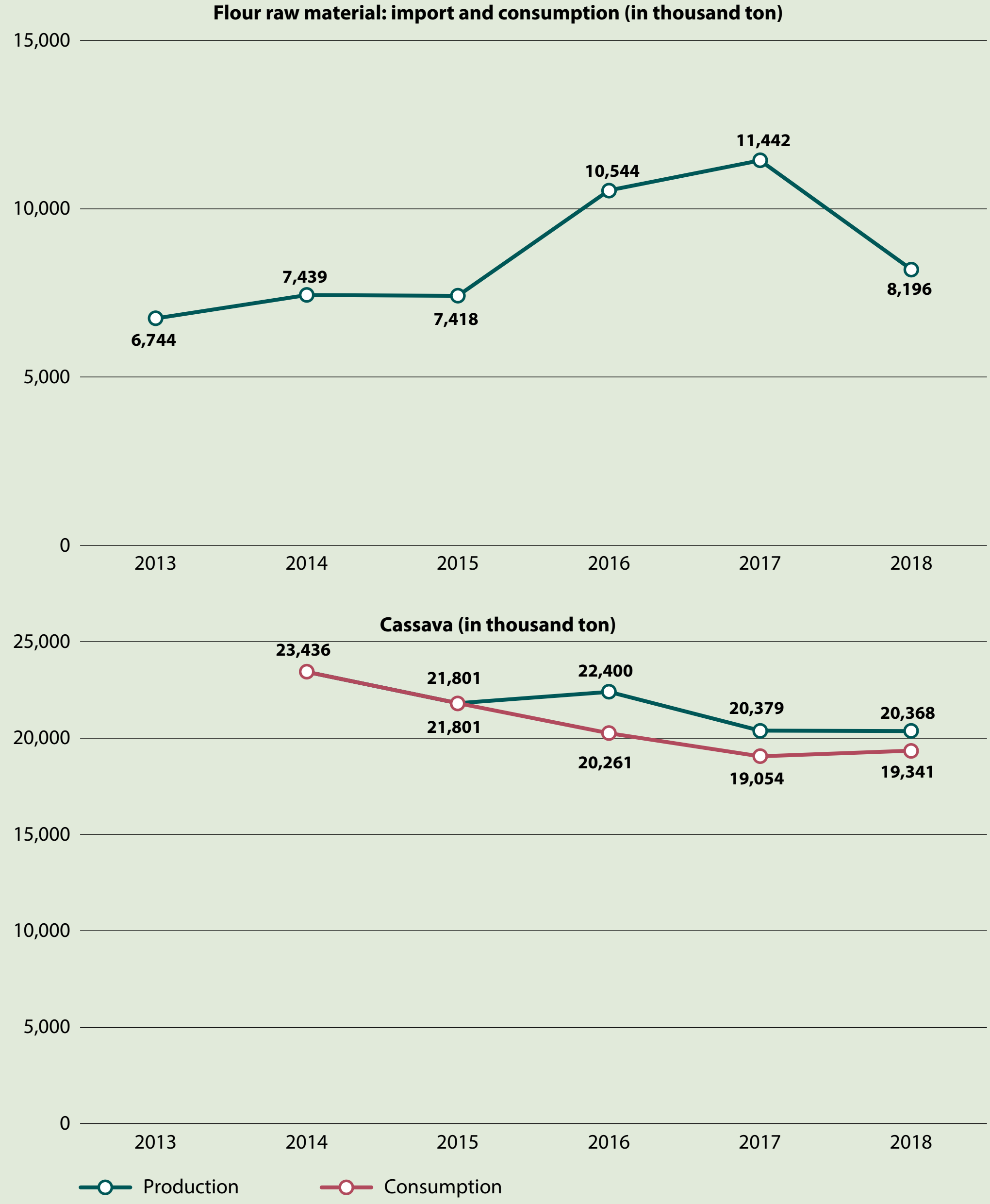
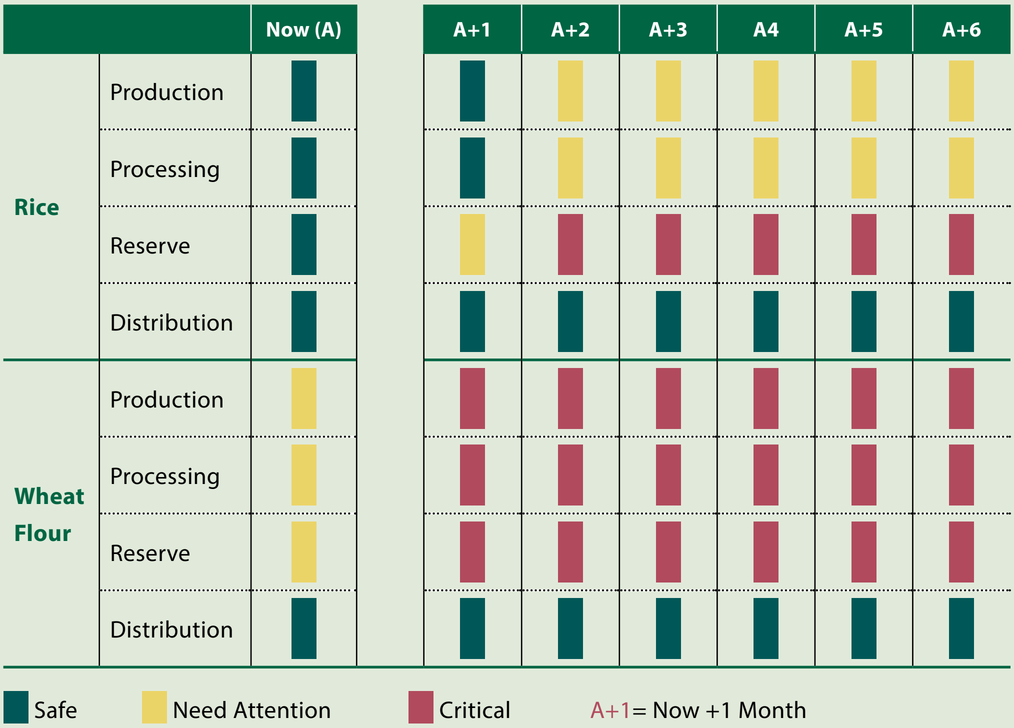


Indonesia has achieved self-sufficiency in commodities like rice and maize. However, wheat flour raw materials are not domestically produced (see Figure 3). Over the years, rice production and consumption have remained nearly balanced, but Indonesia relies on rice imports for reserve purposes. In contrast, wheat flour raw materials are entirely imported for consumption. Wheat flour is utilized in various forms such as noodles, cakes, and other processed foods.

Indonesia currently maintains food security for at least the next month, as depicted in Figure 4. Moreover, according to data from the Agricultural Ministry of Indonesia and the USDA, the country possesses food reserves exceeding 60 days. However, relying solely on the food reserve indicator may not adequately capture food security. Instead, resilience is a more appropriate

FIGURE 4

INDONESIA'S STRATEGIC FOOD STATUS, CASES IN 2020.



measure, encompassing factors such as quantity, price, and quality. Official government data from 2019, coupled with forecasts of production, processing, distribution, and resilience to operational disruptions (both natural and non-natural), suggest that Indonesia is projected to maintain food reserves for the next two months.

The number of households in the agricultural business in 2013 was 26.14 million, having decreased 16.32% from 2003. The majority of households in the agricultural business were in the crop farming food subsector (68% of the total agricultural business actors) and the majority of households controlling land was less than 0.5 ha (56% or 14.62 million). They were dominated by those aged 35–64 years, with education levels only up to elementary school [12].

TABLE 2

AVERAGE LARGE LAND MASTERED PER HOUSEHOLD EFFORT AGRICULTURE IN HA.

Land type	Agricultural census	
	2003	2013
Land, not agriculture	0.06	0.03
Land agriculture	0.35	0.86
- Rice field	0.10	0.20
- Not rice field	0.25	0.66
Land that is mastered	0.41	0.89

Source: BPS [12].

A decrease in the number of agricultural business households causes an increase in the area of land per agricultural household (see Table 2). However, the land mastered for agriculture was still relatively small at 0.86 ha in 2013. Table 3 provides the information that the majority of households controlled less than 1,000 m^2 land in 2003, but they may have controlled up to 2,000–5,000 m^2 land in 2013.

TABLE 3

QUANTITY DISTRIBUTED BY HOUSEHOLDS IN AGRICULTURAL BUSINESS BASED ON LAND TENURE AND GROUP.

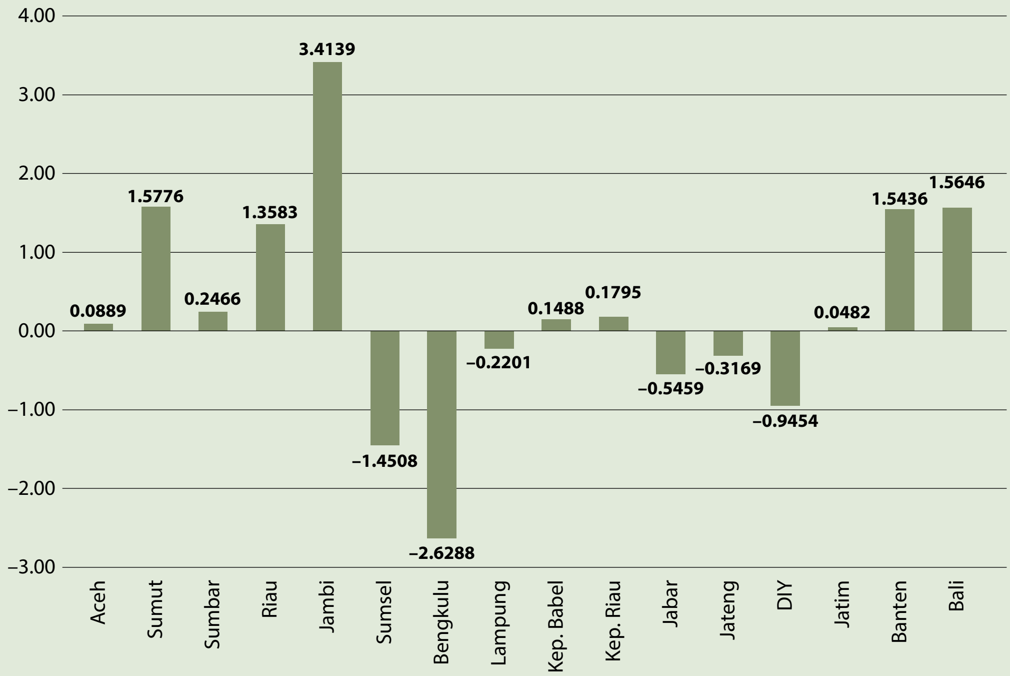
No.	Group with large land (m^2)	Households in agriculture business		Household distribution (%)	
		2003	2013	2003	2013
1	<1,000	9,380,300	4,338,847	30.0	16.6
2	1,000–2,000	3,602,348	3,550,185	11.5	13.6
3	2,001–5,000	6,816,943	6,733,364	21.8	25.8
4	5,001–10,000	4,782,812	4,555,075	15.3	17.4
5	10,001–20,000	3,661,529	3,725,865	11.7	14.3
6	20,001–30,000	1,678,356	1,623,434	5.4	6.2
7	>30,000	1,309,896	1,608,699	4.2	6.2
	Total	**31,232,184**	**26,135,469**	**100.0**	**100.0**

Source: BPS [12].

Essential Aspects of Agriculture and Relevant Productivity Indicators

FIGURE 5

GROWTH OF TFP IN INDONESIA, 2014–17.



Source: BPS [12].

At the provincial level, the highest achievement for sustainable agricultural land by the prevalence of land degradation is for West Java, at 97.96% of the total agricultural land [12]. However, the highest growth of TFP is in Jambi. It reached 3.42% for the period 2014 until 2017 (see Figure 5), in contrast with the growth of total productivity in West Java decreasing 0.55%.

TABLE 4

EXISTING PARTIAL FACTOR PRODUCTIVITY IN INDONESIA.

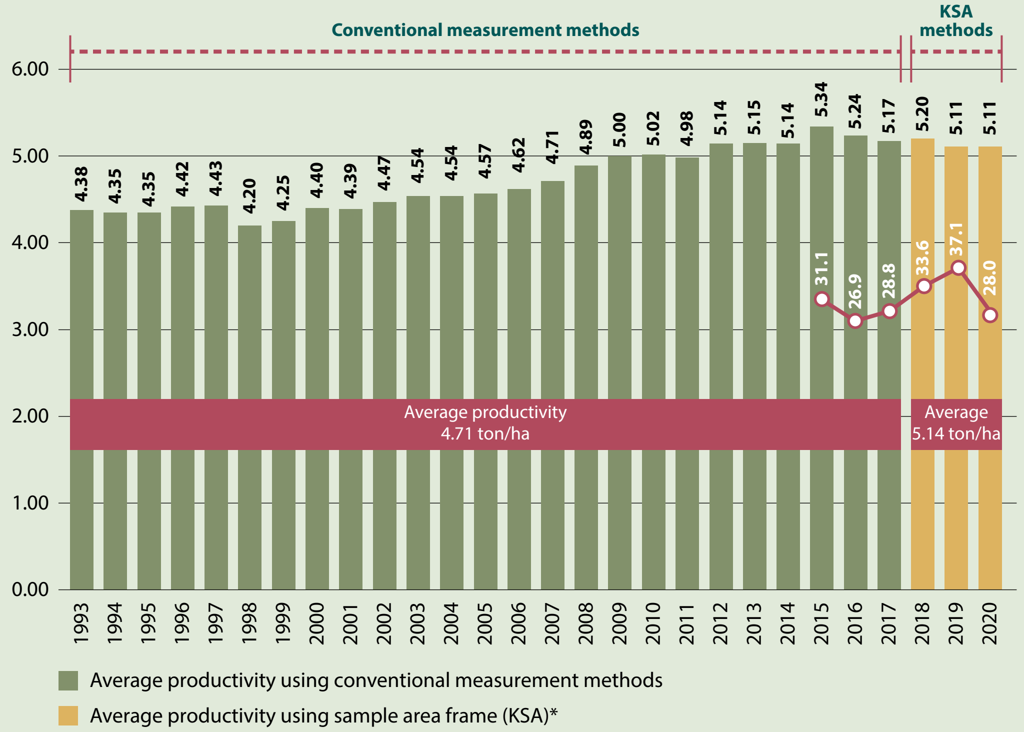
Crop	Year of research	Productivity of	Value	Average/ standard/ control	Place/ medium	Category
Paddy	2015	Land (ton/ha)	6.78	5.19, BPS 2018	Open field	Low tech
	2021	Water (g/m^3)	1.09	0.69, IRRI	Vertical hydroganics	Medium tech
	2021	Urea (g/g)	160	70	Open field	Medium tech
Maize	2017	Land (ton/ha)	20.7	5.33, BPS 2018	Open field	Low tech
	2021	Land (ton/ha)	20.7	3.97	Open field	Low tech
Chili pepper	2021	Land (ton/ha)	8.69	6.7	Open field	Low tech
	2021	Urea (g/g)	60.35	58.96	Open field	Low tech
	2021	Labor (kg/man day)	10.35	10.11	Open field	Low tech
Mustard greens	2020	Width leaves (cm)	7.5	4.37	Hydroponics	Low tech
	2021	Height leaves (cm)	15.75	5.75	Hydroponics	Low tech
Cocoa	2020	Land (ton/ha)	2.5	0.7	Open field	Low tech
Coffee	2020	Land (ton/ha)	2.5	0.6	Open field	Low tech
Rubber	2020	Land (ton/ha)	1.7	1	Open field	Low tech
CPO	2020	Land (ton/ha)	6	2.5	Open field	Low tech
Tea	2020	Land (ton/ha)	3	1	Open field	Low tech

Table 4 informs the existing partial factor productivity in Indonesia using data from various research in Indonesia. Paddy in Indonesia still needs more water in farming (around 1.09 g/m^3) and exceeds the IRRI requirement of 0.69 g/m^3. Application of urea (160 g/g) in the field also exceeds the requirement of 70 g/g. However, the productivity of paddy in Indonesia is generally higher than the BPS standard of 5.19 ton per ha. The productivity of land for maize, chili pepper, mustard green, and some plantation commodities also exceed the standard.

Based on the data in Figure 6, for almost 20 years, agricultural productivity, especially that of rice, stagnated at 4.7–5.0 ton per hectare. Other plantation commodities also experienced the same phenomenon and did not reach their productivity potential. This is a common challenge, and the government continues to pay attention to what is happening and to understand the causes of stagnation and low productivity of the food and agriculture sector. This involves the aspects of land quality, seed usage, damage to irrigation infrastructure, and the effectiveness of the implementation of subsidized fertilizers.

FIGURE 6

PRODUCTIVITY OF RICE IN INDONESIA DURING 1993–2020 IN TON PER HA.



* In 2018, Agricultural Ministry of Republic of Indonesia used the Area Sample Framework (KSA) method to calculate the harvested area, production, and productivity of rice. The Statistics Indonesia (BPS) and the Agency for the Assessment and Application of Technology (BPPT) employ KSA survey to oversee rice phenology. Samples are derived from 5% of the entire rice field area and are gathered on a monthly basis using predetermined coordinates to estimate the monthly rice harvest [36].

Rice production, calculated from dry milled grain (GKG) production, exhibited a seasonal trend, peaking in March–April (see Figure 7). Overall, there was no notable difference in the production performance of GKG between 2018 and 2021. However, prior to 2020, monthly data for corn production were unavailable, hence the graph depicts yearly trends. Notably, there was a consistent annual increase in corn production from 2018 to 2021.

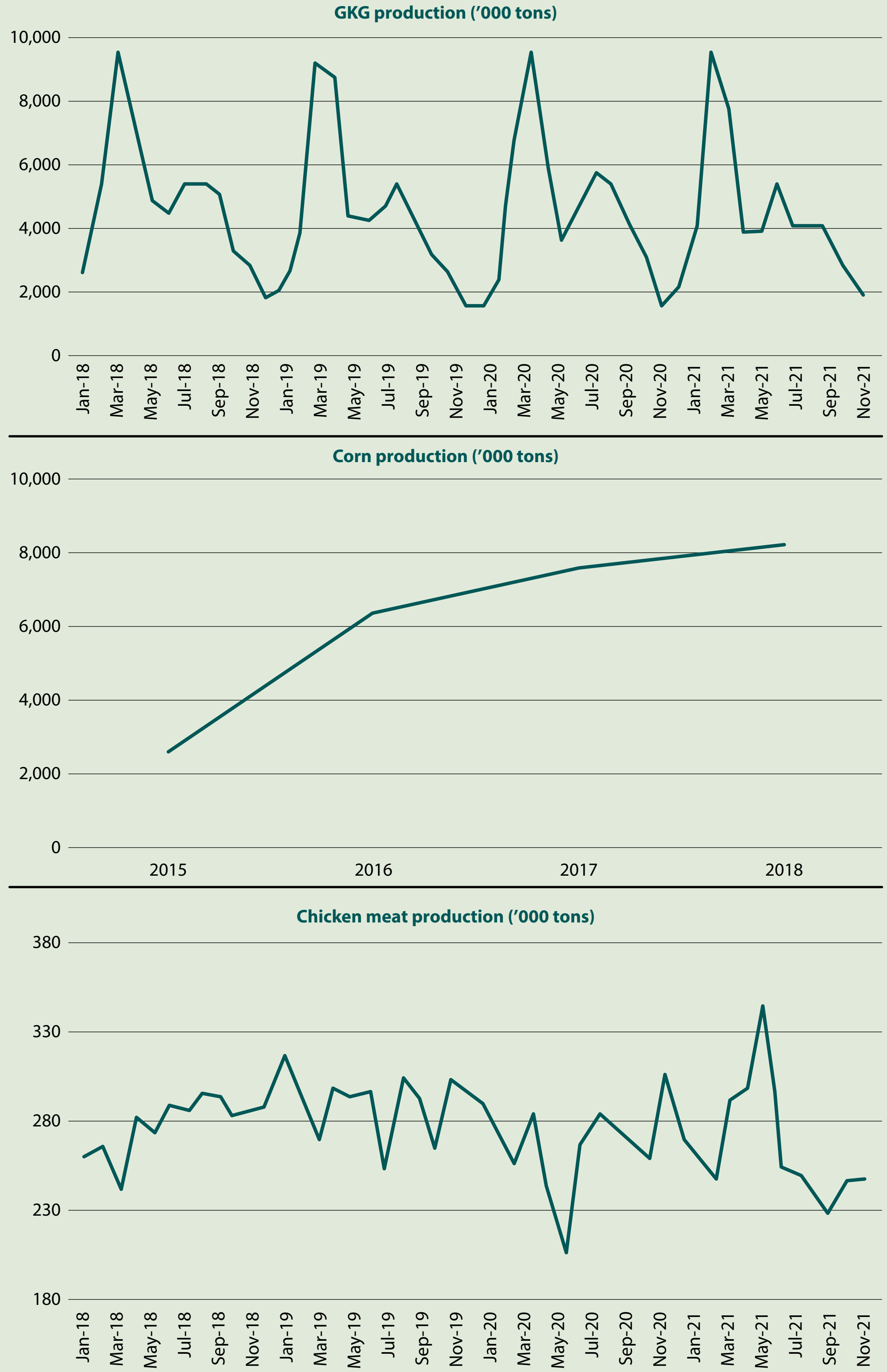
Chicken meat production, as shown in Figure 7, did not exhibit a clear seasonal pattern, with relatively stable numbers that did not vary much from month to month. However, there were higher fluctuations observed in 2020. Similarly, chicken egg production did not demonstrate a seasonal pattern (like chicken meat). While there was a notable increase between December 2018 and January 2019, production figures remained relatively stable between 2019 and 2021.

Shallot production followed a seasonal pattern, with peak production occurring in January and August, and the lowest production in December. Overall, there were no significant differences in shallot production between 2018 and 2021. Banana production data, available quarterly, also exhibited a seasonal pattern, with higher production in the first and fourth quarters compared with the second and third quarters. Banana production showed a consistent increase each year from 2018 to 2021.

Rice productivity, like that of shallot, followed a seasonal pattern (as depicted in Figure 8). Interestingly, while the peak production occurred in March–April, the highest productivity was

FIGURE 7

PRODUCTION OF SIX COMMODITIES IN INDONESIA, 2018–21.



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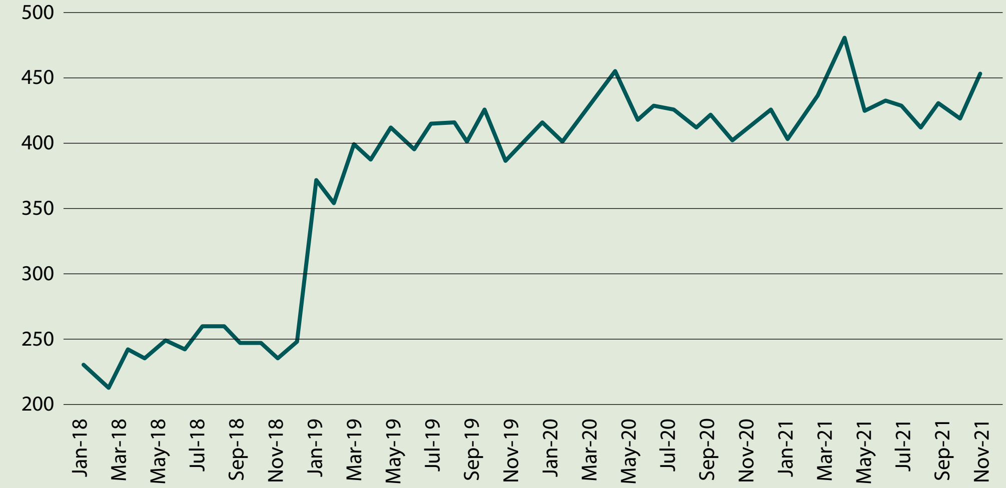
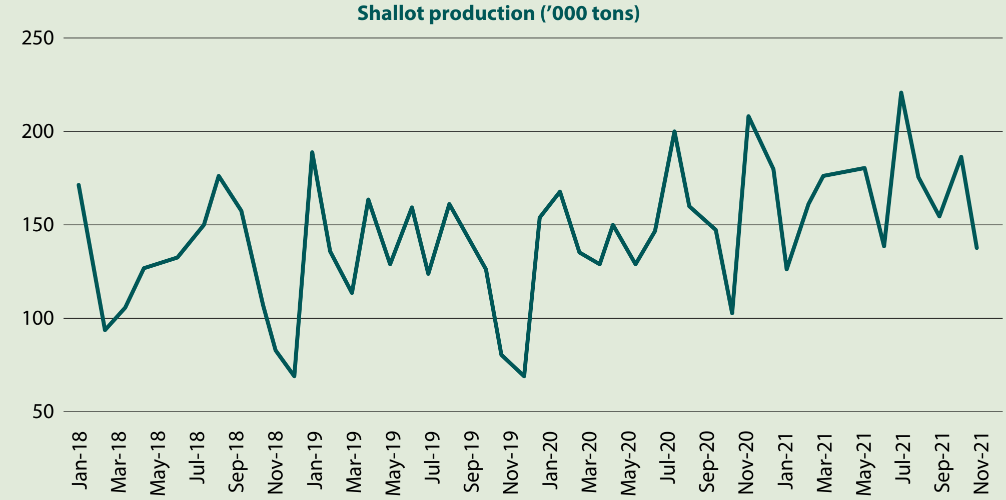
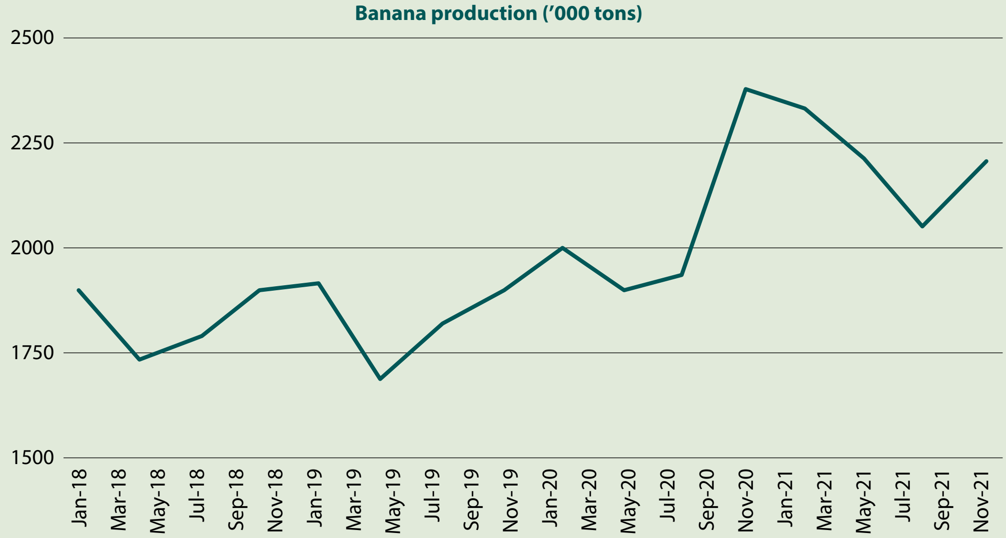
Chicken egg production ('000 tons)



Shallot production ('000 tons)



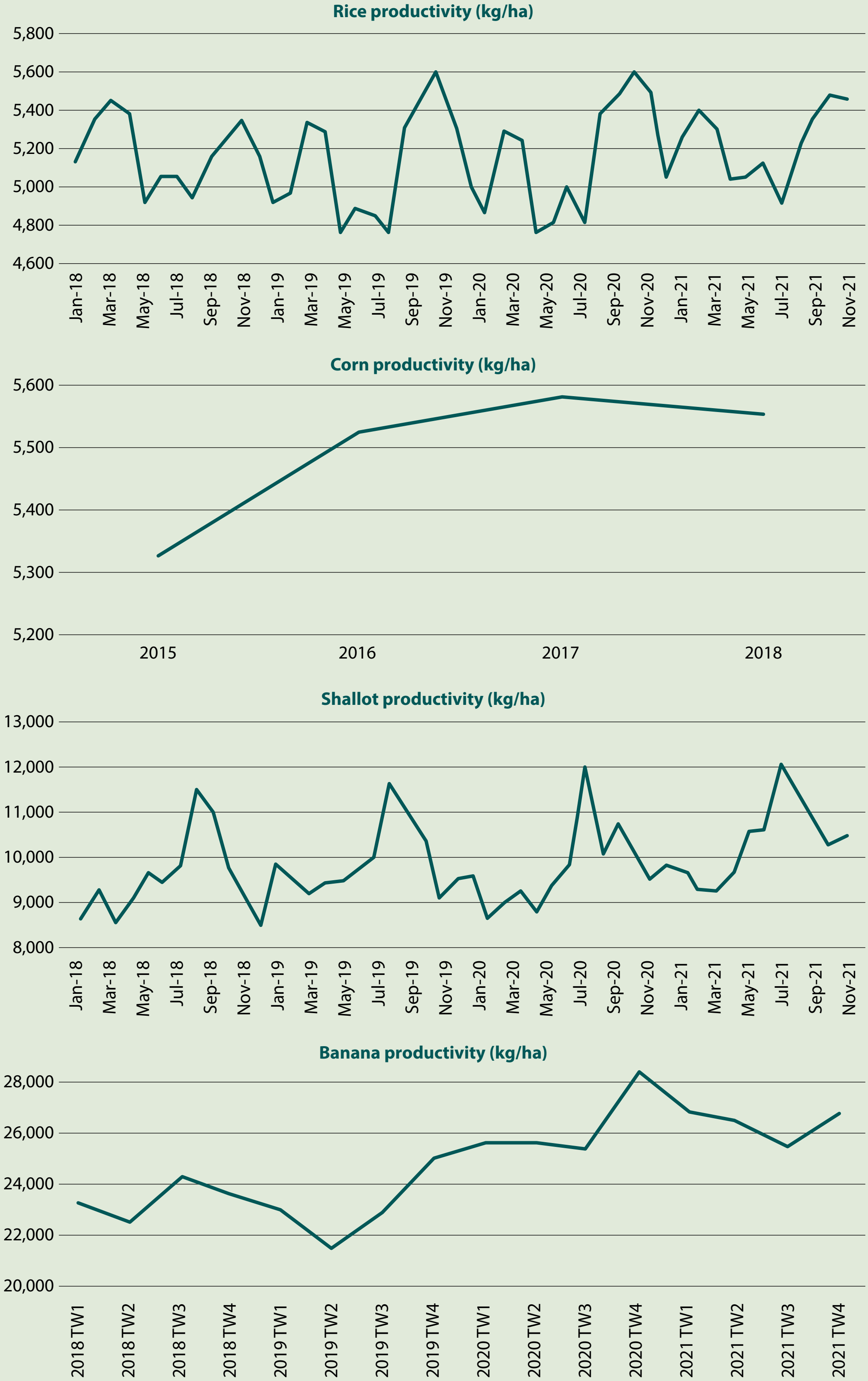
Banana production ('000 tons)



Source: BPS [12].

FIGURE 8

PRODUCTIVITY OF FOUR COMMODITIES IN INDONESIA, 2018–21.



Source: BPS [12].

consistently observed in November every year. Corn productivity, analyzed on a yearly basis, showed an increasing trend over the years, although it experienced stagnation during the pandemic years (2020 and 2021). Shallot productivity exhibited a seasonal pattern with its peak in August (corresponding to its peak production). Over the period from 2018 to 2021, there was also a discernible increase in productivity. Banana productivity, on the other hand, did not exhibit a seasonal pattern, but there was a consistent increase in productivity from 2018 to 2021.

In static panel data analysis, two models are commonly employed: the fixed effect model (FEM) and the random effect model (REM). For the regression model on rice productivity, the REM model was selected as the preferred choice. This decision was based on the results of the Hausman test, which yielded a p-value of 0.9960, exceeding the significance level of 5%. Thus, there was insufficient evidence to reject the null hypothesis, which favored the REM model. To address heteroscedasticity and autocorrelation issues, the REM model was estimated using a robust standard error approach, ensuring that standard error values were not overestimated or underestimated.

TABLE 5

RANDOM EFFECT MODEL WITH ROBUST STANDARD ERROR FOR PRODUCTIVITY OF RICE.

Rice productivity	Coefficient	t-statistic	P-value
Gender	–0.13845	–0.72	0.474
Size	–0.2265404	–2.51	0.012*
Age	0.0263189	2.22	0.026**
Education	0.518846	4.29	0.000***
Treatment	0.3295745	1.47	0.143
Time	0.8017533	3.07	0.002***
Idea	–0.6965838	–2.14	0.033**
Constant	2.106421	2.23	0.026**

R-squared = 0.0321 F-stat = 49.33 P-value = 0.0000***
*** for 1% significance level; ** for 5% significance level; and * for 10% significance level.

The number of observations for rice productivity regression was 1,344, consisting of 778 control farmers and 566 treatment farmers. The regression results show that of the seven independent variables tested, five variables had a significant effect on rice productivity, namely land area, age, education, dummy time, and dummy idea (see Table 5). Meanwhile, there were two variables that had no significant effect, namely gender and dummy treatment. This can be seen from the p-value being greater than 5% or 10% significance levels.

The variable land area (size) had a significant negative effect on rice productivity with a coefficient of 0.226 with a p-value of 0.012, i.e., less than 5% significance level. This means that every 1 ha increase in the area of land owned by farmers will decrease the level of rice productivity by 0.226 ton per ha, assuming cateris paribus. The age variable has a significant positive effect on rice productivity with a coefficient of 0.0263 and a p-value of 0.026, i.e., less than 5% significant level. This means that age differences in farmers who are 10 years older will increase the value of rice productivity by 0.026 ton per ha, assuming cateris paribus.

Moreover, the ‘education level’ variable exhibited a positive and statistically significant impact on rice productivity, with a coefficient of 0.518 and a p-value of 0.000, indicating significance at the

1% level. This implies that for every increment in the farmer's education level by one unit, rice productivity increases by 0.518 ton per ha. Thus, higher levels of farmer education are associated with higher rice productivity.

The 'time dummy' variable shows the difference in the value of rice productivity between the baseline and the endline. The regression analysis reveals a positive and statistically significant impact of this variable on rice productivity, indicated by a coefficient of 0.801 and a p-value of 0.002, demonstrating significance at the 1% level. In its interpretation, these results illustrate that there is a difference of 0.801 ton per ha in the value of rice productivity between the baseline and at the endline (the average productivity of rice at the endline is higher by 0.0801 ton per ha compared with that at the baseline).

Finally, the dummy idea variable is an interaction between the dummy treatment and dummy time variables. This variable describes the impact of treatment on farmers before and after the program (or baseline and endline). The dummy idea variable has a significant negative effect on rice productivity with a coefficient of 0.696 with a p-value of 0.033 (less than 5% significance level). This means that the treatment of farmers has a negative impact on rice productivity (compared with control farmers) after the program. There is an average difference of 0.696 ton per ha after the program was implemented between treatment farmers and control farmers. The average productivity of treatment farmers was lower than that of control farmers.

The best model of maize productivity selected in the test is the REM model, where the p-value is equal to 0.2855 or greater than the 5% significance level, so there is no evidence to reject the null hypothesis. Furthermore, the model is estimated using a robust standard error approach to overcome heteroscedasticity and autocorrelation problems.

TABLE 6

RANDOM EFFECT MODEL WITH ROBUST STANDARD ERROR FOR PRODUCTIVITY OF MAIZE.

Maize productivity	Coefficient	t-statistic	p-value
Gender	0.023361	0.06	0.949
Size	−0.1546512	−2.44	0.015**
Age	0.0293394	1.99	0.046**
Education	0.0580876	0.43	0.669
Treatment	−0.9468613	−2.22	0.026**
Time	−0.2298494	−1.25	0.211
Idea	0.397735	1.66	0.097*
Constant	4.376849	3.82	0

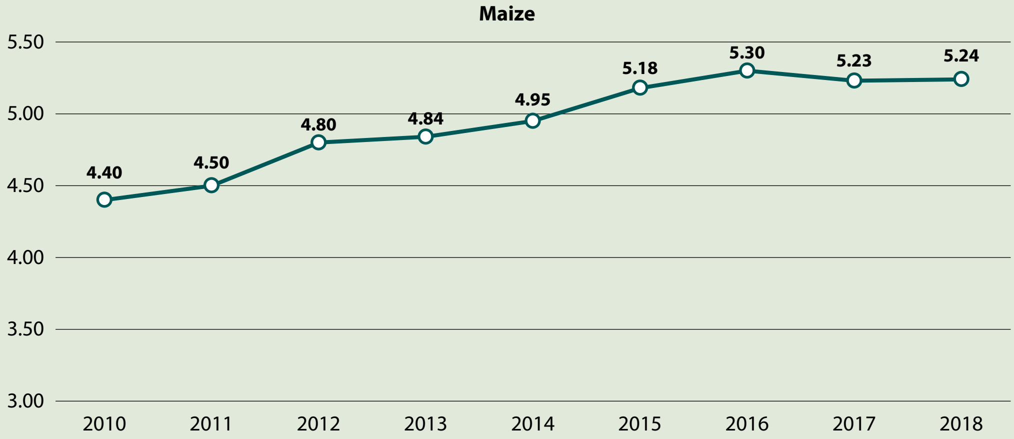
R-squared = 0.0321 F-stat = 49.33 P-value = 0.0000***

*** for 1% significance level; ** for 5% significance level; and * for 10% significance level.

The maize productivity regression model encompasses 182 observations, consisting of 62 control farmers and 120 treatment farmers. Table 6 reveals that among the seven independent variables examined, only four variables exhibit a statistically significant impact on maize productivity: land area, age of the farmer, treatment dummy, and idea.

FIGURE 9

PRODUCTIVITY OF MAIZE IN INDONESIA DURING 2010–18 IN TON PER HA.



Source: BPS [12].

The variable land area has a negative and significant effect on the level of maize productivity with a p-value that is less than the 5% level, meaning that if there is an increase in the area of maize land by 1 ha, the level of maize productivity will decrease by 0.1546 ton per ha, caeteris paribus. The farmer's age also has a positive and significant effect on the level of maize productivity, as evidenced by the p-value which is less than the 5% level. Therefore, if farming is run by older maize farmers, the productivity level will also be higher. Statistically, for every 10 years increase in the age of the farmer, the productivity level of maize will increase by 0.229 ton per ha, ceteris paribus.

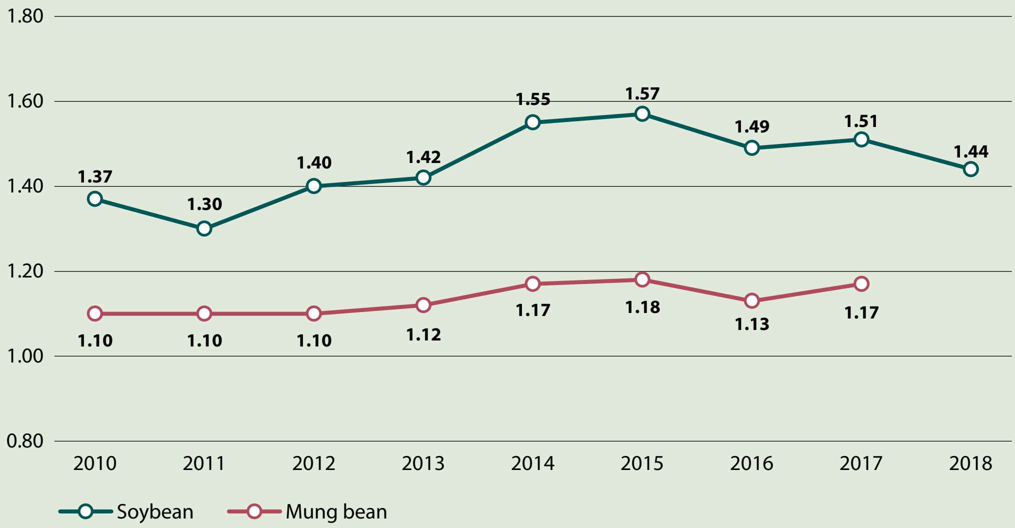
Treatment, which is a dummy variable between control and treatment farmers, has a negative and significant effect at 5% level. This means that the treatment of farmers has a negative impact on maize productivity. Furthermore, the average difference in maize productivity levels between control and treatment farmers was 0.946, where the productivity of treatment farmers was lower than that of control farmers. The dummy idea variable describes the impact of treatment on farmers before and after the program or the baseline and the endline. The dummy idea variable has a significant positive effect on rice productivity with a coefficient of 0.397 and a p-value of 0.097 (less than 10% significance level). This means that the treatment of farmers has a positive impact on rice productivity compared with control farmers after the program. There was an average difference of 0.397 ton per ha between treatment farmers and control farmers, caeteris paribus, after the program was implemented.

The plantation sector is the backbone of Indonesia's agricultural exports. The production of plantation commodities in Indonesia such as palm oil, coffee, rubber, cocoa, and coconut are increasing (the productivity in 2020 is shown in Figure 12). Exports of these commodities are mostly raw materials or semi-finished goods. The downstream plantation industry is still being encouraged to increase added value and competitiveness to the goods.

Horticultural commodities are included among high value products (HVPs) having a higher demand, which must be met by imports. There need to be efforts to boost productivity (the productivity in 2020 is shown in Figure 13).

FIGURE 10

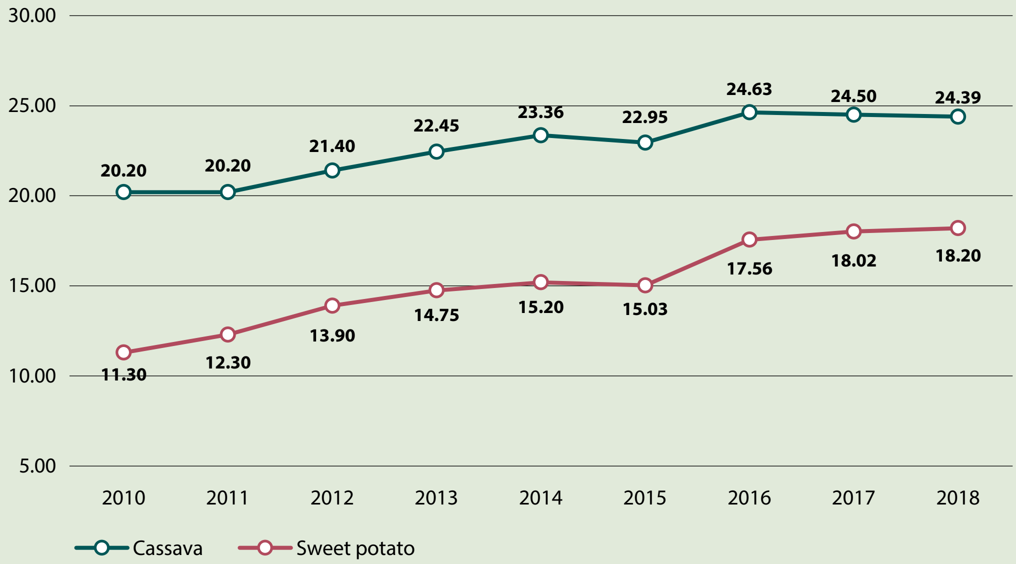
PRODUCTIVITY OF SOYBEAN AND MUNG BEAN IN INDONESIA DURING 2010–18 IN TON PER HA.



Source: BPS [12].

FIGURE 11

PRODUCTIVITY OF SWEET POTATO AND MUNG BEAN IN INDONESIA DURING 2010–18 IN TON PER HA.

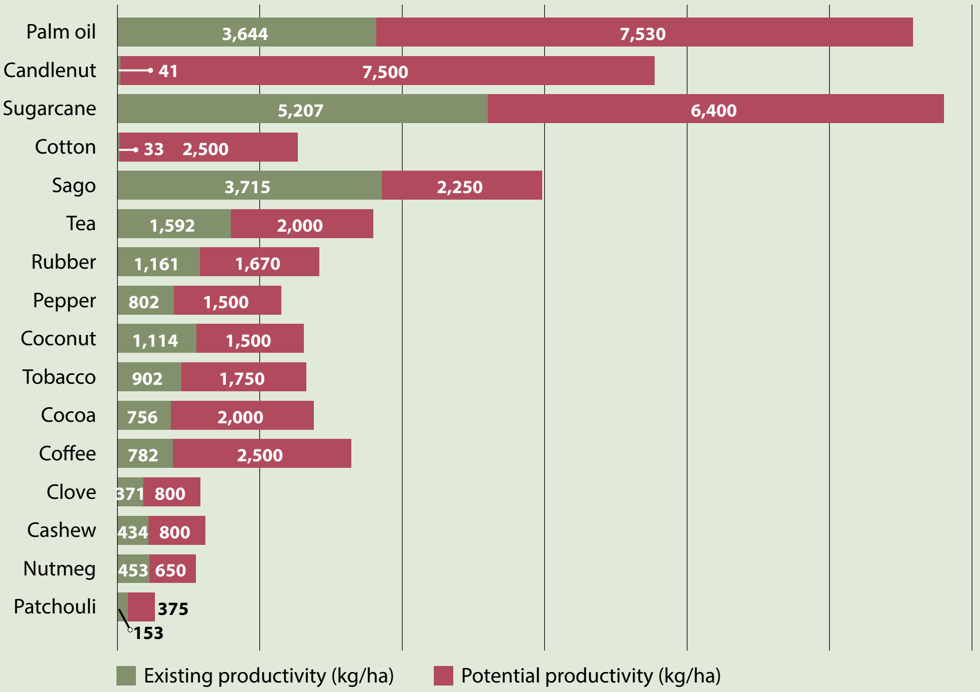


Source: BPS [12].

Table 7 shows the chili productivity regression model. The REM model was chosen as the best model. The results of the Hausman test statistic show a p-value of 0.9935 or greater than the 5% significance level so that there is no evidence to reject the null hypothesis and the model chosen is the REM model. Furthermore, the model is estimated using a robust standard error approach to overcome heteroscedasticity and autocorrelation problems.

FIGURE 12

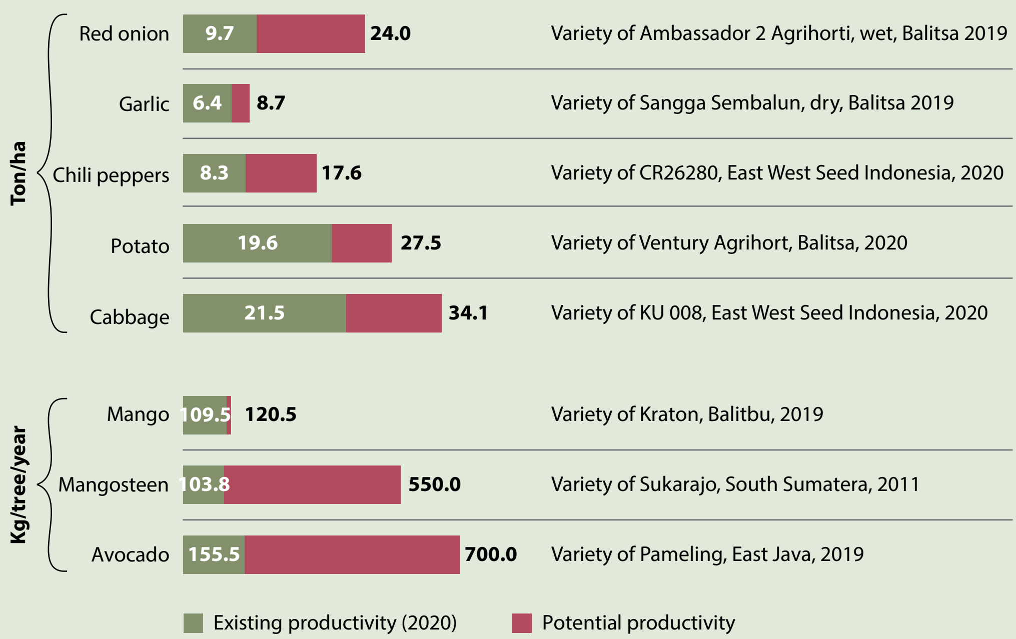
PLANTATION PRODUCTIVITY IN INDONESIA 2020.



Source: BPS and Agriculture Ministry of RI [12].

FIGURE 13

HORTICULTURE PRODUCTIVITY IN INDONESIA 2020.



Source: BPS and Agriculture Ministry of RI [12].

TABLE 7

RANDOM EFFECT MODEL WITH ROBUST STANDARD ERROR FOR PRODUCTIVITY OF CHILI.

Chili productivity	Coefficient	t-statistic	p-value
Gender	2.184196	1.28	0.201
Size	4.33405	1.45	0.147
Age	−0.0434512	−0.37	0.708
Education	1.215251	1.59	0.113
Treatment	0.8619991	0.52	0.602
Time	−0.4429346	−1.3	0.195
Idea	0.2491773	0.33	0.74
Constant	−2.087257	−0.26	0.797

The number of observations in the chili productivity regression model was 206 (farmers), consisting of 42 control farmers and 164 treatment farmers. Based on the regression results, of the seven independent variables tested, there were no variables having a significant effect on the level of chili productivity.

The variables gender, land area, length of education, treatment, and idea have positive effects on the level of chili productivity, but the effect is not statistically significant because the p-value is greater than the significance level. The variables age and time have negative effects and are not statistically significant for the level of chili productivity.

FIGURE 14

TECHNICAL EFFICIENCY OF RICE, MAIZE, AND SOYBEAN.

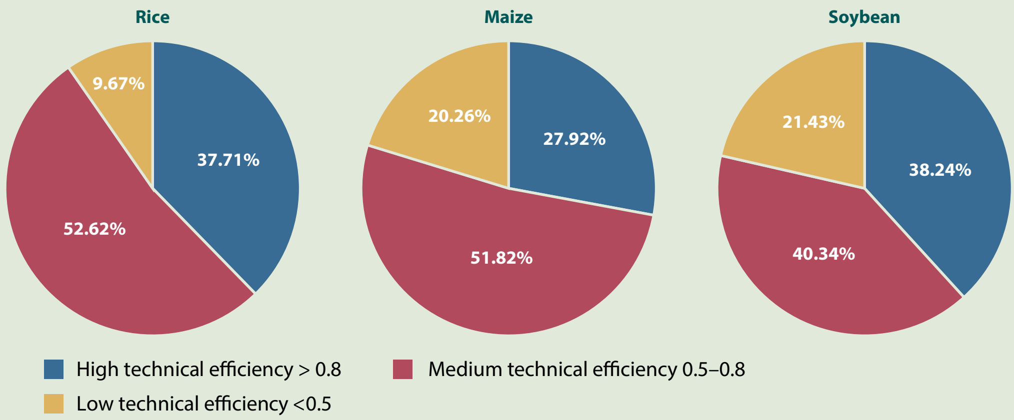


Figure 14 shows the technical efficiencies of rice, maize, and soybean. It shows that 52.62% rice, 51.82% maize, and 40.34% soyabean are having medium technical efficiency. In addition, about 37.71% rice, 27.92% maize, and 38.24% soybean are in the category of high technical efficiency. It can be said that around 72% of farming in Indonesia has sufficient technical efficiency while around 7.5 million household can improve their technical efficiency through the determinants that affect them. The variables that are thought to affect the inefficiency of farming in Indonesia and used in this study include age, education level, loans, subsidies, counseling, farmer group membership, training, type of land (rice field or non-rice field), and land ownership status [33].

Developing Productivity Indicators for SAM

According to the production value per hectare, a significant portion, 89.72%, of agricultural land utilized in West Java, East Java, and West Nusa Tenggara falls under the category of underproductive management standards for ensuring sustainable agriculture. This implies that only 10.28% of agricultural land in these three provinces meets the standards for productive management as sustainable agricultural land.

If categorized by province, West Java has the highest achievement for sustainable agricultural land based on the production value per hectare, at 13.52%. In West Nusa Tenggara, only 1.57% of agricultural land is considered sustainable.

Based on the farm profit indicator, specifically observed through the subindicator of farmer net income, 97.13% of the agricultural land in West Java, East Java, and West Nusa Tenggara is categorized as sustainable land. Among these provinces, West Java has the highest proportion of sustainable land based on farmers' net income, accounting for 97.33% of the total agricultural land. East Java follows closely with 97.28%, while West Nusa Tenggara has 94.67% of sustainable agricultural land. Within this classification, 32.05% is categorized as desirable, 65.08% as acceptable, and 2.87% as unsustainable agricultural land.

The subindicator of risk mitigation mechanisms assesses the implementation of strategies to mitigate risks in agricultural activities. A farm holding is considered resilient if it has availed or has access to these mechanisms. Based on this subindicator, only 8.16% of agricultural land in West Java, East Java, and West Nusa Tenggara is classified as unsustainable, while 91.85% is deemed sustainable (with 90.33% categorized as desirable and 1.52% as acceptable). When examined by province, West Nusa Tenggara has 15.06% of unsustainable agricultural land, while East Java has 13.46%. In West Java, 96.77% of agricultural land is classified as sustainable.

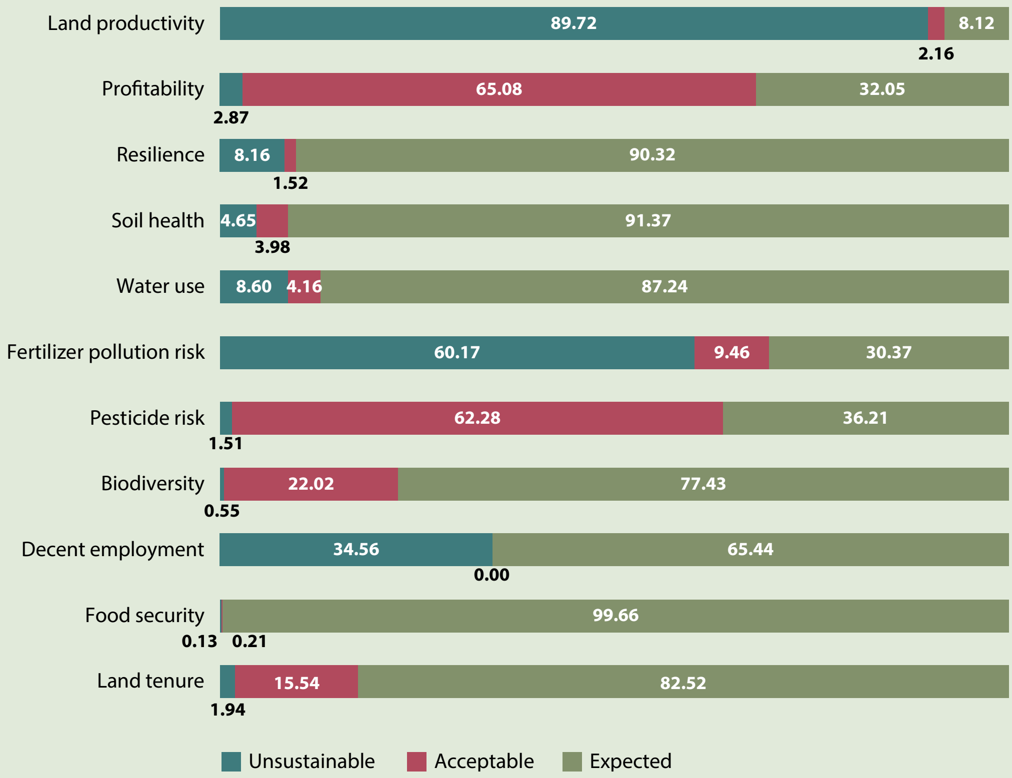
The subindicator of soil degradation prevalence assesses the impact of agricultural activities on soil health, a crucial aspect of sustainability. According to this indicator, 95.35% of agricultural land in West Java, East Java, and West Nusa Tenggara is categorized as sustainable. Within this, 91.37% falls under the desirable category, while 3.98% is classified as acceptable. However, 4.65% of agricultural land is managed in a manner that leads to unsustainable agriculture due to inappropriate land management practices.

At the provincial level, the highest achiever for sustainable agricultural land based on the prevalence of land degradation is West Java, at 97.96% of the total agricultural land. Meanwhile, the other two provinces, East Java and West Nusa Tenggara, still have more than 5% of the agricultural land as unsustainable.

The subindicator of water availability assesses the degree to which agriculture contributes to unsustainable patterns of water usage. Ideally, this assessment is conducted at the scale of the river basin or groundwater aquifer, considering the collective impact of all users sharing the same water resource on water sustainability.

FIGURE 15

SUMMARY OF INTEGRATED AGRICULTURAL SURVEY, 2020.



Source: BPS [12].

For the subindicator of water availability conditions, 91.40% of agricultural land in West Java, East Java, and West Nusa Tenggara is categorized as sustainable land. This consists of 87.24% of land falling into the desirable category and 4.16% into the acceptable category, while the remaining 8.60% is categorized as unsustainable agricultural land. Compared with West Java and West Nusa Tenggara, East Java is a province where there is stable water availability for years and it can irrigate more than 10% of the existing agricultural land. This is indicated by the fact that it has 88.95% of the agricultural land in the desirable category.

The subindicator of fertilizers management measures the management of fertilizer usage, including farmers' awareness of environmental risks associated with fertilizer usage and their behavior in managing fertilizers and manures.

Based on the subindicator of management of fertilizer usage, 60.17% of the agricultural land in West Java, East Java, and West Nusa Tenggara is categorized as unsustainable agricultural land, while the remaining 39.83% is categorized as sustainable agricultural land, comprising 30.37% in the desirable category and 9.46% in the acceptable category.

In East Java, 67.58% of the agricultural land utilizes fertilizers without implementing specific measures to mitigate the risks associated with fertilizer usage, resulting in its categorization as unsustainable agricultural land. Similar patterns are observed in West Java and West Nusa Tenggara, where 54.65% and 58.98% of agricultural lands, respectively, exhibit unsustainable practices.

Based on the management of pesticide usage, 98.49% of the agricultural land in West Java, East Java, and East Nusa Tenggara is categorized as sustainable. This includes 36.21% classified as desirable and 62.28% as acceptable, with only 1.51% classified as unsustainable agricultural land.

At the provincial level, in West Nusa Tenggara, there is still nearly 10% of agricultural land that is unsustainable, based on pesticide use management. This illustrates that in these areas, there still are farmers who use pesticides that are dangerous or very dangerous and/or illegal without taking special steps related to environmental health. Meanwhile, the other two provinces, i.e., West Java and East Java, have less than 2% of unsustainable agricultural land in terms of pesticide use management.

Based on the adoption of biodiversity-assisted practices, 99.45% of the agricultural land in West Java, East Java, and West Nusa Tenggara is categorized as sustainable agricultural land. This includes 77.43% classified as desirable and 22.02% as acceptable, with the remaining 0.55% categorized as unsustainable agricultural land.

In West Java, East Java, and West Nusa Tenggara, less than 1% of the agricultural land is classified as unsustainable in terms of agro-biodiversity-supportive practices. This indicates that farmers across these regions apply sustainability criteria for both organic and non-organic agriculture on most of the agricultural land.

Regarding wages in agriculture, approximately 65.44% of agricultural land in West Java, East Java, and West Nusa Tenggara is classified as sustainable, while the remaining 34.56% is categorized as unsustainable. In West Nusa Tenggara, over 60% of agricultural land is classified as unsustainable due to unskilled workers being paid less than the national minimum wage or the minimum wage for agricultural-sector workers. Conversely, in West Java, less than 30% of the agricultural land falls into the unsustainable category based on worker wages.

In terms of the FIES, nearly 100% of agricultural land in West Java, East Java, and West Nusa Tenggara is categorized as sustainable, with 99.66% being in the desirable category and 0.13% in the acceptable category, while only 0.21% is deemed unsustainable agricultural land.

At the provincial level, West Nusa Tenggara does not exhibit any agricultural holdings with severe food insecurity potential. Even in West and East Java, less than 1% of unsustainable agricultural land is associated with farmers experiencing severe food insecurity. Regarding the last subindicator, concerning land ownership rights to agricultural land, 98.07% of agricultural land in West Java, East Java, and West Nusa Tenggara is deemed sustainable (.52% is considered desirable and 15.55% acceptable), while the remaining 1.94% is categorized as unsustainable agricultural land.

Among the three provinces, West Nusa Tenggara is the region with the highest percentage of desirable agricultural land in terms of land ownership rights, at 87.61%. This implies that for 87.61% of the agricultural land, farmers already have formal documents of land ownership or have the right to sell and bequeath.

Productivity Indicator for Enhancing Policies and R&D to Promote SAM

The government is advancing sustainable agriculture through the ICT Digital Eco-System (IDEA) model, illustrated in Figures 16–19. A digital ecosystem constitutes interconnected IT resources functioning cohesively, incorporating suppliers, customers, trading partners, applications, third-party data service providers, and associated technologies. Interoperability is pivotal for the ecosystem's efficacy [13].

Digital ecosystems are often spearheaded by industry leaders and are rapidly reshaping various economic sectors, including agribusiness [13]. However, a closer examination reveals that farmers and other stakeholders in the agricultural domain often lack timely, relevant, and accessible information. Given the widespread adoption of mobile phones among farmers, there is a growing interest in mobile-based solutions to bridge this information gap. Farmers require both static information, such as crop details, pest and disease management practices, and agricultural techniques, as well as dynamic, real-time data on crop production and market prices. This real-time information is crucial not only for farmers but also for agricultural departments, agro-chemical companies, buyers, and government agencies to ensure food security through effective supply chain management [17].

Integrating business-to-business (B2B) practices, enterprise applications, and data within a digital ecosystem empowers organizations to harness both new and existing technologies, automate processes, and foster continuous business growth. However, the uncontrolled, organic expansion of such an ecosystem can pose significant risks to businesses. Therefore, it is crucial to identify and manage all dependencies when building an ecosystem [13].

Creating a digital ecosystem map is a fundamental step toward establishing a robust ecosystem. This map serves as a visual representation of all digital tools and platforms utilized within the organization. It outlines the processes involved, illustrates how data flows between different components of the ecosystem, and indicates whether these processes are automated or manual [13].

For effective mapping, it is essential to document which systems are currently unconnected or unable to exchange data with each other. Additionally, identifying the users of each system and determining who is responsible for maintaining them helps ensure smooth operations and facilitates effective communication within the ecosystem [13].

Indeed, the digital ecosystem offers a plethora of user data that can be leveraged to create value and generate revenue through adjacent business models. Effective management of the digital ecosystem entails harnessing this wealth of data to drive business growth by capitalizing on the creativity of diverse stakeholders and leveraging all available resources [13].

Digital transformation and the establishment of a digital ecosystem are pivotal to enhancing workflow efficiency and fostering stronger relationships with customers and partners. By embracing digital technologies and fostering collaboration within the ecosystem, businesses can streamline processes, improve productivity, and deliver enhanced value to all stakeholders involved [13].

The integration of various services and applications into a unified digital ecosystem, facilitated by platforms like IDEA, offers significant benefits such as enhanced convenience, efficiency, and accessibility for users. By consolidating services such as expense management, digital wallets, online banking, and digital passbooks into a single platform, users can enjoy seamless access to a wide range of functionalities [13].

It is crucial for organizations driving digital ecosystem initiatives to remain adaptable and open to change. As technology evolves and user needs shift, the ecosystem must be flexible enough to accommodate these changes and incorporate new innovations effectively.

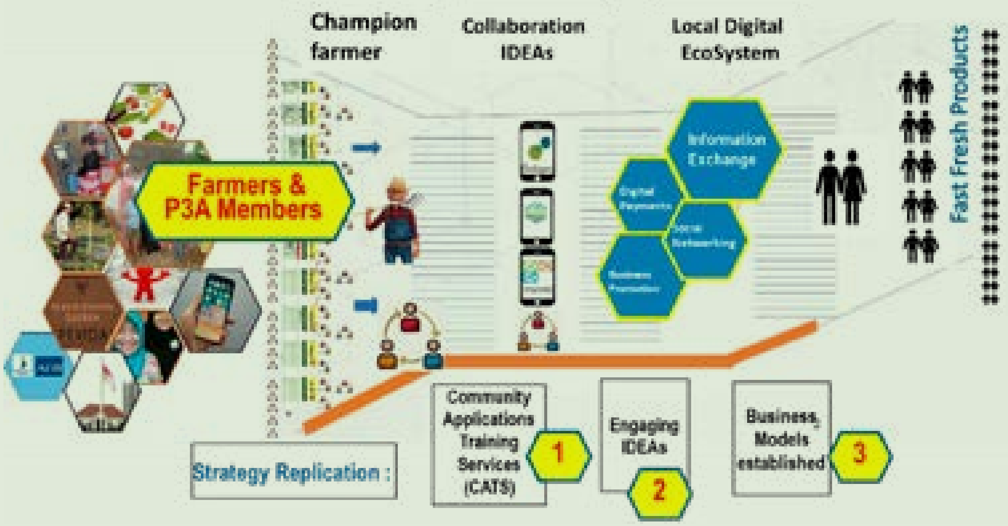
FIGURE 16

THE ICT DIGITAL ECOSYSTEM (IDEA) MODEL.

Source: [37].

FIGURE 17

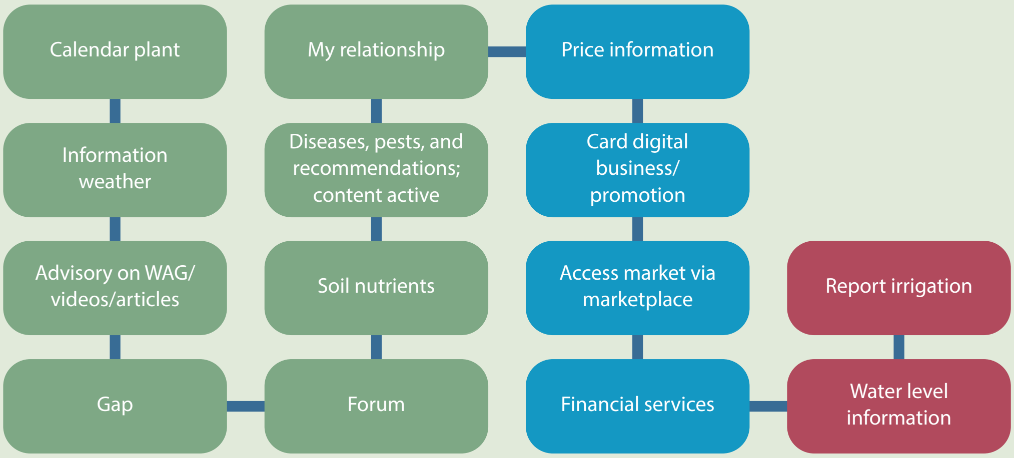
STRATEGY TO REACH WATER USER FARMERS ASSOCIATION (P3A) AND FARMER GROUPS.



Source: [37].

FIGURE 18

IDEA SERVICES THAT CAN BE USED BY FARMERS, MEMBERS OF P3A, OR EXTENSION OFFICERS.

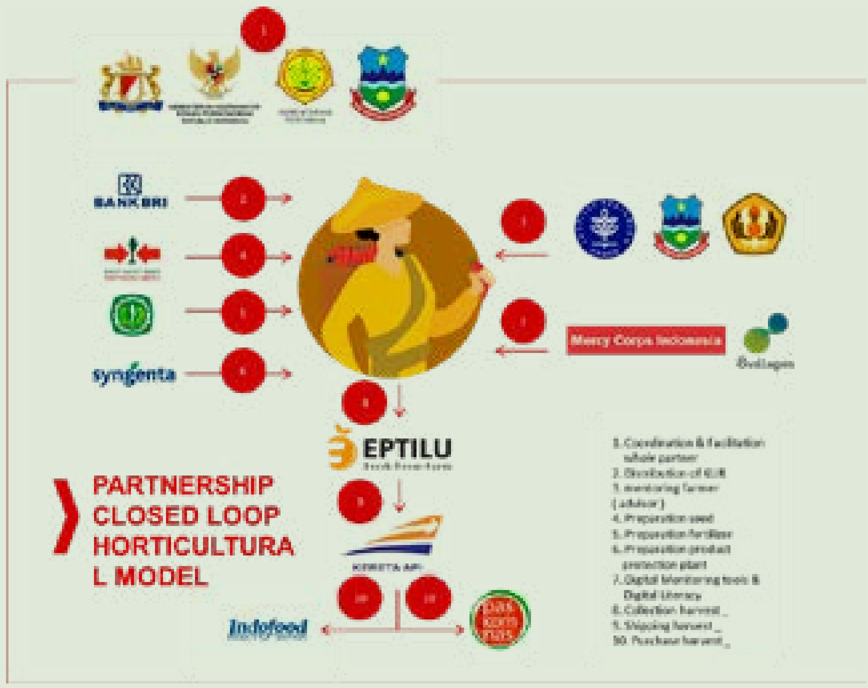


Source: [37].

Collaboration with key institutions and stakeholders, such as the Indonesian Agency for Agricultural Research and Development, PIHPS Nasional, and inventors, can further enrich the digital ecosystem and ensure that it meets the diverse needs of its users. Additionally, the Indonesian government's Partnership model, illustrated in Figure 19, represents a concerted effort to promote sustainable horticulture practices and drive positive outcomes in the agricultural sector through strategic collaboration and innovation.

FIGURE 19

THE L MODEL PARTNERSHIP CLOSED LOOP HORTICULTURE.



Source: [37].

Appendix

Precision Farming Steps using Sensor, Arduino, IoT, and Ubidots

- Check conditions for crops, e.g., climate and weather, soil moisture, temperature humidity, light, and air.

- Arduino Uno serves as the development board or microcontroller that controls the operation of the system. It collects data from sensors and sends it for storage or further processing.

- The sensors are connected to Arduino Uno. Each sensor is typically connected to specific pins on the Arduino board, and the data collected by sensors is transmitted to Arduino for processing.

- Sensors are responsible for collecting environmental data around the plant. The types of sensors mentioned include: (1) temperature sensor, which measures the ambient temperature; (2) air humidity sensor, which measures the relative humidity in the air; (3) soil humidity sensor, which measures the moisture level in the soil; and (4) light intensity sensor, which measures the intensity of light in the environment.

- In oil palm plantation [3, 20], use SEC as well.

- Add organic fertilizer (goat and cow manure).

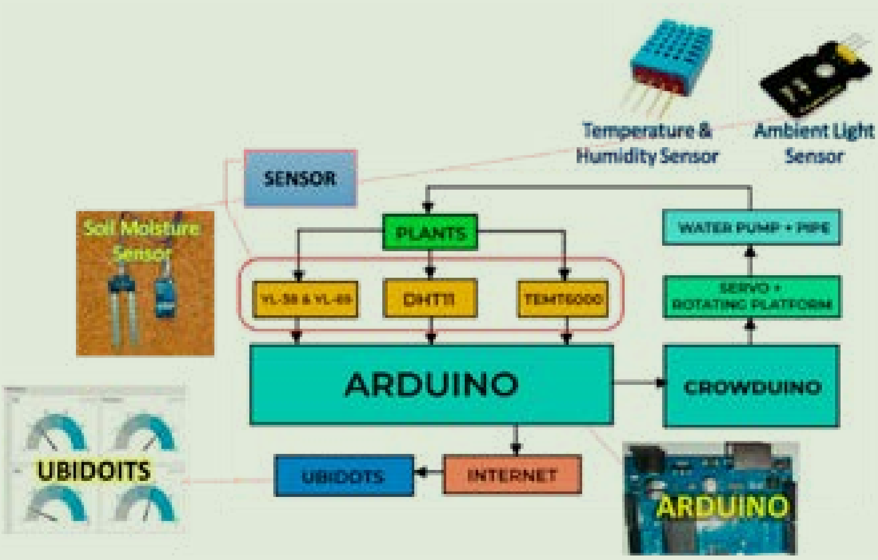
- Use tools such as atomic absorption spectrometry (AAS) to measure heavy metal content to detect chlorosis.

- Improve soil's biological properties.

- The result is increase in soil's capability and productivity.

FIGURE A1

SCHEMATIC DIAGRAM OF PRECISION FARMING IN INDONESIA.

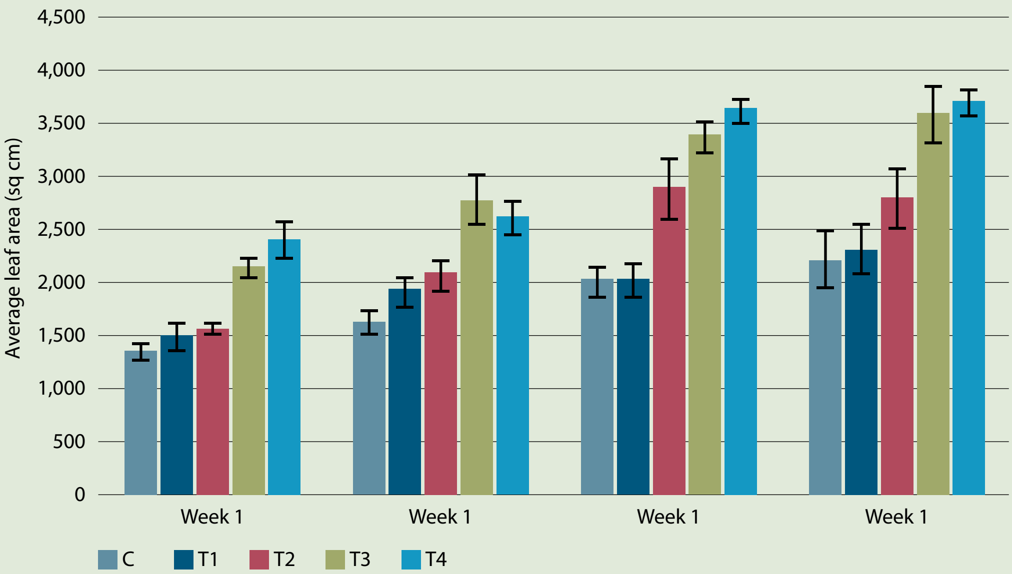


Source: [9].

Soil Electrical Conductivity (SEC) to measure pH [20]

FIGURE A2

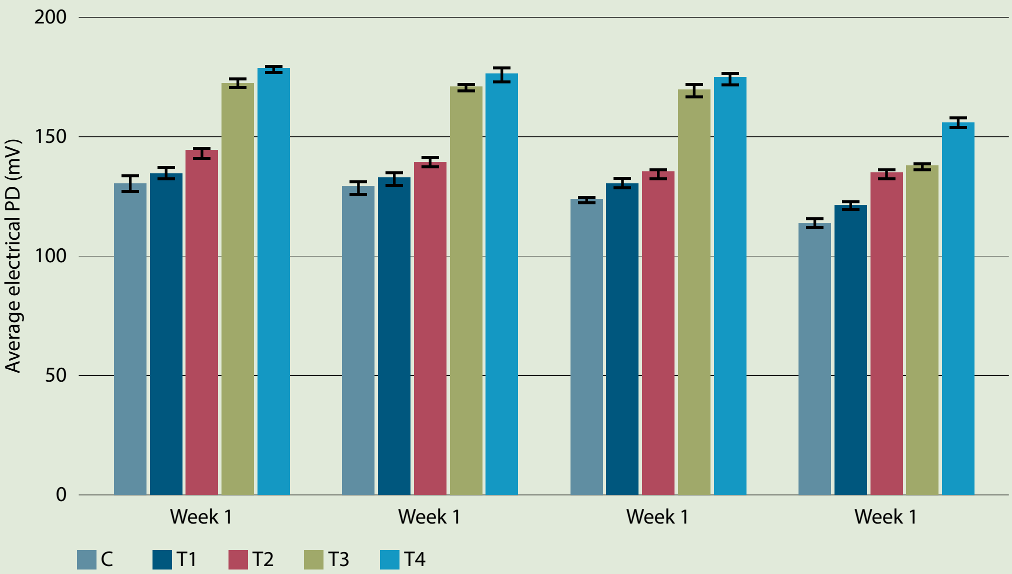
AVERAGE OF LEAVES AREA OF MAIZE GROWN IN DIFFERENT CONCENTRATION OF MANURE.



Note: C = control; T1 = 1/4 S: ¾ GM; T2 = 1/4 S:3/4 CM; T3 = 2/3S:1/3CM; and T4 = 2/3S: 1/3 GM.
Treatment = T; soil = S; cow manure = CM; and goat manure = GM.

FIGURE A3

ELECTRICAL POTENTIAL PD OF MAIZE UNDER DIFFERENT APPLICATION OF MANURE ON THEIR GROWING SOIL MEDIA.



Note: C = control; T1 = 1/4 S: ¾ GM; T2 = 1/4 S:3/4 CM; T3 = 2/3S:1/3CM; and T4 = 2/3S: 1/3 GM.
Treatment = T; soil = S; cow manure = CM; and goat manure = GM.

Increasing Water Productivity: Drip Irrigation, Auto Watering, Automatic Control System

IoT will be a bridge for the process. Setup involves using IoT technology to control sensors and hardware in real time. Here is a breakdown of the components and their roles [28]:

ESP8266 node MCU board: This serves as the access and processing center for the IoT system. The ESP8266 is a popular microcontroller with built-in Wi-Fi capability, making it suitable for IoT applications. It can connect to the internet and communicate with other devices or servers.

Relay: The relay is a switch that can be controlled electronically. It is connected to one of the general purpose input/output (GPIO) pins on the ESP8266 board. The relay serves as an interface between the microcontroller and the motorized solenoid pump, allowing the microcontroller to turn the pump on or off remotely.

Motorized solenoid pump: This is a pump that is activated by an electric current to move fluid (such as water) from one location to another. The pump is connected to the relay, and its operation can be controlled by the ESP8266 board via the relay.

Power supply: This provides the necessary electrical power for the ESP8266 board, the relay, and the motorized solenoid pump to operate. The power supply ensures that the components receive stable and sufficient voltage to function properly.

Drip Irrigation [28]

Tools and conditions: These include IoT, integrated device electronic (IDE), smartphone, sensor YL-69, Esp8266 node MCU, water pump watering automation process, internet network, and the average condition (Tx 46 m/s and Rx 51 m/s and ping 35m/s to 120 m/s in real time).

Auto Watering [30]

Tools and conditions: These include IoT, Arduino, soil moisture sensor, smartphone, water pump watering automation process, and a humidity value always above 41%.

Automatic Control System [26]

Tools and conditions: These include IoT, sensors for temperature and soil moisture, sensor for room air quality, water pump, ultrasonic sensors detecting water levels, servo motors, four-channel relays, rain sensors, and LDR sensor to measure light intensity; automatically controlled greenhouse using IoT and other tools; humidity values of 30% to 70%; and water levels at the height of 5–25 cm in water reservoirs.

Modern Sustainable Agricultural Technologies

IoT, Service System Platform, and System Engineering [4]

- Monitoring chlorophyll and proper fertilizer

- Tools (chlorophyll meter, IoT, and J meter software)

Hydro-organics with Remote Sensing [25]

Measuring various aspects of paddy cultivation using a combination of technologies and methods. Here is a breakdown of the tools and methods mentioned:

(1) **Wireless sensor network (WSN):** WSN involves a network of sensors deployed in the paddy field to collect data on various parameters such as temperature, humidity, soil

FIGURE A4

THE "TO-BE" BUSINESS PROCESS OF RECORDING CHLOROPHYLL CONTENT DATA.

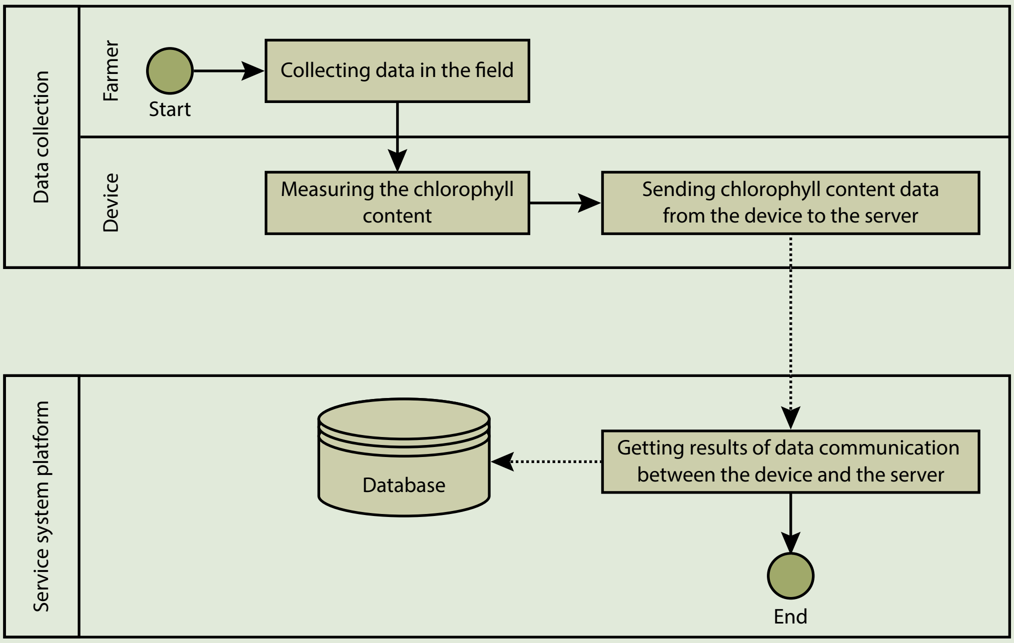


FIGURE A5

THE WORKING PRINCIPLE OF MEASURING CHLOROPHYLL CONTENT.

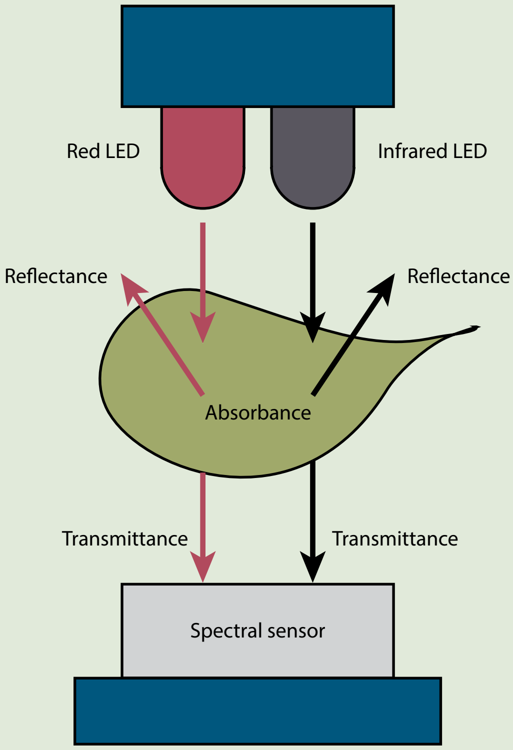


FIGURE A6

ARCHITECTURE OF THE SERVICE SYSTEM PLATFORM BASED ON IOT FOR MONITORING NUTRITIONAL DEFICIENCIES.

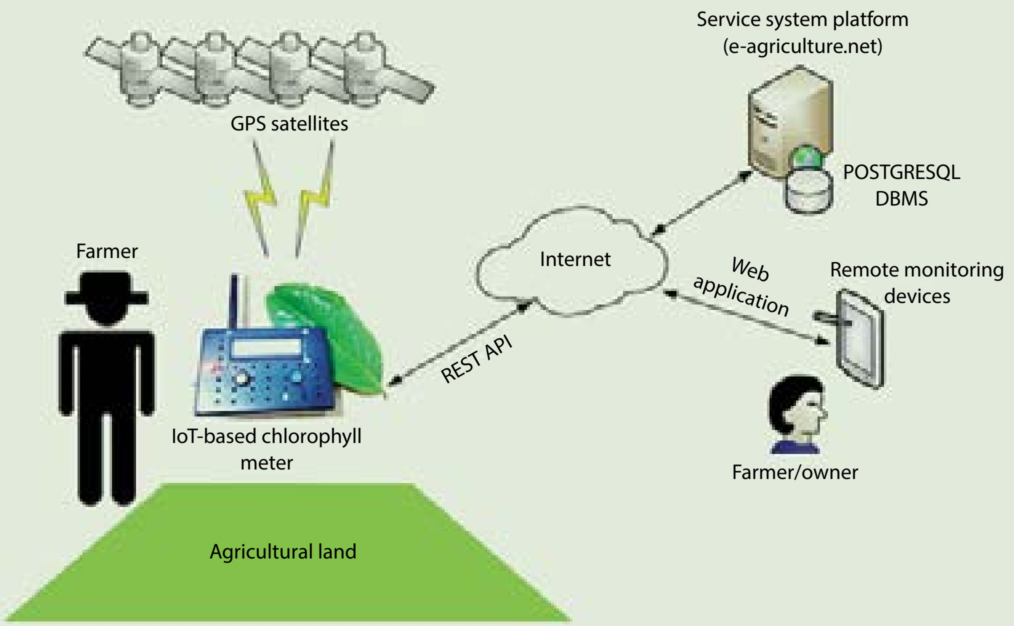
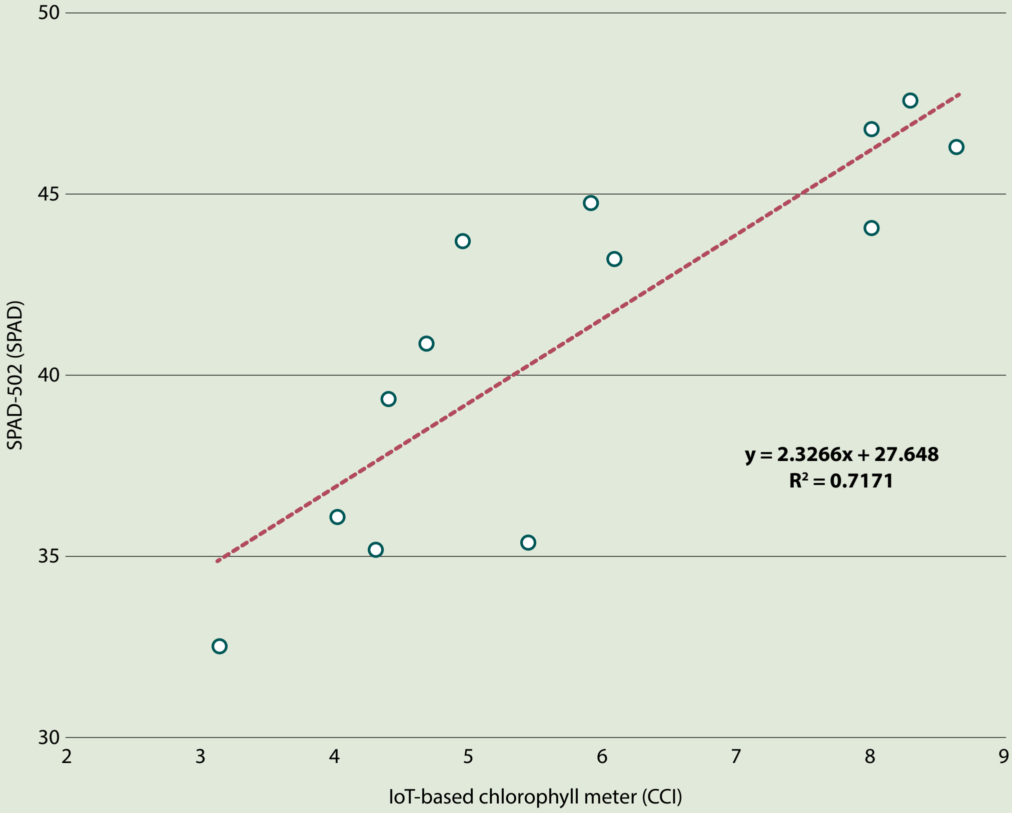


FIGURE A7

MEASUREMENT OF THE CHLOROPHYLL CONTENT OF 13 RICE LEAVES AT 13 SAMPLING POINTS.

FIGURE A8

CORRELATION BETWEEN IOT-BASED CHLOROPHYLL METER VALUES AND SPAD-502 VALUES.



moisture, and other environmental factors. These sensors communicate wirelessly to a central system for data collection and analysis.

(2) **Ground-based remote sensing:** This involves the use of ground-based sensors or instruments to remotely sense and gather information about the paddy field. It may include technologies such as Light Detection and Ranging (LiDAR) or hyperspectral imaging to collect detailed data about the vegetation, soil conditions, and other parameters.

(3) **Chemical analysis:** Chemical analysis is used to measure the nitrogen content in the plants, which is crucial for assessing their nutritional status and growth. This analysis may involve collecting plant tissue samples and performing laboratory tests to determine nitrogen levels accurately.

(4) **Spectrometer and imaging system:** Spectrometers and imaging systems are used to capture detailed data about the paddy plants and their surroundings. This includes parameters such as plant height, leaf length, leaf width, canopy size, total leaves, panicles, water demands, nutrient applications, and root systems. These tools provide highly correlated data (as indicated by the R-square values) for analyzing various aspects of paddy cultivation, including plant growth, water requirements, nutrient needs, and root development.

FIGURE A9

SCHEMATIC DIAGRAM OF A HYDROGANICS SYSTEM.

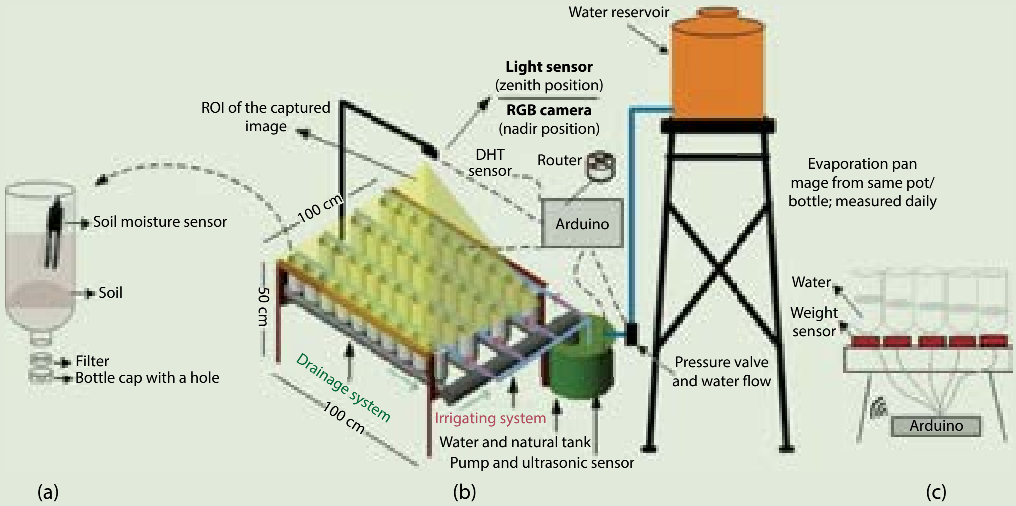


FIGURE A10

TIME SERIES RGB IMAGE EXTRACTION ACQUIRED IN DIFFERENT PLOTS.

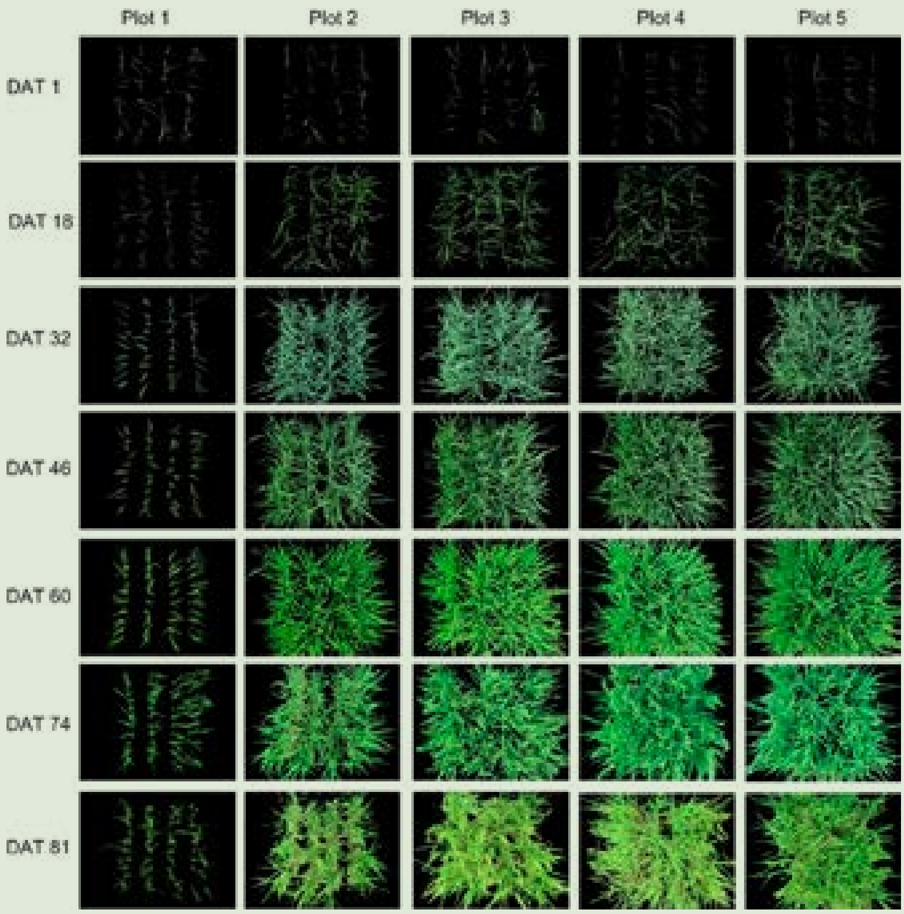
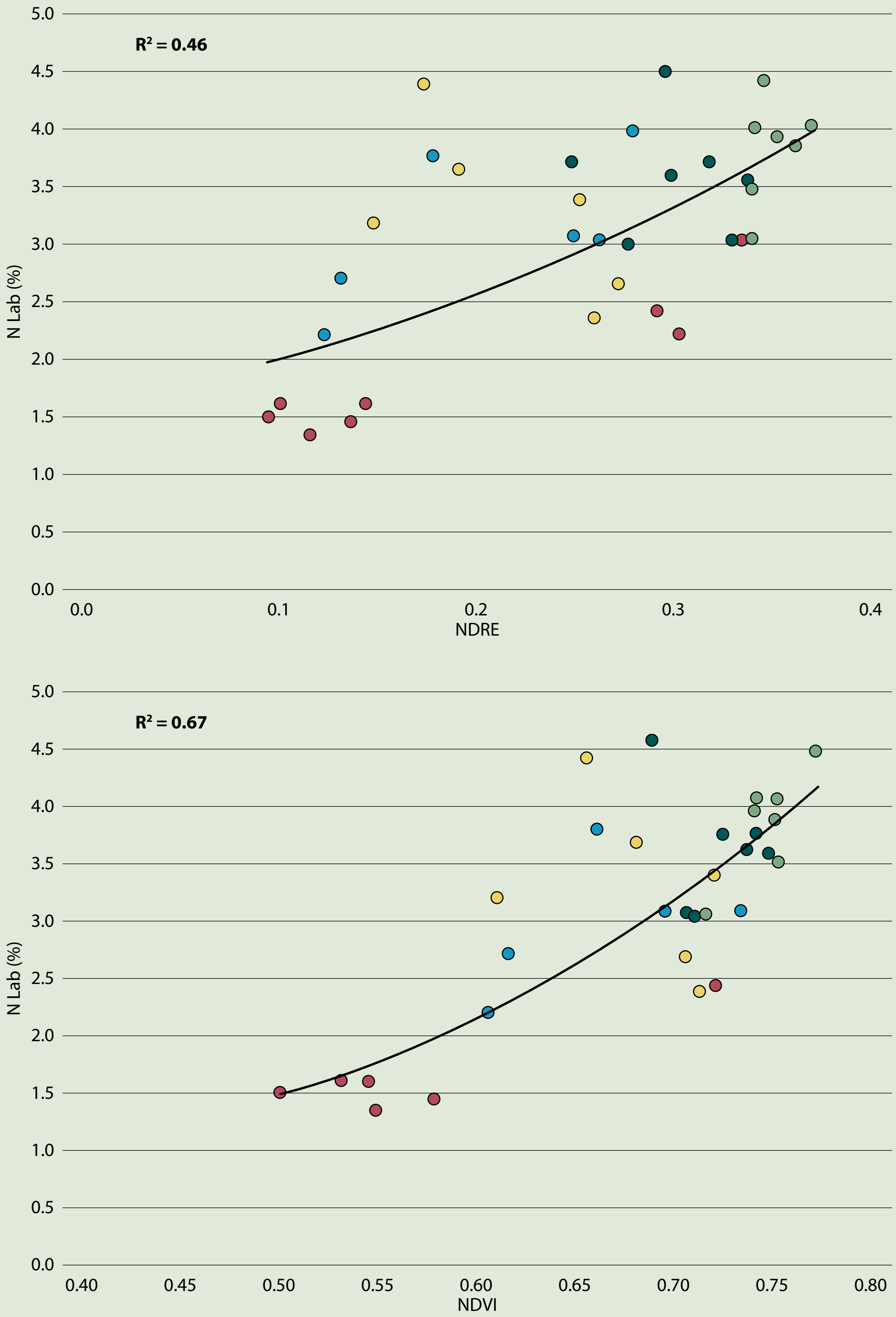


FIGURE A11

CORRELATION BETWEEN N LAB AND DIFFERENT VEGETATION INDICES.



	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
Urea:	0%	40%	70%	100%	150%
Water:	171.3 L	278.8 L	356.7 L	431.3 L	556.2 L

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THE PHILIPPINES

Introduction

Statement of Problem

The legislative framework for agricultural modernization in the Philippines is set forth in RA 8435, the Agriculture and Fisheries Modernization Act (AFMA). According to this Act, agricultural modernization includes not only increasing productivity and market efficiency, but also the protection and preservation of the environment. Section 3 (Statement of Objectives) includes the provision "To provide social and economic adjustment measures that increase productivity and improve market efficiency while ensuring the protection and preservation of the environment and equity for small farmers and fisherfolk (underscoring supplied)."

Numerous measures of productivity of the Philippine agriculture have been developed and compiled. On the other hand, a number of studies have been conducted on the environmental consequences of agriculture and fisheries. Despite the AFMA objective quoted above, there have been few, if any, attempts to combine these into a single comprehensive measure. This study attempts to remedy this gap, and thereby provide a novel quantification of the AFMA objective of modernizing agriculture by increasing productivity while maintaining environmental sustainability.

Objectives of the Study

The objectives of the study are to

(1) develop conceptual framework and method for adjusting standard economic productivity measures with sustainability concerns;

(2) review existing productivity measures and environment trends in Philippine agriculture;

(3) obtain adjusted measures for agricultural productivity for the Philippines; and

(4) draw some preliminary implications for policy.

These objectives are mirrored in the structure of this chapter. The conceptual framework and method, together with the related literature, are developed in the section that follows. Productivity measures are reviewed in the section after that, and environment trends in the subsequent section. The adjusted measure of agricultural productivity with environmental values is presented and discussed next. The last section contains the conclusion.

Conceptual Framework and Related Literature

Measuring Productivity

The most common productivity measures are 'partial' in that they involve a ratio of output to one of the production inputs, usually a factor of production, i.e., land, labor, or capital. Gross output to land ratio is 'yield,' while labor productivity is usually measured by the ratio of agricultural gross value added (GVA) to the number of workers whose primary occupation is agriculture.

However, a partial productivity measure, by its nature, does not control other factors. For instance, crop yield may increase due to intensification, i.e., by applying more fertilizers and other inputs. Moreover, yield for a single crop may also be an incomplete productivity measure for farming systems composed of multiple activities. To correct this, the appropriate measure is total factor productivity (TFP), which is a ratio of an aggregate output index to an aggregate input index, i.e., it accounts for all types of inputs and outputs.

Aggregation of outputs and inputs, say, by a simple summation of physical units runs into the "adding up apples and oranges" problem. To get around this, physical units of output and input are converted into economic values (currency units) using market prices. This in turn runs into the "index number problem," i.e., arriving at an appropriate way to aggregate the information provided by prices and quantities, given that prices and quantities are changing over time. Diewert [6] identifies a class of index number functional forms denoted as 'superlative indices,' which are consistent with flexible aggregator functions. Among these superlative indices are Fisher and Törnqvist indices, widely used in the productivity literature.

The standard production function for a given output Y (ignoring intermediate inputs) is

$$Y = F(K, L) \tag{1}$$

In Equation 1, K denotes the flow of capital services per unit time; L the flow of labor services per unit time; and F is a twice-differentiable function such that $\partial F/\partial K = MP_K > 0, \partial F/\partial L = MP_L > 0$. Y, K, L are all traded in competitive markets at prices p, w_K, and w_L, respectively. Producer behavior is modeled by maximization of profit π, given by Equation 2:

$$\max \pi = pF(K, L) - w_K K - w_L L \tag{2}$$

The first-order conditions imply:

$$pMP_K = w_K; \; pMP_L = w_L \tag{3}$$

That is, the value of marginal products equals the respective factor prices.

Adjustment for Environmental Inputs and Outputs

In fact, production may involve goods not traded in any market. Such inputs or outputs exhibit characteristics of externality or public goods, which prevent a market from forming. The implications of nonmarket byproducts in measuring agricultural TFP are discussed in some detail by Bureau and Anton [3]. First, it may be difficult to measure these nonmarket byproducts even with physical units, e.g., measuring the sediments released by farms cultivated along a mountain range (nonpoint source pollution). Second, even if a byproduct can be physically measured, there is no straightforward way to convert that into an economic value, in the absence of a market price.

Two options for treating nonmarket byproducts are to treat them either as outputs, or as inputs. The former is usually accompanied by the assumption of "weak disposability," which means that reducing the level of production of a market good reduces the level of the byproduct. The latter, on the other hand, involves the assumption of "joint inputs," which means that increasing market inputs involves increasing inputs, say, of ecosystem services.

In terms of the production function given in Equation 1, we add another variable E, also a result of utilization of factors K and L, with the relationship also described by a twice differentiable function G:[1]

$$E = G(K,L);\ \partial G/\partial L > 0, \partial G/\partial L > 0\ .$$

Unlike Y, E is not traded in a market. Hypothetically, let q be the maximum price that a person, or a group of persons, are willing to pay to abate E by one unit. The abatement can occur either by reducing G via K and/or L, or by applying an abatement technology that renders E harmless (denote that price as q). Owing to failure of regulation or transaction cost, a lá Coase [5] says that price is not paid to perform the abatement.

Environmentally Adjusted Multifactor Productivity Measure

Bureau and Anton [3] present the environmentally adjusted multifactor productivity (EAMFP) measure introduced by Cárdenas et al [4] as follows:

EAMFP growth = GDP growth + adjustment for pollution abatement – contribution of labor – contribution of capital – contribution of natural capital;

using the usual decomposition:

> TFP growth = GDP growth – contribution of labor – contribution of capital.

We can restate EAMFP as follows:

> EAMFP growth = TFP growth + adjustment for pollution abatement – contribution of natural capital.

The two adjustments for EAMFP involve pollution abatement and contribution of natural capital. We consider each of these in turn.

Adjustment for pollution abatement: This adjustment enters as a positive contribution to EAMFP growth. Conversely, allowing emissions unabated amounts to a negative contribution to EAMFP growth. The value is equal to the society's willingness to pay to abate the pollution (even if actually not paid). Various techniques in environment-and-resource economics have been developed to value this willingness. In the prominent case of greenhouse gas (GHG) emissions, valuation can draw on existing carbon prices, whether in the form of carbon tax, or the price of carbon credits under a cap-and-trade regime.

Contribution of natural capital: This contribution may be interpreted as the "ecosystem service" from natural resources, interpreted as a form of capital. The standard practice is to ignore this contribution, unless there has been some type of actual or potential disruption in the flow of ecosystem service, such as the loss of a coral reef.

It may be argued that this may also be ignored when the concept of growth is gross of depreciation of capital, of both physical (the standard case) and natural capital. The difference though is that depreciation of physical capital is easily reversible by future investment. However, the loss of

[1] The relationship with L and K may be mediated by Y, i.e., $E = E(F(K,L)) = G(K,L)$.

natural capital is not as easily reversed, e.g., it may take decades to regrow coral reefs, or to reestablish a natural forest stand. It may be a good idea to highlight these irreversibilities by explicitly incorporating an estimate of depreciation of natural capital and incorporating it as a (negative) "contribution of natural capital."

Implications of Profit Maximization for the Environment-adjusted Measure

In our simplified case, we incorporate environment adjustment by considering the following: while Y has been produced at a benefit to the society, estimated by p, E has also been produced at a harm to the society, estimated by a constant q. (The constancy of q is not essential to our conclusion, but it simplifies the following derivations significantly.) Hence, qE must be subtracted to net out the benefit of pY. Ignoring in the meantime the contribution of natural capital, we define the environment-adjusted measure of output EAY as follows:

$$EAY = pY - qE$$

The significance of EAY is seen in the maximization problem given in Equation 4 below:

$$\max\left(EAY - w_K K - w_L L\right) = \pi - qG(K,L) \tag{4}$$

The first-order conditions are given by:

$$\frac{\partial W}{\partial K} = p\frac{\partial F}{\partial K} - q\frac{\partial G}{\partial K} - w_K = 0$$
$$\frac{\partial W}{\partial L} = p\frac{\partial F}{\partial L} - q\frac{\partial G}{\partial L} - w_L = 0.$$

At maximum W, Equation 5 would hold:

$$q = \frac{pMP_K - w_K}{\partial G/\partial K} = \frac{pMP_L - w_L}{\partial G/\partial L}. \tag{5}$$

If $q > 0$, then profit maximization as shown in Equation 3 violates Equation 5. This shows that under profit maximization, there is overproduction of Y owing to non-pricing of E.

Environmentally Adjusted Total Factor Productivity

Expanding Equation 4 offers a natural formalism for classifying E on the input side:

$$W = pF(K,L) - w_K K - w_L L - qE(K,L).$$

We may therefore construct an environmentally adjusted cost measure EAC:

$$EAC = w_K K + w_L L + qG(K,L).$$

We now consider the multioutput, multifactor case: the multiple outputs are denoted Y_i, and the multiple factors by X_j, with $i = 1, 2, ..., M$; $j = 1, 2, ..., N$. Furthermore, we define aggregate value of output and environment-adjusted cost, respectively:

$$Y = \sum_{i=1}^{N} p_i Y_i;\ EAC = \sum_{j=1}^{N} w_j X_j + qE.$$

Let s_i denote the revenue share of output Y_i: $s_i = p_i Y_i / Y$; $c_j = w_j X_j / EAC$; $c_q = qE/EAC$.

We index the aforementioned variables with a time index, with periods 0 and 1. The Törnqvist output index $YT_{0,1}$ is given by the following:

$$\frac{YT_1}{YT_0} = \prod_{i=1}^{M} \left(\frac{Y_{i1}}{Y_{i0}} \right)^{0.5(s_{i0} + s_{i1})}$$

Similarly, the Törnqvist input index is given by the following:

$$\frac{XT_1}{XT_0} = \prod_{j=1}^{N} \left(\frac{X_{j1}}{X_{j0}} \right)^{0.5(c_{j0} + c_{j1})} \left(\frac{E_1}{E_0} \right)^{0.5(c_{q0} + c_{q1})} .$$

Following Teruel and Dumagan [18], the environment-adjusted TFP measure is given as follows:

$$EATFP_{0,1} = \frac{YT_1 / YT_0}{XT_1 / XT_0} .$$

Alternatively, we can express this in growth form using logarithms:

$$\ln EATFP_{0,1} = \sum_{i=1}^{M} 0.5(s_{i0} + s_{i1}) \ln \left(\frac{Y_{i1}}{Y_{i0}} \right) - \sum_{j=1}^{N} 0.5(c_{j0} + c_{j1}) \ln \left(\frac{X_{j1}}{X_{j0}} \right)$$

The Törnqvist index is a type of chained index. Disregarding the averaging over successive periods and stating for the generic period t, leads to Equation 6:

$$\ln EATFP_t = \sum_{i=1}^{M} s_{it} \ln Y_{it} - \sum_{j=1}^{N} c_{jt} \ln X_{jt} . \tag{6}$$

This is the standard growth accounting framework, though with an expanded version of cost (hence a lower figure for the input index compared with standard TFP).

Productivity Trends in Philippine Agriculture

Overview of Agriculture

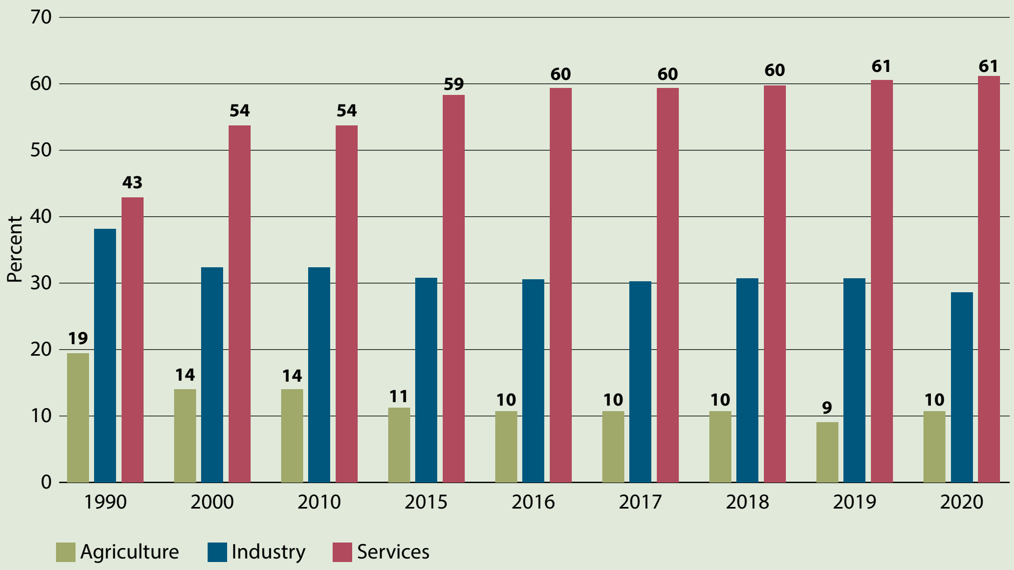
The Philippines is a near-upper-middle-income country, with per capita gross national income already at USD3,640, which is about 10% below the upper-middle-income cutoff of USD4,046. As such, it has already progressed far in terms of structural change, with the GDP share of agriculture being only 9% in 2019, down from 19% two decades earlier (see Figure 1). Meanwhile, in 1990, the output share of the largest basic sector, services, was already 43% and further increased to 61% in 2020.

Table 1 presents GVA over a period of time, in fixed prices, with 2018 as the base year. At the bottom row of the table is the market exchange rate of local currency for the USD. In 2021, total agricultural GVA was PHP1.78 trillion, or USD36 billion, approximately. Crops accounted for more than half, with the largest shares being of paddy rice, banana, maize, coconut, and sugarcane. The next largest share was that of support services (the largest component of other sectors), followed by fishery (including fishing and aquaculture).

Livestock (mostly hogs) and poultry had nearly identical output shares. The sector has been changing over time. In 2000, the total GVA was just over PHP1 trillion, 68% of which was from crops. Over time, the share of crops declined, while that of other sectors increased. Also, livestock output rose consistently until 2020, before suffering a severe contraction in 2020–21 owing to African Swine Fever.

FIGURE 1

SHARES OF GDP BY BASIC SECTOR IN THE PHILIPPINES AT CURRENT PRICES, 1990–2020.



Source: PSA [15].

TABLE 1

GVA IN AGRICULTURE, FISHERIES, AND FORESTRY AT CONSTANT 2018 PRICES.

	2000	2010	2015	2020	2021
	In PHP billion				
Crops	679	848	914	915	935
Paddy rice	284	329	371	369	382
Corn	56	81	94	103	105
Coconut	70	89	83	82	83
Sugarcane	25	21	27	31	33
Banana	86	139	137	134	135
Other crops	158	188	202	197	198
Livestock	135	180	212	216	179
Poultry	79	119	151	176	175
Fishery	104	204	219	223	224
Other sectors	67	149	191	250	263
Total	1,064	1,500	1,688	1,780	1,775
PHP per USD	44.19	45.11	45.50	49.62	49.25

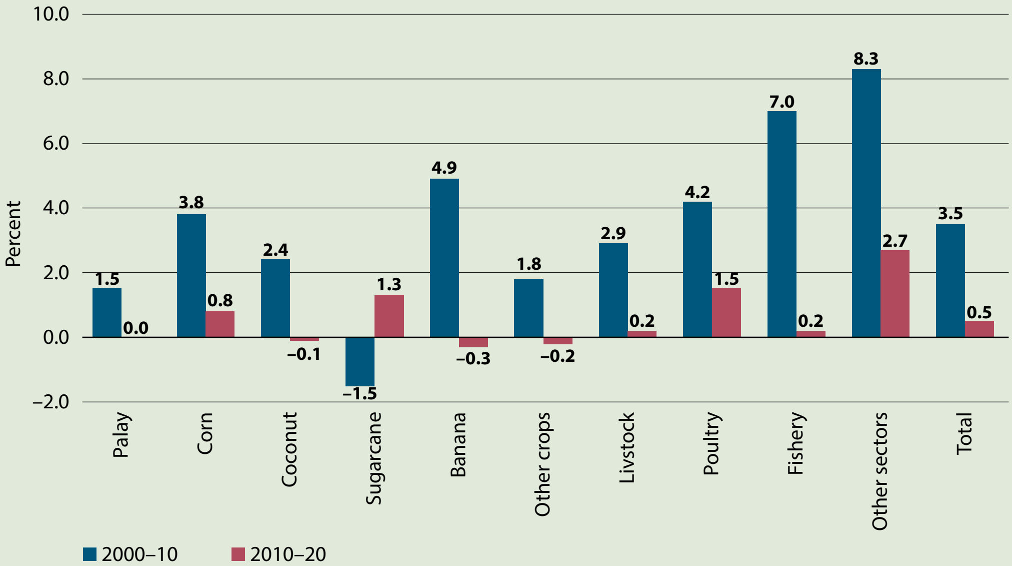
Source: PSA [15].

Growth rates are averaged by decade from 2000 in Figure 2. The pace of overall growth was rapid in the 2000s owing to a commodity price boom over most of the decade but experienced a sharp slowdown in the 2010s. In the 2000s, the fastest growing sectors were other sectors, fishery, and banana, followed by poultry. Sugarcane was the only sector undergoing contraction.

Growth for all these sectors slowed down in the 2010s, with the sharpest drop being for fishery, and banana also contracting over the period. Other sectors undergoing contraction were palay and coconut, while sugarcane flipped to low growth in the 2010s. Livestock still posted a small positive growth over the decade.

FIGURE 2

AVERAGE ANNUAL GROWTH RATES OF AGRICULTURAL GVA IN THE PHILIPPINES, 2000–20.



Source: PSA [15].

Trends Based on Partial Productivity Measures

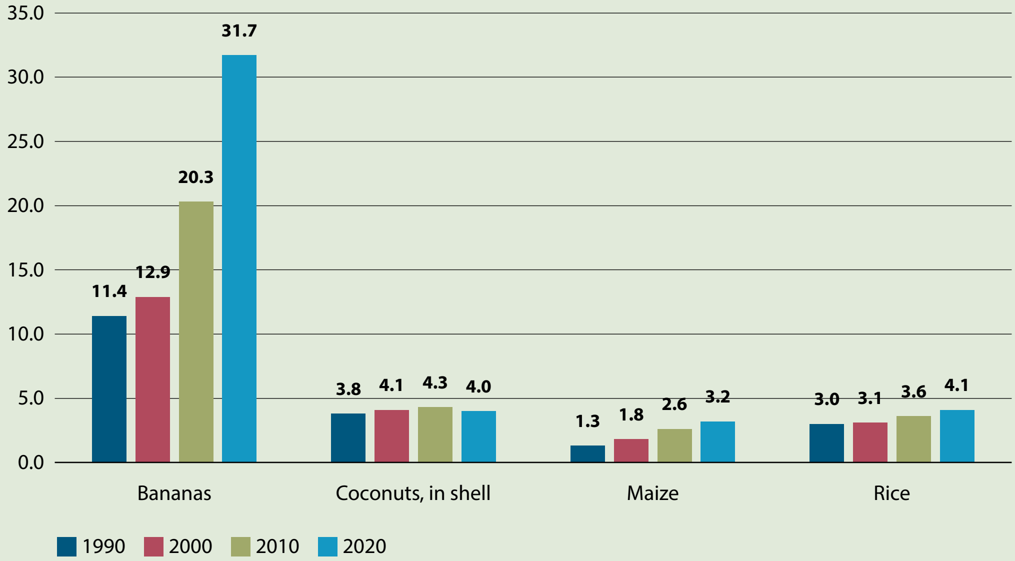
Land productivity based on the yield indicator is shown in Figure 3 for major crops, except for sugarcane, which suffered a decline in yield from 80 ton per ha in 1990 to 50.5 ton per ha in 2010, though recovering somewhat to 61.1 ton per ha in 2020.

Also suffering from a decline, though not so drastic, has been coconut, which actually saw a slight yield improvement from 1990 to 2010. Bananas showed a relatively rapid increase in yield, adding under two-thirds during 2000–10, and further by more than two-thirds from 2010 to 2020. Also showing relatively rapid growth was maize (doubling from 1990 to 2010 and growing by another one-fifth from 2010 to 2020), as well as rice (growing by one-third from 1990 to 2020).

Partial productivity measures for agriculture as a whole, for land and for labor, are shown in Figure 4. Agricultural output per ha and per worker began at very similar levels in 1990 (USD1,866 and USD1,844, respectively). In the 1990s, the two productivity measures diverged, but converged again in 2002 and continued together until 2011. However, agricultural output per ha stabilized at around USD2,600–2,700 agricultural output per worker, marking a phase of accelerated growth as output continued to expand, though the absolute number of agricultural workers declined consistently until 2019 [2].

FIGURE 3

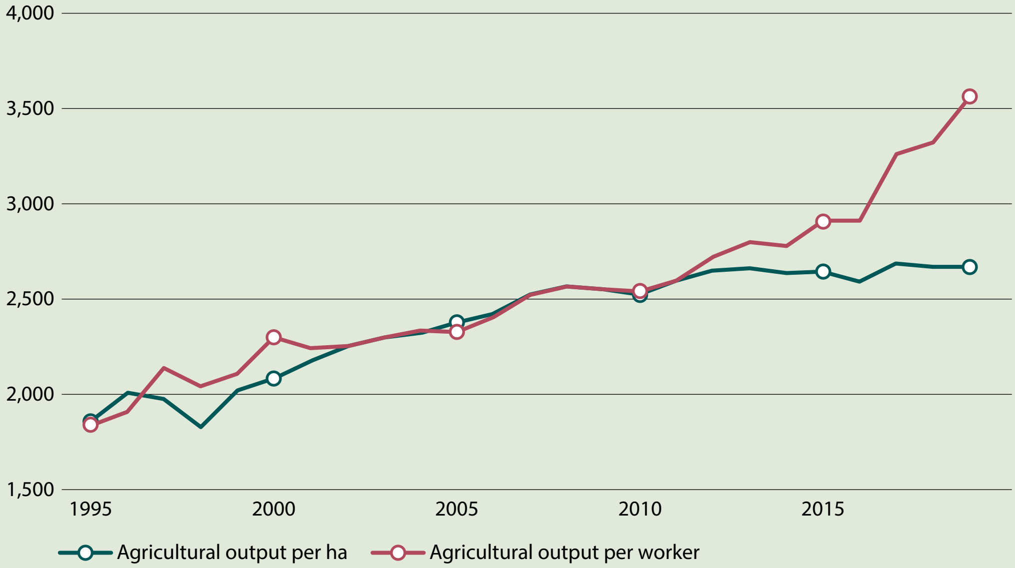
YIELDS OF MAJOR CROPS IN THE PHILIPPINES IN TON PER HA, 1990–2020.



Source: PSA [15].

FIGURE 4

ANNUAL GROSS VALUE OF PRODUCTION PER UNIT IN USD '000 AT 2014–16 PRICES.



Source: FAO [9].

Trends Based on Total Factor Productivity Measures

USDA [20] provides updated estimates for agricultural TFP using standard growth accounting framework, i.e., Equation 6 sans adjustment for non-market inputs. The USDA estimates for the Philippines are given in Table 2.

TABLE 2

GROWTH OF AGRICULTURAL TFP IN THE PHILIPPINES AND ASIA, 1962–2020 (%).

	1962–70	1971–80	1981–90	1991–00	2001–10	2011–20
	Philippine growth rates					
Inputs	2.7	2.0	1.3	1.2	1.4	0.6
TFP	0.6	2.8	1.1	0.7	1.7	0.4
Output	3.3	4.8	2.5	1.9	3.1	1.0
Asia, TFP growth	0.7	0.5	1.8	2.8	2.5	1.9

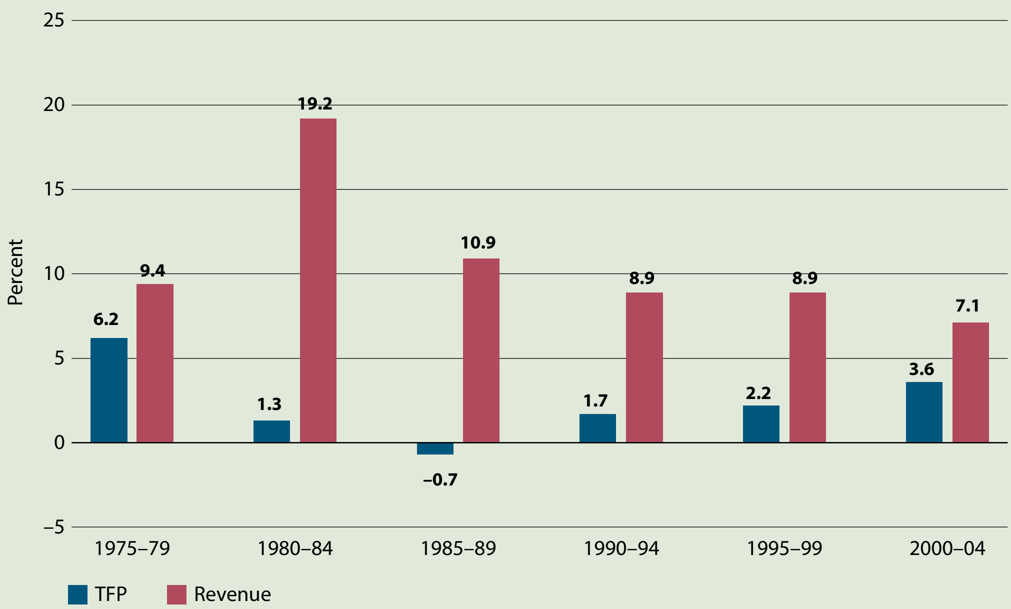
Source: USDA [20].

Output growth started out quite high in the 1960s, though most of this was due to growth in inputs, reducing the TFP growth to levels matching the average for Asia. In the 1970s, agricultural growth in the Philippines accelerated, as did the TFP component. In this decade, TFP growth for the Philippines far exceeded that of Asia. However, TFP growth began to decelerate in the 1980s and the 1990s even as the growth for Asia picked up and reached 2.8% on an average in the 1990s and 2.5% in the 2000s, before leveling off somewhat at 1.9% in the 2010s. The Philippines, however, stayed in the 1% range from 1990 to 2010, before sliding to below 1% in the 2010s.

Alternative estimates of agricultural TFP growth are available from Teruel and Dumagan [18], who used the Törnqvist Index (see Figure 5). They arrived at much higher estimates overall for TFP, particularly for the 1970s. Although TFP growth slowed down in the 1980s in both Table 2 and Figure 5, for the latter, TFP growth accelerated in the 1990s, unlike in Table 2.

FIGURE 5

AGRICULTURAL TFP GROWTH ESTIMATES, 1975–2004.



Source: Teruel and Dumagan [18].

Environment and Natural Resources Trends

Terrestrial Ecosystems

Forest Resources

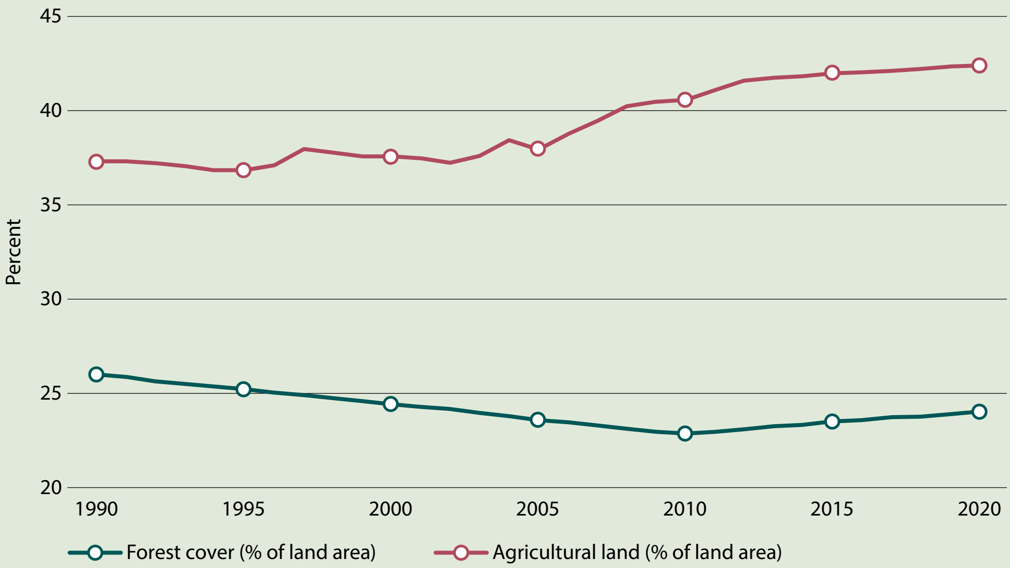
The forest cover in the Philippines, as in many other countries, has fallen dramatically over the past century, from about 70% of the country's land area in 1900 to just 23% in 2018 [19]. This deforestation has been due to logging and land-usage changes, primarily conversion of forestland to agricultural land [7]. In 1990, the forest cover was still 26.1%, but fell over the succeeding years, bottoming out in 2010 at 22.9%, which was equivalent to 68,397 sq km (see Figure 6). From 1990 to 2011, the area of agricultural land increased from 37.4% to 40.6%. Fortunately, over the previous decade, there was an unprecedented expansion of forest cover nationwide. While previously, weak forest protection had led to steady loss of forests, from 2011 onward, a series of Executive Orders reinvigorated public policy on forest resources. First, cutting and harvesting of timber in natural and residual forest was prohibited; second, the National Greening Program (NGP) was instituted. The NGP aimed at rehabilitating 1.5 million ha of open and degraded forestland [11].

Soil Resources

The land usage change in previously forested areas has resulted in land degradation, primarily due to soil erosion [2]. Soil erosion is the displacement of topsoil, which is caused by both natural processes as well as human activities such as deforestation, mining, and crop cultivation, especially intensive tillage. Offsite costs meanwhile cover siltation and sedimentation of reservoirs, irrigation canals, inland water bodies, and coastal zones [7].

FIGURE 6

FOREST COVER AND AGRICULTURAL LAND'S SHARE OF LAND AREA IN THE PHILIPPINES.



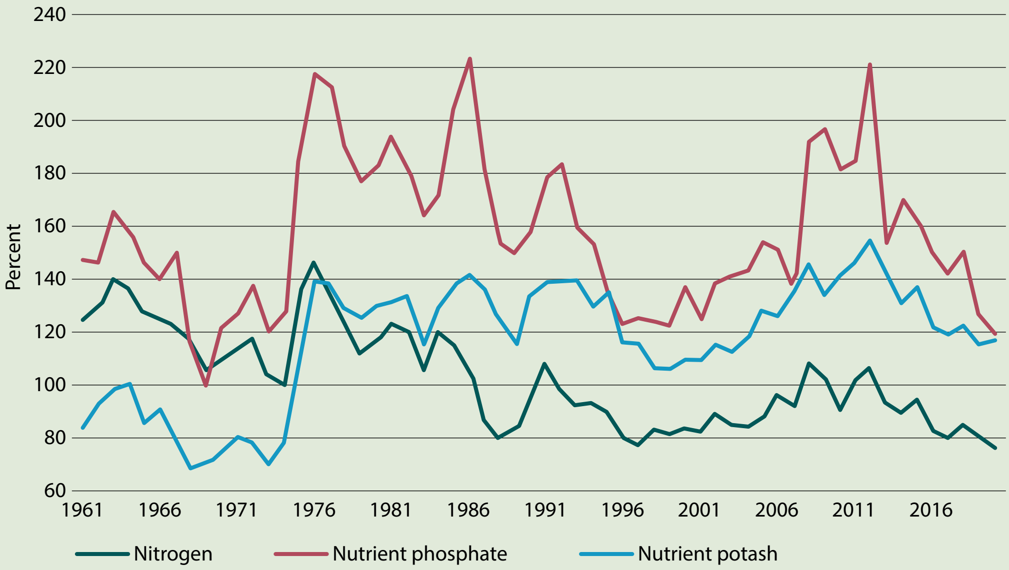
Source: The World Bank [22].

Plant growth involves extraction of nutrients from the soil, while decomposition, involving the soil microbial ecosystem, returns many of those nutrients to the soil through a process called the nutrient cycle. However, agriculture disrupts this by accelerating nutrient extraction and disturbing the soil ecosystem [13]. FAO compiles estimates of nutrient use efficiency (NUE) for the main crop macronutrients, namely nitrogen, phosphorus, and potassium. NUE for a given period is computed as total nutrient removal by plants, divided by total additional nutrients from fertilizers (synthetic and organic) plus natural deposition [10]. The latter is the sum resulting from bioavailable soil nutrients plus added nutrients from fertilizers. A level above 100% implies that nutrient removal exceeds available soil nutrients, while a level below 100% implies that more nutrients were added. The time series for the NUE in the Philippines starts from 1961 (see Figure 7).

Both nitrogen and phosphorus began at above 100%, while potassium started at below 100%. By the 1970s, all three breached 100% as agriculture intensified throughout the country without fertilizer application catching up. This trend continued to hold for phosphorus and potassium. However, nitrogen NUE fell below 100% in 1987, and typically stayed below this level except for 1991, during a sharp depreciation of the currency, and during 2008–09, when there was a rapid escalation in the global price of urea.

FIGURE 7

CROP LAND NUE BY TYPE OF NUTRIENT IN THE PHILIPPINES.



Source: FAO [9].

Water Resources

A persistently low NUE (below 50%) implies excess application, which is likely to lead to a runoff into water bodies and marine waters. Excess nutrient runoff causes ‘eutrophication’ resulting in algal blooms and fish deaths. Of the 19 priority rivers monitored by the Department of Environment and Natural Resources (DENR), only two meet the phosphate criteria all the time. All major rivers in Metro Manila failed the criteria of biochemical oxygen demand (BOD) and dissolved oxygen (DO). However, nationwide, of the 158 water bodies monitored by DENR, 83% met the BOD threshold, while 76% met the DO threshold [7].

Other than crop cultivation, the other major source of agricultural pollution of water bodies is livestock production, especially the rearing of pigs. Water quality has suffered in Manila Bay and Laguna de Bay owing to numerous backyard farms in and around the capital. In Laguna province, up to 68% of poultry and swine farm wastewater is directly discharged into the environment.

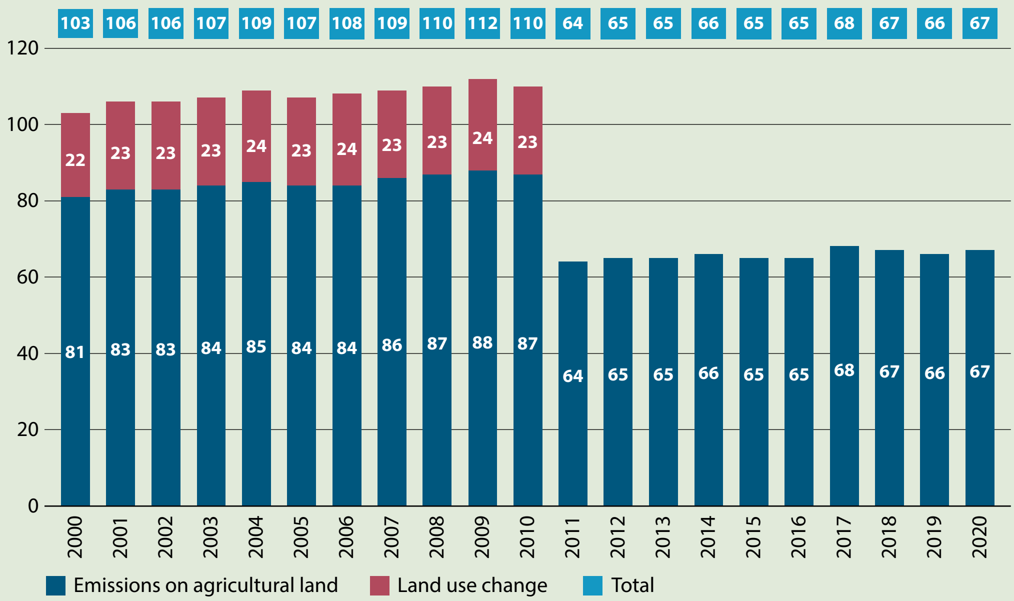
Air Pollution

Agricultural activities are a source of air pollution, namely from crop burning [14] as well as noxious ambient emissions from livestock, poultry, and dairy industries. The most serious form of air pollution from agriculture though is the emission of greenhouse gas (GHG), which contributes to the climate crisis. About a quarter of the country's GHG emissions originated from agriculture, amounting to 65 megatons of CO_2 equivalent. Indirectly, agriculture has also caused forest loss, accounting for perhaps 90% of the deforestation from 2000 to 2021, which is around 788 megatons of CO_2 equivalent [22, 23]. Of the total GHG emissions of agriculture, rice cultivation accounted for nearly two-thirds, mostly due to methane emissions from growing rice plants in irrigated paddy fields as well as nitrous oxide emissions from fertilizers and crop residues. Meanwhile, enteric fermentation (mostly from cattle production) contributed about 13% [8].

GHG emissions from agriculture peaked at 112 megatons of CO_2 equivalent in 2009 (see Figure 8). GHG emissions declined from 2011 onward, mostly by the near complete elimination of emissions attributed to land-use change, owing to a rising forest cover. On the other hand, GHG emissions from agricultural land also fell, from 87 megatons to 64 megatons of CO_2 equivalent.

FIGURE 8

GHG EMISSIONS FROM AGRICULTURE IN THE PHILIPPINES, IN MEGATONS PER YEAR, 2000–20.



Source: FAO [9].

Coastal and Marine Ecosystems

Fisheries

An indicator of the state of the stock is catch per unit effort (CPUE), which is the amount of fish caught per unit of fishing effort, e.g., per day of fishing, per boat, or per horsepower (hp) of fishing gear. Low CPUE implies overfishing of stocks. As early as 1985, Philippine fisheries had shown dramatic decline in CPUE compared with baseline levels in 1965; for small pelagics, CPUE over the interval declined from 2.5 kg per hp per year to 0.84 kg per hp per year. Meanwhile for demersal fish, CPUE came down from 1.13 kg per hp per year to 0.47 kg per hp per year as per Israel and Banzon. More recent data for 2015 [7, 16] shows a number of regions (out of the country's 15 fishing regions) with low CPUE. These are: regions V (75 kg/boat/day); IV-A (92 kg/boat/day); IX (124 kg/boat/day), and VIII (131 kg/boat/day). Regions with higher CPUE are I (4,165 kg/boat/day); IV-B (2,060 kg/boat/day); and VII (2,0005 kg/boat/day). One reason for the overfishing is that much of the activity is illegal, unreported, and unregulated (IUU). In 2019, up to 40% of fish caught in the Philippines was through IUU fishing [7].

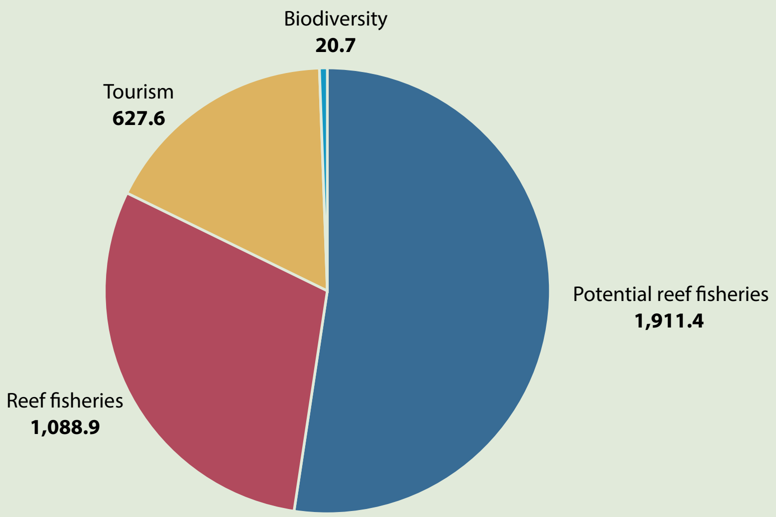
Habitats

Among the key marine habitats for aquatic organisms are coral reefs and mangroves. The coral reef area of the Philippines is estimated at 26,000 sq km and is host to over 3,000 fish species. Natural mangrove cover of the Philippines is around 247,268 ha, together with a planted area of 44,000 ha, down from original levels of around 500,000 ha [1]. These habitats are under severe threat, with reef fish biomass rates being 'low' to 'very low' in most of the regions due to intense fishing and habitat degradation, worsened by climate change. Mangrove loss is largely due to expansion of fishponds [7].

Loss of coral cover has been very rapid, with a third of coral reefs lost over the decade prior to the most recent assessment in 2014 [12]. The annual value of coral reefs ecosystem services in the Philippines is estimated at USD3,648.7 million, divided into various components (see Figure 9). By far the biggest source of value is reef fisheries, both actual (around USD1 billion), and potential (around USD1.9 billion), assuming proper management of reef fisheries. The next largest source is tourism, valued using willingness to pay for protected coral reefs, equivalent to around USD628 million. The last source of value is biodiversity at around USD21 million.

FIGURE 9

VALUE OF CORAL REEF ECOSYSTEM SERVICES BY SOURCE IN USD MILLION, 2015.



Source: Tamayo, *et al* [17].

Adjusted TFP Estimates

Data Sources and Method

Conventional TFP Estimates

For the basic estimate of TFP, we draw heavily on the USDA dataset on agricultural outputs, inputs, and TFP, as documented by the USDA [21]. Inputs are classified into labor, land, capital, and materials (intermediate inputs), mostly available from FAO for the period 1961–2020.

- **Labor:** This consists of total number of adults whose main economic activity is agriculture. It corresponds to ILOSTAT-modeled estimates for 1991 onward, backcast to 161 using FAOStat and other data sources. For a few countries (not including the Philippines), alternative sources are used to construct historical data.

- **Land:** Agricultural land consists of cropland (land in annual and permanent crops) and land in temporary fallows and pastures. Irrigated cropland, rain-fed cropland, and permanent pastures are converted into 'rainfed cropland equivalents,' based on their relative productivity.

- **Capital:** Capital inputs take two forms, namely, farm machinery and livestock inventory. Total agricultural capital stock uses the current inventory method for 1961–94, and the perpetual inventory method for 1995–2020.

- **Materials:** Materials or intermediate inputs take two forms, namely, inorganic fertilizers and animal feed. For the latter, quantities of cereal grains, roots and tubers, sugar crops, and their processing byproducts (brans, distiller grains, and molasses) are from FAOSTAT Commodity Balance Sheets. Quantities of oilseeds, oilseed meals, and fish meal are from USDA PS&D Commodity Balance Sheets.

Representative cost shares are assembled from 21 productivity studies that have estimated cost shares or production elasticities for specific countries or regions. Cost shares are representative of other countries within the same region when country-specific cost shares are not available. For instance, the cost shares for Indonesia are applied to other countries in southeast Asia and the Pacific. Average cost shares are estimated for each decade (1961–70, 1971–80, etc.). This helps avoid any index-number bias when cost shares evolve over time, e.g., if the cost share for intermediate inputs rises relative to those of other inputs.

To match availability of data for environmental indicators, only data for 2009–20 for the Philippines is used (see Table 3 and Table 4). Indices for TFP, output, and inputs are presented, and all indices are normalized to 100 in 2015. Also shown is the growth of TFP, which showed a stagnant level in the period 2010–15, averaging 0.5%, with only small changes in both output and input indices. This was followed by a much more erratic TFP trend in 2016–20, with declines in 2016, 2018, and 2020, offset by a relatively sharp increase in 2017. The average was still low, at 0.2%. Note that cost shares are set to identical figures over the interval, with labor having the largest share, followed by land and capital.

TABLE 3

INDICATORS RELATED TO TFP, 2009–15.

	2009	2010	2011	2012	2013	2014	2015
TFP estimates							
TFP index	96.8	97.3	98.3	100.1	99.4	99.4	100.0
TFP growth (%)		0.5	1.1	1.7	–0.6	0.0	0.6
Input index	95.3	94.1	96.8	98.3	99.2	100.6	100.0
Output index	92.3	91.5	95.2	98.3	98.6	100.1	100.0

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	2009	2010	2011	2012	2013	2014	2015
Cost shares							
Labor	0.392	0.392	0.392	0.392	0.392	0.392	0.392
Land	0.329	0.329	0.329	0.329	0.329	0.329	0.329
Capital	0.135	0.135	0.135	0.135	0.135	0.135	0.135
Materials	0.144	0.144	0.144	0.144	0.144	0.144	0.144
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Source: USDA [20].

TABLE 4

INDICATORS RELATED TO TFP, 2016–20.

	2016	2017	2018	2019	2020
TFP estimates					
TFP index	98.7	103.2	103.1	103.4	101.0
TFP growth (%)	−1.3	4.6	−0.1	0.3	−2.3
Input index	99.4	98.3	98.0	97.9	99.5
Output index	98.1	101.5	101.0	101.2	100.5
Cost shares					
Labor	0.392	0.392	0.392	0.392	0.392
Land	0.329	0.329	0.329	0.329	0.329
Capital	0.135	0.135	0.135	0.135	0.135
Materials	0.144	0.144	0.144	0.144	0.144
Total	1.000	1.000	1.000	1.000	1.000

Source: USDA [20].

Environment Indicators

The review reveals three items that offer the maximum potential for quantifying an EAMFP measure for the Philippines. These are: GHG emissions; nutrient removal from soil; and degradation of coral reefs. Data on GHG emissions from 2009 to 2020 are shown in Table 5. Data on physical emissions in CO_2 equivalent is from FAO, while the carbon price is from the World Bank [23].

Meanwhile, nutrient loss is obtained from NUE (an excess above 100% implies nutrient loss from soil, while a shortfall below 100% implies nutrient buildup in soil, with leaching being ignored). The net nutrient loss is converted to a cost share using the global price of the relevant fertilizer type using data from the World Bank. Note that a net nutrient buildup is set to a zero cost share. Finally, coral reef loss is quantified using estimates from Licuanan and Reyes [12] based on the rate of one-third of the total per decade. This loss is valued using Tamayo, *et al* [17].

Note that the largest externality cost share originates from GHG emissions, which peaked at about 12% during 2009–10. This cost share declined sharply to 7% in 2011 and continued to shrink thereafter, reaching 4.9% in 2020. The next cost share is that of coral reefs, which started out at around 1% in 2010 and declined to 0.5% as coral reef loss in ha decelerated over time.

TABLE 5

GHG EMISSION INDICATORS, 2009–20.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
GHG emission cost share	12.1	11.9	6.9	6.4	5.9	5.8	5.1	6.0	6.0	6.6	5.5	4.9
Carbon price per ton	28	31	36	34	32	32	26	30	30	33	27	27
Value of GHG emissions, in PHP million	147,495	153,237	98,203	93,309	88,867	94,786	78,016	92,048	101,683	117,129	94,137	89,116
Agricultural GHG emissions, in kiloton	111,675	110,309	63,864	64,685	65,487	65,752	64,728	64,684	68,066	67,100	66,128	67,057

Sources: The World Bank 2021; [9].

TABLE 6

SOIL NUTRIENT LOSS INDICATORS, 2009–20.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Nutrient loss cost share (%)	0.0087	0.0011	0.0077	0.0091	0.0034	0.0009	0.0024	0.0000	0.0000	0.0000	0.0000	0.0000
Cost of nutrient loss, in PHP million	107	15	111	132	51	14	36	−3	−31	−23	−48	−67
Nitrogen	6	−39	6	25	−32	−43	−19	−47	−72	−56	−74	−91
Phosphorus	47	26	69	60	44	35	33	29	26	20	13	10
Potassium	54	27	36	47	39	22	23	15	15	13	13	13

Source: The World Bank.

TABLE 7

CORAL REEF LOSS INDICATORS, 2009–20.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Coral reef loss, cost share (%)	1.09	2.08	0.89	0.85	0.79	0.71	0.71	0.72	0.63	0.59	0.58	0.52
Value of loss, in PHP million	13,351	26,834	12,776	12,344	11,938	11,557	10,958	11,077	10,576	10,459	10,004	9,574
Change in cover	−2,518	−4,880	−2,216	−2,079	−1,950	−1,829	−1,716	−1,716	−1,603	−1,497	−1,398	−1,306
Coral reef cover, sq km	38,152	35,790	33,574	31,495	29,545	27,716	26,000	24,284	22,681	21,184	19,786	18,480

Sources: Tamayo, *et al* [17].

Findings

The input index is recomputed using the externality-augmented cost share using the Törnqvist index formula. There being no change on the output side in our methodology, we apply the same output index as in the USDA [20]. The EAMFP using the externality-augmented input index is shown in Table 8 and Table 9, which also show the growth of EAMFP. Note that EAMFP growth is greater than the growth in conventional TFP for the period 2011–15 and the years 2019 and 2020, with the average difference being 0.6 percentage points higher. The reason is that while the conventional input index starts out 4% higher, the difference narrows to just 1–2% by 2019–20. This is because growth in the input index is much slower, in turn due to the sharp decline in 'adjustment for pollution abatement' due to reduced GHG emissions from cropland and from land use on account of an expanding forest cover.

TABLE 8

TFP-RELATED INDICES WITH ENVIRONMENT ADJUSTMENT, 2010–15.

	2010	2011	2012	2013	2014	2015
Adjusted input	97.4	99.1	100.7	100.4	101.0	99.2
Ratio to USDA input	1.04	1.02	1.02	1.01	1.00	0.99
EAMFP	93.9	96.0	97.7	98.2	99.1	100.8
EAMFP growth		2.2	1.7	0.6	0.9	1.7
Difference from TFP growth (%)		1.2	0.0	1.2	0.9	1.1
Ratio to USDA TFP	0.97	0.98	0.98	0.99	1.00	1.01

Source: Author's calculations.

TABLE 9

TFP-RELATED INDICES WITH ENVIRONMENT ADJUSTMENT, 2016–20.

	2016	2017	2018	2019	2020
Adjusted input	100.2	99.8	100.5	99.4	100.8
Ratio to USDA input	1.01	1.02	1.03	1.02	1.01
EATFP	97.9	101.7	100.5	101.8	99.8
EATFP growth	−2.9	3.9	−1.1	1.3	−2.0
Difference from TFP growth (%)	−1.6	−0.8	−1.0	1.0	0.3
Ratio to USDA TFP	0.99	0.98	0.98	0.98	0.99

Source: Author's calculations.

Conclusion

Summary

Our review of agriculture and the environment has revealed a number of negative trends that would seem to imply that accounting for environmental values in agricultural TFP measurement in the form of EAMFP would imply an even slower, perhaps negative growth. On the contrary, accounting for environmental values leads to an EAMFP growth that slightly exceeds the growth in conventional TFP. This is due to a significant gain in 'adjustment for pollution abatement,' namely the reduction in GHG emission from 2011 onward.

Policy Implications

The foregoing analysis shows the importance of reflecting environmental values in productivity measurement, to provide a more comprehensive measure of sustainable modernization. In doing so, it helps strengthen the case for actions that tend to increase the EAMFP. More specifically, the analysis recommends the following:

- Reinforce gains in EAMFP from reduced GHG emissions, by accelerating rehabilitation of denuded forestland as well as reducing other GHG sources in agriculture.
- In particular, the second largest source of emissions is rice cultivation. To reduce this, avoid prolonged flooding of rice plants through water saving techniques such as alternate wet-and-dry irrigation.
- Avoid other sources of environmental loss with priority placed on preventing degradation of coral reefs.
- Expand the scope of measurement to cover other potentially important environmental values missed in this analysis. This includes water quality of inland water bodies affected by agricultural pollution.
- Another area for future measurement is loss of soil quality. While the value of nutrient loss seems small, critical indicators of soil quality were omitted in this analysis, e.g., health of the soil microbiome and carbon sequestration in soil organic matter.

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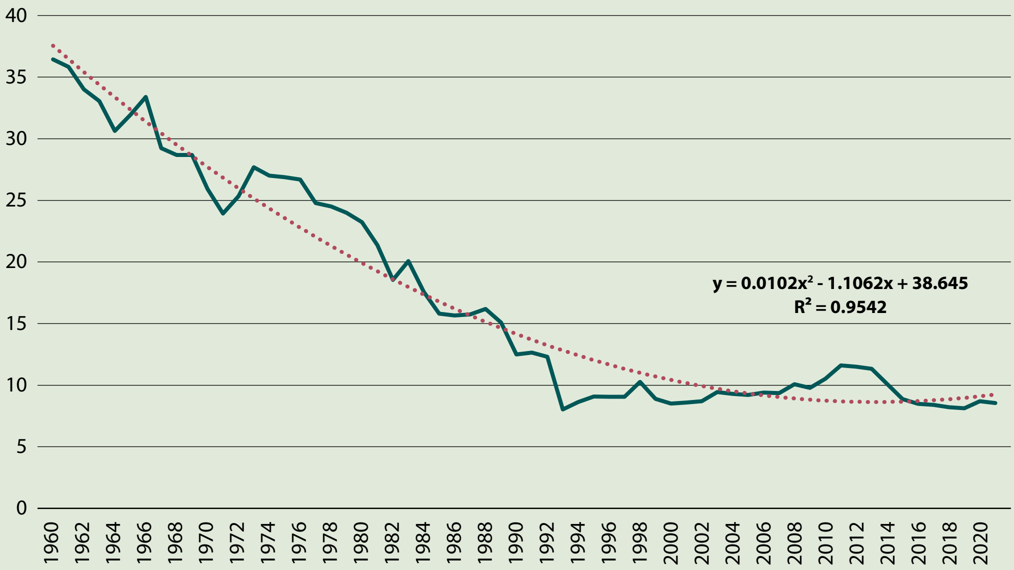
THAILAND

Introduction

Thailand is one of world's prominent agricultural suppliers. It has a sharp food processing sector, and is the 13th largest food exporter in the world [36]. It has one of the finest food processing industries in southeast Asia, which empowers it to export value-added products. Thailand's food-and-beverages industry is its third-largest industry, accounting for 21% of the country's gross domestic product (GDP). The country is the main food exporter of rice, canned tuna, sugar, chicken meat, cassava products, shrimp, and canned pineapple. The value of Thai food exports was USD32.7 billion in 2020. [8]. An important fraction of the population in Thailand works in the agriculture sector, which is a vital component of the country's economy. The percentage of Thailand's GDP that comes from the agricultural sector, however, has indicated a declining tendency, and in 2021, the percentage of GDP that comes from agriculture got reduced to 8.5%. In addition, the agricultural sector is essential for assuring the population's access to food and for exporting agricultural goods, which brings in foreign exchange. Moreover, the nation's cultural history and identity are strongly influenced by the agriculture industry.

FIGURE 1

PERCENT OF GDP FROM AGRICULTURE IN THAILAND.



Source: [43].

In Thailand, the agricultural sector occupies a significant portion of the country's total area of 320.70 million rais, with 149.24 million rais dedicated to agricultural land use. On an average, each household holds 22.48 rais of agricultural land. The main agricultural products grown in Thailand include rice, cassava, and sugarcane. Rice fields take up the largest portion of agricultural land at 46.88%, followed by field crops at 20.88%, horticulture at 23.40%, vegetable gardens and flowering/ornamental plants at 0.09%, and other crops at 7.90%. Currently, the irrigation department has successfully developed 31.83 million rais of land for irrigation, which accounts for 52.79% of the total potential area for irrigation. This includes 6.69 million rais of land under medium-sized irrigation projects and 7.18 million rais of land under small irrigation projects, both of which are overseen by the Irrigation Department [13].

Thai Agricultural Sector Facts

The agriculture sector in Thailand employs around 30% of the total labor force, impacting 6.4 million households [39]. Despite this, the sector has a relatively low value added per worker and a slow growth rate compared with other economic sectors. In addition, the sector's contribution to the national income has decreased over the past three decades, and starting from 2015, has accounted for less than 10% of the GDP. In addition to the low value added per worker and slow growth rate, the agricultural sector in Thailand is also facing various problems such as poverty, debt, aging, land ownership, access to water resources, small farm sizes, and limited farming portfolios. Specifically, around 40% of farming households earn an annual income below the poverty line, 30% have debt levels above their average annual farming income per person, and 10% have more than three times higher debt. The aging of Thai farmers is also an issue, with 23.4% of them being over 60 years of age in 2020 [17]. As the number of farmers has steadily dropped due to migration of young farmers from agriculture, there is a particularly noticeable rise in the senior population in Thailand and Japan [26]. Access to land ownership and water resources is also a problem, with 40% of farm households not having land ownership and only 42% having access to water resources. Furthermore, many farming households own small plots of land with an average of 14.3 rais per household, while 50% of total farming households have productivity levels below the mean. In addition, two-thirds of households still grow one crop a year, mainly the key economic crops.

Given the various problems facing the agricultural sector in Thailand, it is essential for policy reforms to be implemented to improve the sustainability and productivity of the industry. The government should encourage young people to join the sector and introduce innovative tools and farm management techniques to enhance productivity and add value to farm products. Furthermore, increased investment in research and development (R&D) is essential for driving innovation and sustainable productivity growth. To accomplish this, the government should work toward removing any barriers to private-sector innovations and investments in R&D, facilitate the dissemination of private knowledge, and promote public–private partnerships for R&D. By addressing these issues, it is possible to achieve positive outcomes and reinforce the motivation of Thai farmers to improve the agricultural sector [39].

Literature Review

Agricultural Modernization in Thailand

Inputs of rice production are classified into tradable inputs, such as imported fertilizers and pesticides; and non-tradable inputs, such as land, labor, and local capital. The inputs that are important to Thai farming are capital, labor, chemical fertilizers, pesticides, and technology/equipment (e.g., harvest tractors). Thai farmers have incurred higher costs due to use of pesticides and chemical fertilizers rather than organic fertilizers. Also, farmers' sources of funds are Bank for Agriculture, agricultural cooperatives, merchants, and relatives [12].

To ensure long-term rice production and food security in major Asian rice-producing countries, it is important to focus on key factors such as cultivated area, fertilizer consumption, and the rural labor force. These factors have a significant impact on rice production and addressing them will help increase overall production levels [3]. To enhance production, it is essential to implement flexible financial and agricultural policies that can help farmers increase their productivity [4]. Research on labor productivity in rice production has shown that labor wages are low, and labor use is inefficient. In addition, return on rice production has been found to decrease as the scale increases [5]. Moreover, research on rice farmers in Thailand has shown that they tend to use more fertilizers and pesticides as they are risk averse. This leads to an overuse of these inputs and reduces yield. To mitigate these impacts and reduce the inefficient use of these inputs, it is crucial to provide crop insurance and train farmers on using inputs properly. This will help farmers to be more aware of the risks and manage them, and also improve the efficiency of inputs [22].

In Thailand, the trend of farm modernization has been moving away from heavy machinery toward automation technology. This includes the use of technology for planting, irrigation systems, machine-operated dispensers, modern harvesting technology, dryers using biomass fuel, storage facilities, and fully automated rice mills [11]. Researchers have compared the smart-agriculture literacy levels of farmers in the provinces of Khon Kaen and Chiang Mai. They assessed the smart farmer's abilities in five different categories, including technology use, digital literacy, farming standards and practices, marketing expertise, and smart farming techniques. As a result of their farming backgrounds, education, age, and experiences, farmers in both the provinces had varying degrees of smart-agriculture literacy, according to the study's findings [35].

The geographical and temporal management of rice production can be improved through laser-controlled land leveling (LLL). It enables farmers to boost production while using fewer inputs, such as water and land. It was used in Thailand to level the terrain to produce rice sustainably [20] and would be the first step toward improving the yield for farmers. However, this technology has a high cost and if farmers do not own the farmland, there is no incentive for them to invest in land leveling.

The adoption of renewable energy can reduce environmental damage, increase revenues and productivity in agriculture, and decrease greenhouse gas emissions. The use of renewable energy in agriculture can also decrease dependency on fossil fuels, which is beneficial for farmers. Trade policy can encourage the flow of money and technology to specialize in economies of scale and manufacturing. ASEAN countries should consider policies that would improve living standards while protecting the environment, which includes measures that will promote agricultural sector production and create active marketplaces for international trade. The ASEAN nations' agricultural sectors should focus on sustainable agriculture production and sensible climate improvement. It is recommended to assist ASEAN countries in establishing policies that can increase agricultural output and build a well-organized marketplace for global trade. This can lead to technology-driven specialization movements and investment opportunities for economies of scale and manufacturing [44].

To conclude the cause and effect in the local agriculture system, the causal loop diagram was proposed. Agriculture productivity was influenced by a variety of elements, including the regulation of the climate, farmland biodiversity, ecological quality, institutional reform/implementation of sustainable policies, and agriculture technology [31].

Cassava production in Thailand is predicted to fall by 14.74–21.26% from the baseline due to the effects of climate change [24]. The components of climate-smart agriculture and mitigation strategies have been put forth as a means of preparing for the climate change [6], e.g., switching varieties or changing cropping calendars, nutrient management, or organic fertilizer application for crop management.

Applications of Digital Technology in Agriculture

Data collection technology in the agriculture sector includes the use of sensors for measuring soil health and other field-specific values, as well as the use of drone cameras for medium-range data collection and satellite images for long-range data collection [17]. This technology can be used to identify planting conditions, crop types, growth stages, and issues at the individual farm level. The applications of digital technology in agriculture are as follows:

(1) Use of big data in agriculture can provide detailed information on topography, weather conditions, and farming practices at the field level, both in the present and in the past, for all regions in the country. This can help in understanding the various issues and needs of farmers.

(2) IoT technology in agriculture can connect agricultural tools and machinery via the internet or mobile networks, thus helping to automate and optimize agricultural activities on the farm, such as watering and fertilizer application, with precise timing and quantity and without human intervention; and can monitor conditions and quickly find solutions to problems in the field.

(3) Mobile technology can connect farmers to the market, input providers, consumers, government officers, and other farmers. This can help farmers to access information and knowledge easily, quickly, and at a lower cost, on aspects such as crop prices, weather forecasts, and solutions for plant diseases.

(4) Data analysis using machine learning and artificial intelligence (AI) combined with big data in various aspects can help find precise, proper, and effective agricultural approaches for each farming area and each farmer, known as precision farming.

(5) Platforms can connect data from service providers to users or farmers and match the users, such as farmers and consumers, input providers, government agricultural experts, or farmers. This can promote sharing economy in different forms through the internet and mobile technologies.

Limitations of Precision Agriculture in Thailand

There are several limitations to precision agriculture in Thailand. Some of the main limitations include:

(1) High costs: The cost of implementing precision agriculture practices can be high, particularly for small-scale farmers who may not have the resources to invest in new technology and equipment. For example, to collect data, the sensors should be installed in key agricultural production areas.

(2) Access to technology and infrastructure: Some farmers in Thailand may not have access to the necessary technology and infrastructure, especially transportation to implement precision agriculture practices. This can include a lack of access to the internet; research to obtain quality information; mobile networks; and necessary equipment such as sensors, drones, and satellite imagery. In addition, there is a lack of sufficient soil analysis labs and quality and modern irrigation systems, which are very significant factors for agriculture. Knowledge of the most recent big data applications in smart agriculture, along with the associated social and economic concerns, as well as techniques for creating data, accessibility of technology, accessibility of equipment, and accessibility of software tools and data analytic methodologies were reviewed [2].

(3) **Lack of technical expertise:** For being effectively implemented, precision agriculture practices require a skilled workforce with expertise in data analysis, machine learning, and AI. This includes researchers, data analysts, and technical experts who can effectively use and analyze the data collected through precision agriculture technologies.

(4) **Readiness of stakeholders in agriculture:** The use of technology in agriculture also requires the adaptation of farmers and staff to new practices and ways of working. This can be a significant obstacle for some farmers and their staff, particularly older farmers, who may not be comfortable with new technologies.

(5) **Government policy:** The government can play an important role in creating an enabling environment for precision agriculture by providing access to funding and resources, improving infrastructure, and developing policies and regulations that promote the use of precision-agriculture technologies. In addition, the government should work with research institutes and universities to provide technical assistance and expert support to farmers by sending staff and experts to assist in the implementation of precision agriculture practices. This collaboration will help bridge the gap between research and practice and ensure that farmers have access to the latest technologies and knowledge.

(6) **Data privacy and security:** This issue prevents farmers and agricultural organizations from sharing critical information about their farm operations. The important idea in an intelligent agricultural system is intellectual property (IP). A smart agricultural system's IP leakage harms all related intellectual concepts, including rights to plant varieties and cultivation techniques. IP theft entails striping a person or business of ideas, inventions, or creative expressions that contain trade secrets or soft goods, also referred to as "cultural property." Commercialization and labeling of agricultural products are crucial for new crop production and farm equipment design. IP has a lasting impact and is very important in various agriculture sectors [10].

(7) **Weather and climate change:** It is challenging to apply precision agriculture technology under the climate change situation in Thailand. The study of climate change's effect on harvested area and yield of cassava production in Thailand is a point in case [24].

(8) **Data management:** Big data handling and management can be complicated and challenging, thereby needing expert knowledge and software [19].

(9) **Dependency on external factors:** Precision farming is very dependent on external variables including temperature, humidity, soil properties [18, 34], market prices, and governmental regulations. Efficient planning and execution of precision agricultural operations may be difficult.

Result

Important Aspects of Agriculture and Relevant Productivity Indicators at A Macro Level

Consider the indicators from the Agricultural and Cooperative Action Plan 2023–27, which is a plan to drive the development of the country's agricultural sector in an integrated manner between the Ministry of Agriculture and Cooperatives and external agencies; and the Government Action Plan of the Ministry of Agriculture and Cooperatives for the five-year period of 2023–27, which is the action plan for the agencies under the Ministry of Agriculture and Cooperatives, as shown in Table 1.

TABLE 1

THE VISION OF THAI AGRICULTURE.

Agricultural and Cooperative Action Plan 2023–27	Ministry of Agriculture and Cooperatives' five-year Action Plan (2023–27)
The vision is to drive Thai agriculture toward high-value agriculture, so that farmers have high incomes. There are four development issues: Development issue 1: Empower farmers and farmers' institutions to become modern agribusiness entrepreneurs. Development issue 2: Promote and develop the production of high-value agricultural products and services. Development issue 3: Increase efficiency in agricultural resource management. Development issue 4: Develop agricultural infrastructure and facilities.	The vision is that farmers have a good quality of life, and increase their incomes by at least 10% per annum. There are five development issues: Development issue 1: Strengthen agricultural security. Development issue 2: Enhance the competitiveness of the agricultural sector. Development issue 3: Create equality and distribute social equality. Development issue 4: Achieve balanced and sustainable management of agricultural resources and the environment. Development issue 5: Develop public-sector management systems and agricultural research.

TABLE 2

AGRICULTURAL INDICATORS AS PER THE MINISTRY OF AGRICULTURE AND COOPERATIVES.

Agricultural and Cooperative Action Plan 2023–27	Ministry of Agriculture and Cooperatives' five-year Action Plan (2023–27)
Plan-level indicators include • the growth rate of GDP in agriculture and agricultural products; • Farmers' Well-being Index; • net cash income, agricultural households; and • agricultural households benefitting from water management. Development issue 1: Empower farmers and farmers' institutions to become modern agribusiness entrepreneurs. The indicators are: • number of agricultural cooperatives, class 1, according to the criteria for cooperative strength rating; • number of community enterprises are at a good level according to the criteria for grading the strength of community enterprises; • number of farmer groups, class 1, according to the criteria for grading the strength of farmer groups;	Plan-level indicators include • the growth rate of GDP in agriculture; • productivity rate of the agricultural sector; • net cash income, agricultural households; • farmers' institutions (cooperatives, community enterprises, and farmer groups) registered with the Ministry of Agriculture and Cooperatives strengthened at the standard level wherein, cooperatives are strengthened at levels 1 and 2, community enterprises are assessed for their potential at a good level, and farmers' groups are strengthened at levels 1 and 2; and • agricultural households benefitting from water management; Development issue 1: Strengthen agricultural security. The indicators are • Thai export fishing products are not bounced back from the EU due to IUU reasons; • the use of labor in commercial fishing vessels is legal; and

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Agricultural and Cooperative Action Plan 2023–27	Ministry of Agriculture and Cooperatives' five-year Action Plan (2023–27)
• number of agribusiness entrepreneurs; and • number of farmers' institutions providing agricultural services. Development issue 2: Promote and develop the production of high-value agricultural products and services. The indicators are: • value of indigenous agricultural products, safe agriculture, bio-agriculture, and processed agriculture; • income from agricultural tourism; and • yield value of farms/plots that adopt modern technologies including crops, livestock, and fisheries. Development issue 3: Increase efficiency in agricultural resource management. The indicators are: • farmers entitled to land benefits; • decrease in unsuitable cropland; • increase in irrigated area; • Increase in water flow into reservoirs throughout the country; and • efficient irrigation system. Development issue 4: Development of agricultural infrastructure and facilities. The indicators are: • turnover of agricultural products and products sold on online platforms; • big data on agriculture with links throughout the supply chain in key agricultural products; • proportion of research, technology, and innovation in agriculture to be utilized/commercialized; and • logistics costs of agricultural products that are critical to sales.	• farmers participating in the occupational development program in the southern border provinces earn more. Development issue 2: Enhancing the competitiveness of the agricultural sector. The indicators are increase in • value of major tropical fruit yields, Jasmine rice, Thai silk, livestock, fisheries, and others; • value of safe agricultural products that have been certified by good agricultural practices and organic agriculture; • value of raw materials used to produce renewable energy (cassava, palm oil) as well as the value of herbs and spices, economic insects, and bio-based agricultural products; • gross product value of the agro-processing industry, namely food, beverages, wood and wood products, leather goods, and tires and other products; • value of the output of farms/plots that adopt modern technologies including crops, livestock, and fisheries; • productivity per unit of farms/plots that adopt modern technologies including crops, livestock, and fisheries; • yield value of important agricultural products (rice, maize, cassava, oil palm, rubber, pineapple, dairy cattle, beef cattle, broilers, laying hens, pigs, white shrimp, vannamei, and tilapia); • the rate of expansion of business volumes of cooperatives and farmer groups; • income from agricultural tourism; • the proportion of logistics costs of agricultural products that are important to sales; • community enterprises and farmers that have been developed into income entrepreneurs; and

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Agricultural and Cooperative Action Plan 2023–27	Ministry of Agriculture and Cooperatives' five-year Action Plan (2023–27)
	• the growth rate of gross agricultural production of the Eastern Special Development Zone area at the annual price. Development issues 3: Create equality and distribute social equality. The indicators are increase in the number of • targeted farmers who implement the King Rama IX idea with effective results; • elderly farmers trained in occupation and implementation; • farmers entitled to take advantage of the land; and • farmers having developed and promoted careers. Development issue 4: Balanced and sustainable management of agricultural resources and the environment. The indicators are • increased catchment volume; • managed irrigated areas; • increased irrigated area; and • rainfall from royal rain operations. Development issue 5: Development of public sector management systems and agricultural research. The indicators are • agricultural information used to drive; • percentage of agencies with criteria for assessing the status of government agencies in bureaucracy 4.0 at a progressive level; • departments of the Ministry of Agriculture and Cooperatives that meet the ITA assessment criteria (85 points or more); • percentage of the number of laws reviewed by the law development plan of Ministry of Agriculture and Cooperatives; and • the proportion of agricultural technology and innovation research that has been utilized compared with completed research.

Current KPI of Significant Produce

The current KPIs of significant agricultural products by institutions are listed in Table 3. The agriculture KPIs from the Office of the National Economics and Social Development Council are given in Table 4. Next, the related KPIs from the Office of the National Economics and Social Development Council are shown in Table 5.

TABLE 3

AGRICULTURAL INDICATORS BY VARIOUS INSTITUTIONS.

Institution	KPIs
OAE	Major KPIs for significant products such as rice, rubber, cassava, livestock, and shrimp are: • the number of households that grow crops or raise livestock; • the planting/farm area and the yield area/the number of livestock raised; • production quantity (ton); • production quantity per rai (for rice at 15% moisture); • production cost (Baht/ton); • farmer selling price (Baht/ton); • net profit (Baht/ton); • logistics cost per sales of significant produce; • number of cooperatives that collect the produce; • the ability to provide agricultural logistics services on time; • value added of organic products per year; • number of farmers certified in PGS and organic Thailand; and • organic farm area;
Provincial KPI	These KPIs include • agricultural system structure; • enabling institutional framework; • resilience and sustainability; and • productivity.
Office of the National Economics and Social Development Council (NESDC)	The KPIs are: • the growth rate of GDP in agriculture (average percentage); • productivity rate of the agricultural sector (average percentage); • The expansion rate of the value of indigenous agricultural products (average percentage); • the expansion rate of the value of safe agricultural products (average percentage); • Consumer Confidence Index on Quality Food and Nutrition Safety;

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Institution	KPIs
Office of the National Economics and Social Development Council (NESDC)	• the expansion rate of the value of agricultural products exported to countries that meet the criteria of food safety standards (average percentage); • the expansion rate of the value of biological agricultural products (average percentage); • the number of small and medium-sized agricultural enterprises and bio-based products; • the expansion rate of the value of processed agricultural products and products (average percentage); • value of products using modern/intelligent technology (average percentage); • productivity of farms using modern technology/smart farming (average percentage); • production efficiency of agricultural products per unit (average percentage); and • farmers' institutions (cooperatives, community enterprises, and farmers' groups) registered with the Ministry of Agriculture and Cooperatives that are strengthened at standard level (average percentage).

TABLE 4

AGRICULTURE KPI FROM THE OFFICE OF THE NESDC, 2021.

Aspect	KPI
GDP	The growth rate of GDP in agriculture (average percentage)
Agriculture productivity	Productivity rate of the agricultural sector (average percentage)
Value added of indigenous agricultural products	The expansion rate of the value of indigenous agricultural products (average percentage)
Food safety of agricultural products	The expansion rate of the value of safe agricultural products (average percentage)
	Consumer Confidence Index on Quality Food and Nutrition Safety
	The expansion rate of the value of agricultural products exported to countries that meet the criteria of food safety standards (average percentage).
Biological agricultural products	The expansion rate of the value of biological agricultural products (average percentage)
	The number of small and medium-sized agricultural enterprises and bio-based products
Value added of processed agricultural products	The expansion rate of the value of processed agricultural products and products (average percentage)

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Aspect	KPI
Agriculture modernization	Value of products using modern/intelligent technology (average percentage)
	Productivity of farms using modern technology/smart farming (average percentage)
	Production efficiency of agricultural products per unit (average percentage)
	Farmers' institutions (cooperatives, community enterprises), and groups registered with the Ministry of Agriculture and Cooperatives are strengthened at standard level (average percentage)

TABLE 5

RELATED KPI FROM THE OFFICE OF THE NESDC, 2021.

Aspect	KPI
Logistics and infrastructure	Infrastructure competitiveness rankings
Society	Human Development Index
	Social capital indicators
	Income disparity between the last 20% per group and the top 20% (times) of income
	Debt service ratio
	The proportion of the population in remote areas, highlands, or hill tribes that have access to state services in all dimensions
	Multidimensional Poverty Index of target groups in need
Environment	Environmental Performance Index
	The proportion of all types of green areas, including natural forests, economic forest areas for utilization, urban and rural green spaces, as well as urban forests and recreational learning communities (percent of the country's total area)
	Overall greenhouse gas emissions in the field of energy and transportation; decrease in industrial processes and product use and waste management fields (in million tons of carbon dioxide).
	Water quality of surface water, groundwater, and seawater sources being suitable for the type of utilization (percentage of the total target area).
	Water Security Index
	Water Disaster Response Index (level)
Research and development	Global Innovation Index (GII)
	Social Innovation Index
	Green R&D per GDP

The determination of indicators of the Agricultural and Cooperative Action Plan 2023–27 and the Government Action Plan of the Ministry of Agriculture and Cooperatives for five years (2023–27) is consistent and linked with the national strategy. The Master Plan under the National Strategy

Government policy and policy of the Ministry of Agriculture and Cooperatives convey the goals and indicators of the agency's practices to drive Thailand's agricultural development in the same direction. The plan's indicators will be updated after the NESDC reviews the master plan under the National Strategy every five years or in circumstances of significant changes.

Since 2014, the Geo-Informatics and Space Technology Development Agency (GISTDA) has been using satellite imagery to estimate land use for cash crops such as rice, sugarcane, corn, cassava, palm, and rubber. The images are analyzed every two weeks for rice, sugarcane, corn, and cassava fields, and once a year for rubber and palm. The information is then passed on to the Office of Agricultural Economics (OAE). The images are interpreted using computer systems, and then experts adjust the information based on their experience to increase the data's accuracy. Each crop requires 1–2 experts. The data is then validated through random surveys in conjunction with the Irrigation Department and the Department of Agricultural Promotion. Currently, the land use accuracy is 80–90%. The yield per rai is determined using the constant provincial yield from the OAE. At present, it is not possible to convert the area for growing fruits and vegetables, but it is used to convert shrimp cultivation areas. GISTDA also uses a variety of sensors to manage agriculture, such as satellite technology to extract physical and biological factors from photographs, helping to meet the needs of smart farming. It also uses drones to capture photographs of certain areas. GISTDA is exploring the use of infrared cameras to capture fields and determine the health and growth of plants and use of various wave ranges to extract information for agriculture, such as forecast on plant health and nitrogen fertilizer needs. However, most of these projects are currently focused on rice. They use a constant value of yield but plan to implement crop modeling in the future yield forecast. At present, there are limited number of experts in crop modeling, with most experts being in geography and environment.

Identifying Important Aspects of Agriculture and Relevant Productivity Indicators at a Micro Level

(1) **Yield per rai:** This measures the amount of crop produced per unit of land; and is a key indicator of a farm's efficiency and productivity. Farmers can compare this indicator with the average value provided by the OAE on its website.

(2) **Production cost:** This measures the cost of inputs such as seeds, fertilizers, and labor, and is an important indicator of a farm's profitability. However, many farmers underestimate this cost by not accounting for their labor, the value of their land, homemade fertilizer, and other expenses.

(3) **Net profit:** This measures the farm's income after subtracting the cost of production (baht per ton); and is a key indicator of a farm's financial performance.

However, some missing productivity indicators are not typically provided by agricultural organizations, such as labor and materials productivity, risk coping efficiency, and the sustainability of the business model.

Limitations of Using Agricultural Indicators in Thailand

The limitations of using agricultural indicators in Thailand include

(1) decentralized agricultural data collection, which leads to a long and complex process of gathering information from different sectors;

(2) incomplete data in agriculture, particularly concerning agricultural modernization, which leads to less accurate data;

(3) fragmented databases, which require significant effort to map data from different sources and raise questions about data accuracy;

(4) microdata, which is often collected through sampling, rather than representing the entire population, thereby leading to concerns about data accuracy in terms of yield and cost per rai;

(5) measures and policy establishment are often based on GDP rather than productivity at the micro level;

(6) evaluation of measures and projects often focuses on output rather than outcome and productivity, thus making it difficult to determine if the measures are effectively addressing problems; and

(7) farmers and agricultural organizations either do not collect the necessary data or are unable to accurately calculate the costs.

Recommendations for Agricultural Indicators in Thailand

(1) Enhance efficiency in managing agricultural resources by conserving and maintaining resources that support value creation and food security, including water and soil resources; utilize agricultural databases for production planning and implement proactive management of agricultural land through agricultural plans; and improve the management of agricultural and community resources.

(2) Ensure food security for households, farmers, and communities by promoting local farming and reducing dependence on external sources of food; encourage self-sufficiency through the philosophy of a sufficiency economy; involve local government and authorities in the development of food security in various dimensions, including nutrition for all ages; stabilize farmers' income and provide access to food for low-income individuals through measures to support universal access to agricultural products; and monitor changes in food prices and their impacts.

(3) Develop information systems, surveillance, and warning systems for agricultural products; promote the creation of a standardized, comprehensive agricultural information database system, including farmers and supply-and-demand information; implement surveillance and alarm systems to manage issues related to agricultural products, including product price stability, regulations, international trade, natural disasters, climate change, and food security; establish support measures, warning measures, adaptation measures, food reserve systems, and insurance; ensure easy access to information for farmers and users and effective inter-agency data linkages; and analyze trends in agricultural product production.

(4) Promote farmers' integration to strengthen cooperation among community enterprises and cooperatives, and connect farmers with the private sector and relevant agencies for the production and marketing of agricultural products; support the expansion of networks, increase access to capital with more lenient conditions, and enhance farmers' development

into strong agricultural entrepreneurs; and implement mechanisms to ensure farmers benefit from the integration and value addition of agricultural products.

(5) Conduct research and development of technology and innovation to support the agricultural sector, including basic and applied research in various fields to develop value-added products; encourage technology and product innovations that are adaptable to changes in the agricultural sector and can be commercially applied; enhance farmers' access to knowledge and technology for production and marketing; and utilize digital technology and information through learning centers to increase efficiency in local agricultural production and elevate agribusiness entrepreneurship.

(6) Enhance the quality standards of agricultural products to align with market needs and establish a quality assurance system for agricultural products; and implement a fast and cost-effective inspection process, including a traceability system to build consumer trust.

(7) Promote the marketing of agricultural products using a variety of technologies and tools, such as traditional and online marketing, trade shows, and educational campaigns to promote the value and story of agricultural products and establish a recognizable Thai brand internationally; and utilize innovative technologies and creative packaging design while prioritizing the benefits of use and protecting intellectual property domestically and throughout the supply chain.

(8) Streamline trade and improve agricultural logistics by increasing efficiency, offering commercial services, and making it easier for entrepreneurs to conduct fast and cost-effective trade transactions; and develop agricultural logistics infrastructure to minimize losses during transportation, shorten delivery times, and establish collection centers and warehouses to maintain product quality and standards.

Recommendations for Improvement of Agricultural Productivity

The suggestions for agricultural productivity improvement are as follows:

(1) Productivity should be evaluated over a set time frame, to monitor progress, evaluate different types of crops, and improve productivity. Measuring productivity per period gives a better understanding of how resources are utilized and goals are achieved, and also allows for comparison of productivity over time, thereby identifying trends and making changes to improve productivity.

(2) In evaluating crop productivity, the payback period should be taken into account, i.e., the time it takes for a farmer to recoup the initial investment in a crop through its sales. This includes all the costs associated with growing and harvesting the crop, such as seeds, fertilizers, labor, and other expenses. In addition, it is important to consider the production time without yield, such as durian needing to grow for 3–5 years before it can be harvested, as it affects the profitability of the crop. By considering these factors, farmers can make more informed decisions on which crops to grow and how to manage their operations to maximize profits over time.

(3) Evaluating the potential financial losses that may occur as a result of factors such as weather, disease, or pests is crucial for farmers and community enterprises when it comes to

considering the expected risk cost for major crops. This type of analysis allows them to make more informed decisions on which crops to plant, how much to plant, and how to mitigate potential losses. By assessing the potential risks associated with different crops, farmers and community enterprises can make better decisions on how to allocate resources and make more profitable choices. This could include implementing risk management strategies such as crop insurance, diversifying crop portfolio, or investing in new technologies to mitigate risks. By considering the expected risk cost for major crops, community enterprises can better plan for potential challenges and make more profitable decisions.

(4) Involving sustainability or resource usage in agricultural planning refers to taking into account the environmental impact of different crops and farming methods. This includes evaluating the number of resources like water, fertilizer, and energy required to grow and maintain different crops. For example, growing crops like rice requires a large amount of water, making it a less sustainable option compared with other crops that require less water. By considering the resource usage of different crops, farmers and agricultural planners can make more informed decisions about which crops to grow and how to manage them in a way that is environmentally responsible and sustainable in the long term. This could help minimize the negative impact of farming on the environment and preserve resources for future generations, while also promoting efficient and profitable farming.

(5) Involving the financial status, health, safety, and food security aspects of farmers in agricultural planning refers to taking into account the wellbeing and livelihood of farmers when making decisions about agricultural practices and policies. This includes considering factors such as the farmers' income, debt, and access to credit for ensuring that they have the resources they need to invest in their farms and support themselves and their families. In addition, it also means ensuring that farmers have access to safe working conditions and adequate protective equipment to prevent injuries and illnesses. Furthermore, food security is also a crucial aspect to consider as it refers to the availability and accessibility of enough food to meet the needs of individuals and communities, which can help prevent hunger and malnutrition. Overall, involving these aspects in agricultural planning can help ensure that agricultural practices and policies are not only productive and sustainable but also support the wellbeing and livelihood of farmers, thereby resulting in a more equitable and resilient agricultural system.

(6) The price and quantity of agricultural products can be affected by a variety of factors such as the type of crop, the time of the year, the size of the harvest, the quality or grade of the product, the stakeholders involved in the sale, and the specific area where the product is grown. Understanding these factors can help farmers and agricultural planners make more informed decisions about when to plant, harvest, and sell their products, and how to price and market them to maximize profits and meet the needs of consumers. For example, a farmer may choose to plant a particular variety of crop that is in high demand during a specific time of year, or they may choose to sell a higher quality or grade of product to command a higher price. Similarly, understanding the needs and preferences of different stakeholders such as wholesalers, retailers, and consumers can help farmers tailor their products and strategies to meet their needs.

(7) It is also worth noting that government subsidies and fundings can also come with certain conditions, such as specific requirements that farmers must meet to qualify for a funding,

and that farmers should carefully read and understand the terms of a subsidy or funding before applying for or accepting them. Overall, considering subsidies or funding from the government can be a valuable resource for farmers and agricultural planners, to support sustainable agricultural practices and promote food security while also helping farmers to manage the financial risks of farming.

To further improve agricultural productivity in Thailand, the following factors should also be considered [37]:

(1) Enhance access to irrigation water to allow farmers to cultivate crops year round, increase crop yields, and diversify into high-value crops.

(2) Utilize improved inputs and modern technologies, such as climate-resilient seeds and fertilizers, modern machinery, and digital technology. This will increase efficiency and help to geographically concentrate crops for greater economic benefits.

(3) Provide improved agriculture extension and information services, including training and access to weather information.

(4) Diversify into higher-value crops to share the risk of crop failure.

(5) Increase access to markets through online marketing and e-commerce to improve the reach of farmers' products.

Restrictions to Improve Agriculture Productivity

The World Bank [37] has identified several restrictions that impede the improvement of agricultural productivity in Thailand. These are discussed below:

(1) Limited access to irrigation water prevents farmers from cultivating year round and diversifying into high-value crops. The total water demand in the country is 151,750 million cubic meter, with a manageable demand of 102,140 million cubic meter and an unmanageable demand of 49.61 billion cubic meter [13].

(2) Small farm size and weak tenure security make it difficult for farmers to access credit and invest in improvements such as land leveling.

(3) There is increasing risk from climate change, particularly flooding, drought, and natural disasters.

(4) Ineffective crop insurance takes 3–6 months to process and does not cover all losses. Insurance companies also lack information on specific risks and have difficulty assessing losses.

(5) Low levels of agricultural R&D make it difficult to develop new technologies that can help farmers adapt to climate change.

(6) Unconditional farm assistance programs offered by the government do not take into account the specific needs of farmers.

(7) Inefficient use of water resources leads to wastage and limits the productivity of farms.

(8) There is lack of access to markets due to poor road infrastructure and logistics systems.

Measures to Increase Agriculture Productivity

Measures to improve agriculture productivity include

(1) expanding access to irrigation and promoting the use of water-efficient methods to reduce water usage and increase crop yields;

(2) implementing risk mitigation strategies to address increasing weather volatility for farming households, such as early warning systems and effective crop insurance;

(3) increasing access to finance for farmers to invest in productivity improvements and reduce debt;

(4) strengthening agricultural research and development to increase competitiveness and promote public-private partnerships for technology implementation;

(5) implementing policy and institutional reforms, including securing land tenure, implementing optimal water pricing schemes, and assessing unconditional farm assistance programs; and

(6) providing skills development opportunities such as extension services, vocational training, and digital literacy to improve input management and climate adaptation, as well as leveraging existing farmer institutions to enhance social learning and modernize agriculture practices.

Measures to Support Access to Markets

Measures to support access to markets include:

(1) improving rural infrastructure to connect farmers with markets, including investing in roads and logistics to facilitate direct delivery from farms to consumers; and

(2) fostering the growth of e-commerce platforms to create new income opportunities for farmers.

Utilizing Data to Develop Productivity Indicators for SAM at a Micro Level in Thailand

The current practices or needs of agriculture organizations in assessing their own productivity/efficiency are data collection, farm accounting skills, and profitability assessment skills. The current practices or needs in data management are efficient data collection, accounting, planning, and risk management. Many farmers and community enterprises are not effectively managing their farming operations. They may face challenges related to data collection, planning, and accounting.

Without accurate data, a clear plan, and proper accounting methods, it can be difficult for these enterprises to understand the true costs of their operations. This lack of information can make it difficult for enterprises to make informed decisions and may negatively impact their financial performance. This can lead to poor performance, inefficiency, and a lack of profitability for the community enterprise [27].

Risk management is a process of identifying, assessing, and prioritizing risks and then taking appropriate measures to mitigate or manage them. Risk management is essential for ensuring the long-term sustainability and profitability of an organization. However, it appears that many farmers and community enterprises are not effectively utilizing risk management strategies, which may leave them vulnerable to a variety of potential threats. Without adequate risk management, they may be unprepared for unexpected events or changes in the market, which may lead to financial losses and other negative consequences. Furthermore, without risk management, community enterprises may have difficulty identifying and addressing potential issues before they become major problems, which can further exacerbate the negative impacts of the risks they face [40].

Utilizing Data to Develop Productivity Indicators for SAM at Macro Level in Thailand

The current practices for assessing national and regional agriculture productivity include:

(1) using conventional farm surveys conducted by officers from the OAE who collect data by sampling farms and use it to calculate country-wide statistics;

(2) implementing intervention policies, such as the government's 20-year Agricultural Development Plan (2017–36) [25];

(3) utilizing modern technologies such as remote sensing and big data, as reported by interviews with the GISTDA and the OAE;

(4) building analytical capacity to effectively analyze and interpret the data collected;

(5) conducting research on agriculture productivity and comparing the results to alternative methods; and

(6) implementing risk management strategies to mitigate potential losses in productivity.

The current practices or needs in data governance are discussed below:

(1) Intervention policy or projects or research directions to collect the high-accuracy national database refer to the government's efforts to collect accurate and up-to-date data on agriculture productivity in the country. This could involve implementing policies, launching projects, or directing research to specifically target data collection. The goal is to create a comprehensive and reliable national database that can be used to inform decision-making and track progress in the agricultural sector. This data collection may include information on crop yields, land use, weather patterns, and other relevant factors that impact agricultural productivity. The intervention policy or projects or research directions should aim at improving the quality, accuracy, and reliability of the data collected to help better understand the state of the national agriculture productivity.

(2) Funding of local universities and research institutions is done to gather and analyze local data on agricultural productivity in specific regions or areas. This data collection can include surveys, field observations, and other methods of gathering information. The goal of this approach is to create a comprehensive and accurate database of information on agricultural productivity at the local level. This data can then be used to inform decision-makers and track progress in the agricultural sector, allowing for more targeted and

effective interventions. In addition, this approach allows for more timely identification of trends and issues, thereby enabling more prompt and effective intervention. In summary, the use of local research and data collection allows for a more comprehensive and accurate understanding of the agricultural industry at both the national and local levels.

(3) Despite the availability of various mobile applications for data collection, their usage is currently limited. Factors contributing to this include a lack of awareness and understanding among farmers and other stakeholders, as well as a lack of training and support to effectively use these applications. In addition, internet connectivity and other technical challenges may also play a role. However, with the growing accessibility of mobile technology and the internet in rural areas, mobile applications have the potential to become valuable tools for data collection in the agricultural sector. They enable farmers and other stakeholders to easily and quickly submit data, which can then be analyzed and used for informed decision-making and improved agricultural productivity. Therefore, it is important to invest in efforts to increase awareness, training, and support for mobile applications. Also, using them enhances their adoption and effectively utilizes them for data collection.

(4) The GISDA organization has a team to monitor major crops and conduct an analysis of the current situation. It uses a variety of tools and methods to gather data on crop growth and production, such as field inspections, remote sensing, and data analysis. The goal of this monitoring and analysis is to gain a deeper understanding of the current state of major crops and identify any potential issues or opportunities for improvement. This information is shared with government decision-makers to outline strategies for improving agricultural productivity.

(5) Capacity building is necessary to ensure that researchers and local experts have the skills and knowledge to properly collect data, both manually and automatically. This includes training on techniques for data collection, as well as on tools and technologies that can be used to collect, analyze, and model data. The goal is to create a skilled workforce that can effectively collect and analyze data for informed decision-making and forecasting of crop production. This can help improve agricultural productivity and support sustainable development in the sector.

Application of Productivity Indicators to Promote SAM Policies at Micro Level

As for the current practices in applying productivity indicators for their sustainable business models, most farmers and agriculture organizations rarely collect the data and calculate the productivity indicators.

Farmers and community businesses should be encouraged to collect and calculate their agricultural performance indicators, and then use these indicators for planning, in conjunction with national-level indicators published by the Ministry of Agriculture and Cooperatives. The initial challenge is a lack of skills in data collection, accounting, calculation of performance indicators of themselves or their organizations, analyzing, and planning. The government may have a role in developing standard forms of data collection, providing training in data collection skills, and providing support for organizations in calculating and planning. There may be consultants or experts in agriculture and data analysts who use simulation of market situations, weather, and various risks to consider.

The government should extend the project to train agricultural organizations, for which the following steps may be taken:

(1) **Trainee selection:** Identify the specific organizations that would benefit from the training. These could include small-scale farmers, cooperatives, and large-scale agribusinesses. It is best to select a variety of crops.

(2) **Develop a training curriculum:** Determine the specific needs of the selected organizations such as crop management, crop modeling, soil health, and precision farming techniques.

(3) **Collaborate with universities:** Collaborate with universities or research institutions that have expertise in these areas to deliver the training. The training materials can take forms of handbooks, video clips, and online broadcasts on platforms such as government websites and YouTube. In addition, mobile applications may also be utilized as tools to assist organizations in improving their productivity through learning.

(4) **Encourage participation:** Promote training among the targeted organizations and encourage participation.

(5) **Ongoing support:** After completing the training, put in place a system for ongoing support and monitoring to ensure that the organizations can effectively implement the techniques they have learned and are noticing productivity improvements. This can be done through local trainers who can provide ongoing guidance.

Next, the government should establish success cases that use the productivity indicators to determine or plan their farming activity and then extend these cases as learning centers by

(1) identifying the agricultural operations that currently plan and monitor their farming activity using productivity indicators;

(2) compiling information on their output and the effect of the indicators;

(3) creating success stories and case studies that show the advantages of employing the indicators and the ensuing increases in productivity;

(4) disseminating these success tales to other agriculture groups and urging them to adopt the indicators' use as a best practice;

(5) designating the productive farms as learning institutions where other organizations can stop by and learn about the indicators and how they have been used on the farm; and

(6) giving the learning centers ongoing assistance and resources to enable them to develop and impart their expertise to others.

Application of Productivity Indicators to Promote SAM Policies at Macro level

The current practices and needs of the public sector include using modeling analyses to identify policies that can enhance productivity. Next, R&D policies improve the analytical capacity of the agricultural sector. Then, there is a need for research in the agricultural area to continue developing new and effective productivity-enhancing policies. Finally, there is a need for projects that aid agricultural institutions, such as training program providers that teach about productivity indicators and to calculate, analyze, and compare them in different scenarios. These activities and initiatives are important for improving the overall efficiency and effectiveness of the public sector.

We summarize the comparison of the agricultural indicators in Vietnam and Thailand in Table 6.

TABLE 6

AGRICULTURAL INDICATORS IN VIETNAM.

Component	Indicator	Subindicator	Thailand
(A1) Coherence	(B1) Coherent with the natural conditions (1 = absolutely not coherent; 5 = very coherent)	(C1) Coherent with soil conditions	LDD
		(C2) Coherent with climate conditions	GISTDA
		(C3) Coherent with local ecosystems	LDD
	(B2) Coherent with community capacity (1 = absolutely not coherent; 5 = very coherent)	(C4) Coherent with the skills and knowledge of farmers	NSO
		(C5) Coherent with local experiences and local backgrounds (not too new)	OPS
		(C6) Coherent with the financial and investment capacity of farmers	OAE
	(B3) Coherent with local customs and policies (1 = absolutely not coherent; 5 = very coherent)	(C7) Coherent with local policies	NA
		(C8) Coherent with community needs	NA
		(C9) Coherent with local customs	NA
(A2) Efficiency	(B4) Economic efficiency	(C10) Yield (1 = very low; 5 = very high)	OAE
		(C11) Cost of production (1 = very high; 5 = very low)	OAE
		(C12) Profits (1 = very low; 5 = very high)	OAE
		(C13) Risks (1 = very high; 5 = very low)	No risk data for each produce
		(C14) Stability of input prices (1 = absolutely not stable; 5 = very stable)	NA
		(C15) Stability of output market (1 = absolutely not stable; 5 = very stable)	NA
	(B5) Social efficiency	(C16) Improving the living standards of vulnerable groups (women, children, and poor people) (1 = not improved; 5 = very improved)	CDD
		(C17) Risks of increasing the gap between rich and poor people (1 = very high; 5 = very low)	NSO
		(C18) Job opportunities (1 = very low; 5 = very high)	NSO, the unemployment rate

(Continued on next page)

(Continued from previous page)

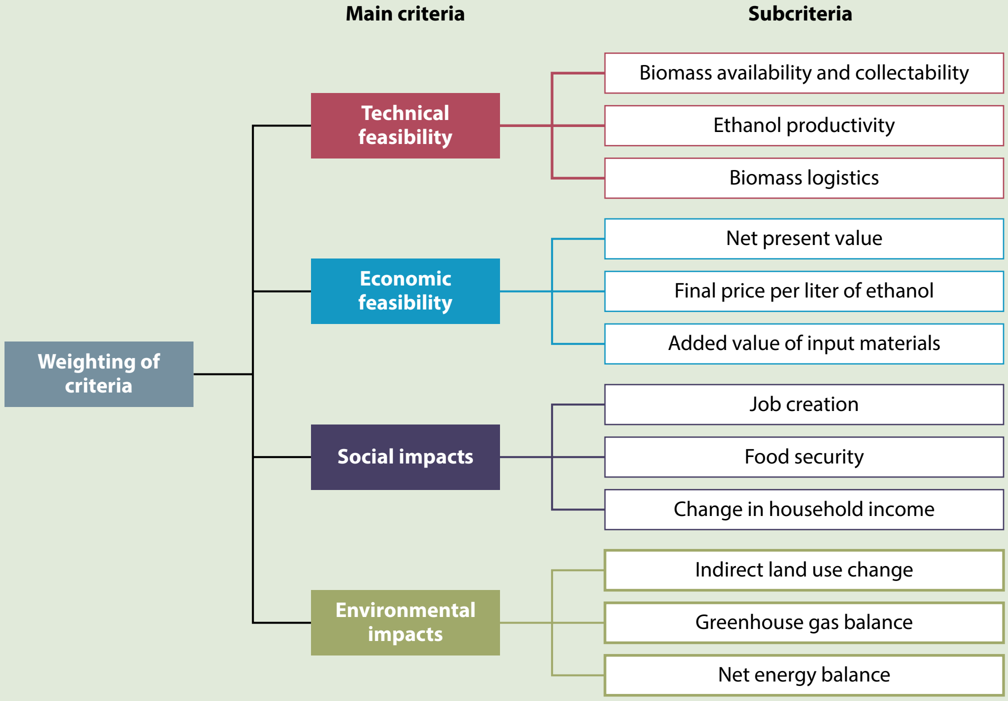
Component	Indicator	Subindicator	Thailand
(A2) Efficiency	(B6) Environmental efficiency	(C19) Risk of soil erosion and land degradation (1 = high risk; 5 = low risk)	LDD
		(C20) Risk of water pollution (1 = high risk; 5 = low risk)	PCD
		(C21) Risk of exhausting water sources (1 = high risk; 5 = low risk)	ONWR
		(C22) Risk of air pollution (1 = high risk; 5 = low risk)	PCD
(A3) Ability to confront and adapt	(B7) Ability to confront	(C23) Ability to confront floods (1 = very low; 5 = very high)	ONWR
		(C24) Ability to confront droughts (1 = very low; 5 = very high)	ONWR
		(C25) Ability to confront saltwater intrusion (1 = very low; 5 = very high)	ONWR
	(B8) Ability to adapt	(C26) Ability to recover after saltwater intrusion (1 = very low; 5 = very high)	ONWR
		(C27) Crop season flexibility to avoid SWI (1 = very inflexible; 5 = very flexible)	RID
		(C28) Ability to confront a worsening SWI situation (1 = minor limitation; 5 = major limitation)	Varieties of agricultural production (NESDC)
(A4) Sustainability and equity	(B9) Sustainability	(C29) Income diversity (1 = low diversified; 5 = high diversified)	Income (OAE)
		(C30) Coherence with CC scenarios (1 = very incoherent; 5 = very coherent)	NA
		(C31) Expanding abilities (adaptation options can be upscaled) (1 = very low; 5 = very high)	NA
		(C32) Developing abilities (adaptation options can be maintained for a long time) (1 = very low; 5 = very high)	NA
	(B10) Equity	(C33) Proportion of farmers impacted by SWI who can access information about adaptation options (1 = very small proportion; 5 = very large proportion)	NA
		(C34) Proportion of farmers impacted by SWI who can apply adaptation options (1 = very small proportion; 5 = very large proportion)	NA
		(C35) Vulnerable groups (women, poor people, elderly) are targeted specifically through the adaptation options (1 = low disagreement; 5 = high agreement)	NA

Source: [21].

Using the Delphi–AHP method, the research criteria prioritize sustainable development of second-generation bioethanol in Thailand [14]. The second generation of bioethanol's major requirements and supporting criteria are prioritized according to a hierarchical framework. Technical viability, economic viability, social viability, and environmental effect are the four criteria. As illustrated in Figure 2, each criterion is composed of three subcriteria.

FIGURE 2

HIERARCHICAL STRUCTURE TO DETERMINE THE IMPORTANCE OF MAIN CRITERIA AND SUBCRITERIA FOR SECOND-GENERATION BIOETHANOL.



Source: [14].

Conclusion

In Thailand, agriculture plays a crucial role in the economy and is being converted into an agro-industry to add more value. Therefore, improving agricultural productivity is crucial for the country's growth and development. However, the current agricultural indicators used are diverse, with a focus on GDP in the agricultural sector and other subindices, such as data on rice, cassava, and rubber.

The Office of the NESDC is responsible for developing policies and scorecards, which are then sent to the Ministry of Agriculture and Cooperatives for implementation. However, there are several challenges facing the collection and analysis of agricultural data in Thailand. These include:

(1) decentralized agricultural data in many departments lead to long processes for gathering information from different sectors;

(2) incomplete data on agriculture particularly data related to agriculture modernization lead to less accurate data;

(3) fragmented databases require time-consuming mapping and processing of data, which raises concerns about data accuracy;

(4) microdata is collected through sampling and not for the entire population, which leads to concerns about data accuracy;

(5) measurement and policy establishment are based on GDP, not productivity at the micro level; and

(6) lack of evaluation of measures and policies is based on outcomes and productivity.

To address these challenges, the following suggestions are proposed for improving agricultural productivity in Thailand:

(1) measure productivity over a specific period of time to track progress, adjust, and compare different types of produce as needed to increase productivity;

(2) consider the production time without yield and determine the payback period for crops to make more informed decisions about which crops to grow and how to manage their operations to maximize profits over time;

(3) involve sustainability and resource usage in agricultural planning by taking into account the environmental impact of different crops and farming methods;

(4) involve the financial status, health, safety, and food security aspects of farmers in agricultural planning to ensure that agricultural practices and policies support the wellbeing and livelihood of farmers;

(5) take into account various factors that can affect the price and quantity of produce, such as variety, time, size, quality or grade, stakeholders, and area; and

(6) consider the availability of subsidies or funding from the government to reduce the financial risks associated with farming and support sustainable agricultural practices and food security in local communities.

Appendix: Review of AHP

An analytical hierarchy process (AHP) is a multi-criteria decision-making tool. It was invented by Thomas L. Saaty in 1970 [30]. It is another way to structure the decision problem, and is used to prioritize alternatives and build an additive value function. It attempts to mirror the human decision process. AHP is easy to use, used often, well accepted by decision makers, and can be used by multiple decision makers.

The decision-making elements are discussed below:

(1) Problems or goals of decisions: A problem or goal is the beginning of the decision-making process, which will affect the consideration and evaluation of alternatives, so correctly positioning the problem or goal will steer the elements in the right direction. It begins by roughly defining the issues and questions, testing, and refining them accordingly. Subsequently, the problem or goal is put into a fast and efficient decision-making process.

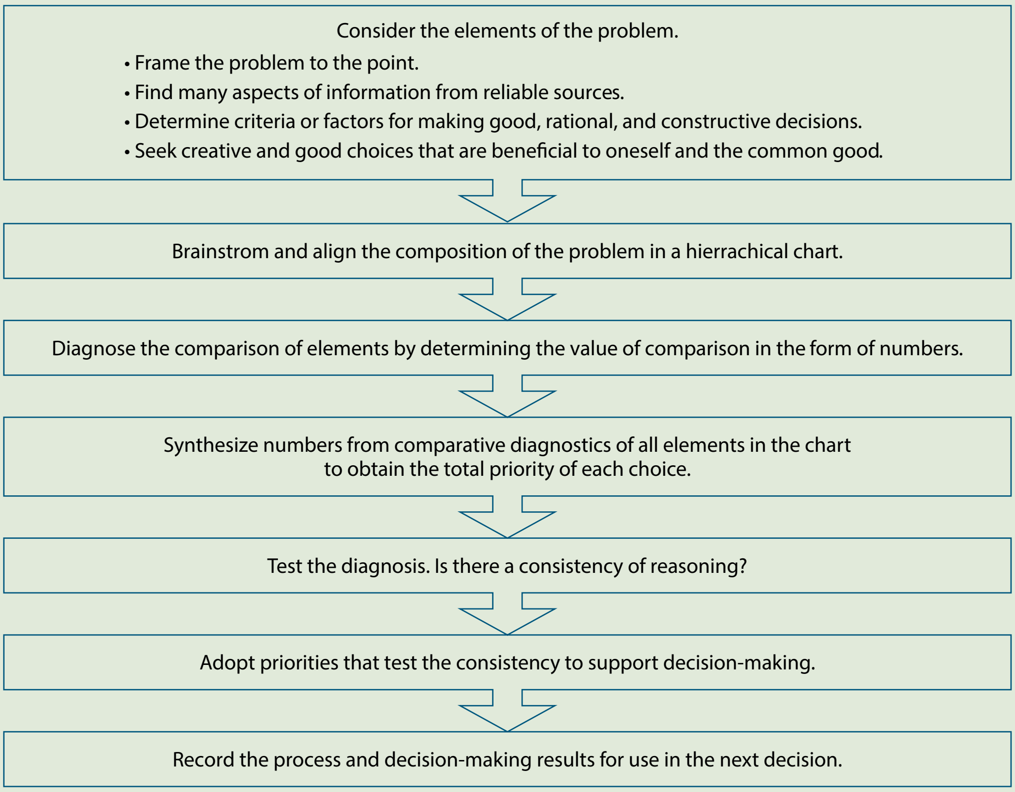
(2) **Primary and secondary decision-making criteria:** Decision-making criteria allow for an efficient decision-making process, especially in analyzing complex issues, where decision-makers should look at the problem from a wide angle, and in reverse, balance concrete and abstract criteria; look at the long-term consequences of decision-making and the impact it has on others; and open their minds to opinions of others without prejudices.

(3) **Alternative:** It is the most important step in the decision-making process, because the solution to the desired outcome depends on whether there is a valid alternative. It also affects the ability to diagnose. Therefore, decision-makers must reason, reflect, and ponder carefully, as well as constantly seek creative alternatives, starting to question how, why, etc.

The steps of the AHP can be summarized as shown in Figure 3 by creating a hierarchical chart. The chart can be divided into several hierarchies, depending on the complexity of the problem such as the three hierarchies in Figure 4, where the top hierarchy is the goal or the problem as the focal point. The second hierarchy is one that may have many factors or criteria. If the chart has more than three hierarchies, the number of factors in this hierarchy should be no more than three factors, but if the chart has three hierarchies, it can contain up to nine factors. Hierarchy 3 can have any number of options. It is up to the reader to have enough experience and expertise to determine the factors, where the selected factors must be equally important.

FIGURE 3

SUMMARY OF PROCEDURES OF AHP PRINCIPLES.



The application of AHP/fuzzy AHP in agriculture in different countries is shown in Table 11.

TABLE 11

APPLICATION OF AHP/FUZZY AHP IN AGRICULTURE IN DIFFERENT COUNTRIES.

Country	Application of AHP/fuzzy AHP
Thailand	Selection of ecofriendly crop farming in Mae Hong Son province [16];
	evaluation of the appropriateness of land use for agriculture in lower Prachinburi watershed [29];
	identification of the important factor related to corn price [15];
	prioritization of the importance of criteria of second-generation bioethanol [14];
	drought risk assessment in Lam Ta Kong Watershed [42]; and
	use of AHP and Delphi in water resource management [38].
India	Assessment of agricultural land's suitability [33]; and
	understanding smallholder perceptions of conservation agriculture adoption in Nepal and India [28].
Indonesia	Determining the best strategy for developing organic agriculture in Bengkulu province [7]; and
	prioritization of irrigation area [32].
Philippines	Identifying the major factors of land suitability that affect sugarcane production [1]; and
	selecting the suitability of land for sugarcane residue production [9].
Vietnam	Sorting saltwater intrusion adaptation options for farmers in two provinces in the central coastal region (the results showed that sustainability and equity were the most important criteria; and identified related indicators such as coherence, efficiency, ability to confront and adapt to sustainability, and equity [21]); and
	evaluating the as-is agricultural production and pinpointing the criteria involving agricultural farming and defeating the constraints in the agricultural production of Chau Thanh [41].

Case Study on Determination of Suitable Technologies for Thai Rice Industry

An online questionnaire was distributed to relevant experts for scoring based on their individual opinions. 14 responses were then analyzed using the AHP method. The results indicate that the selection of rice technology [23] is based on the weighting of four criteria: cost of technology implementation, benefits of the technology, appropriateness of technology in the Thai context, and readiness for technology implementation. Four alternative technologies were considered: precision farming; community and area-based research and crop management; fertilizer/integrated pest management; and breeding technology. The AHP tool was used to create a hierarchical structure, as illustrated in Figure 4.

The focus groups have selected the following key technologies for implementation:

Precision farming: It offers a variety of technologies that can be tailored to the rice industry and provide a worthwhile investment for farmers who own land.

Community and area-based research and crop management: It is necessary for optimal management in different areas and communities, each of which has unique characteristics such as farmer traits, attitudes, and integrations.

Fertilizer/integrated pest management: It aims to reduce the excessive use of chemicals, including chemical fertilizers and herbicides that are harmful to users and the environment.

Breeding technology: It aligns with government policies promoting reduced rice cultivation and higher quality rice, including varieties with high nutritional value or those suitable for processing into medicinal or supplementary products.

The criteria for selecting important technologies for the Thai rice industry are as follows:

The cost of technology implementation: It is a crucial factor for those in the supply chain, particularly farmers and mills, when deciding whether to invest in technology.

Benefits of the technology: Benefits of investing in technology include less labor resources, reduced time, increased efficiency, and enhanced security and convenience.

The appropriateness of the technology in the Thai context: This is about taking into account the environment, attitudes, and experiences of those involved in the rice supply chain, as certain technologies may not be suitable in this context.

The readiness for the technology's implementation: It is important to consider if the personnel involved in the rice supply chain have the necessary knowledge and understanding, and are willing to accept the technology for implementation.

FIGURE 4

HIERARCHICAL CHART OF GOALS, CRITERIA, AND ALTERNATIVES FOR DETERMINATION OF SUITABLE TECHNOLOGIES FOR THE THAI RICE INDUSTRY.

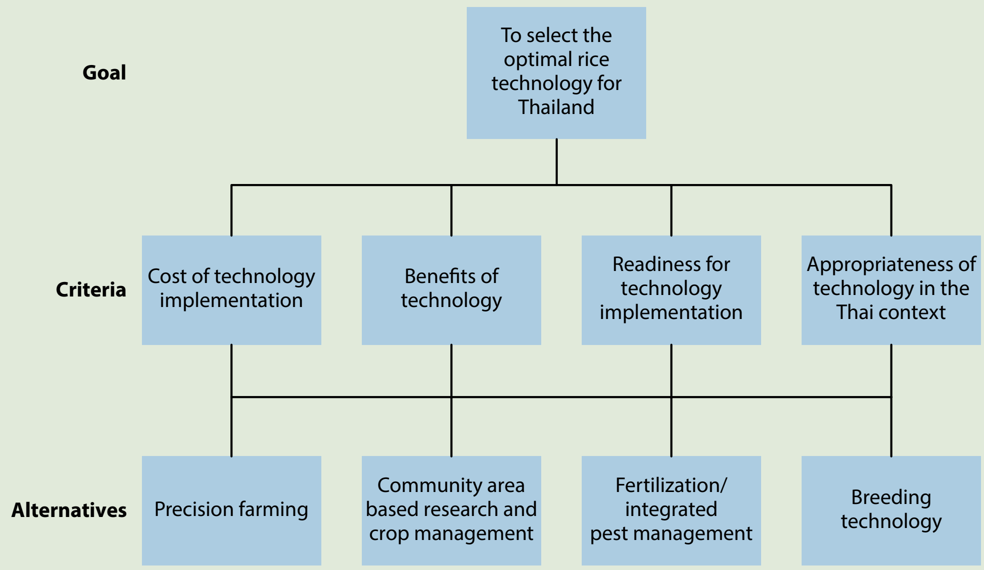


TABLE 12

THE IMPORTANCE OF TECHNOLOGICAL ALTERNATIVES IN AHP.

Technology alternatives	The cost of technology implementation	Benefits of the technology	Readiness for the technology's implementation	Appropriateness of technology in the Thai context	Weight of the technology	Rank
Weight of criteria	0.17	0.269	0.247	0.314	–	–
Community area-based research and crop management	0.354	0.26	0.343	0.29	0.306	1
Fertilizer/ integrated pest management	0.219	0.216	0.283	0.268	0.249	2
Breeding technology	0.27	0.25	0.251	0.203	0.239	3
Precision farming	0.156	0.273	0.123	0.239	0.206	4

The results of the online questionnaire sent to relevant experts, using the AHP method, indicated that the criteria for selecting rice technology, in order of importance, are the appropriateness of technology in the Thai context, the benefits of technology, the readiness for technology implementation by those involved, and the cost of the technology's implementation. Four technology alternatives were evaluated: precision farming; community area-based research and crop management; fertilizer/ integrated pest management; and breeding technology. The consistency ratio (CR) calculations of the 14 experts showed that the choices were consistent and the first priority criteria was the appropriateness of technology in the Thai context, followed by the benefits of the technology, the readiness for technology implementation, and the cost of technology implementation, respectively.

Based on the priority scores of each criterion, it was found that community area-based research and crop management had the highest priority score, followed by precision farming, breeding technology, and fertilizer/integrated pest management. Experts agreed that technological development should start at the community level by choosing the right technology and management for that community or area, such as the right varieties, soil analysis, and community learning centers. Fertilizer-related technologies and management of weeds and pests were considered of secondary importance, while rice breeding technology was important for developing new varieties with high nutritional value. However, precision farming was considered not suitable for the time under consideration (for the five years starting from 2017) due to the lack of cognition, basic information, tools and devices, and personnel to introduce and transfer the technology. Experts viewed post-harvest technologies as important, but less so than pre-harvest technologies due to downstream stakeholders' abilities, funding, and access to high-tech solutions. In-demand post-harvest technologies included paddy drying technology and technology to eliminate moths for food quality and safety. DNA testing technology for jasmine rice varieties was also sought after for its affordability and speed.

Future research can be to identify the importance of criteria to determine the productivity KPI using AHP, based on the KPI being

(1) relevant to the policymaker to develop the country's performance;

(2) measurable quantitatively, or being a number that has reliable input data;

(3) controllable or its goal being adjustable;

(4) comparable with other organizations' performances or overseas (against a benchmark); and

(5) affordable in terms of time and budget for data collection, and economical.

Appendix

FIGURE A1

INTERVIEW WITH THE OFFICE OF THE NESDC.

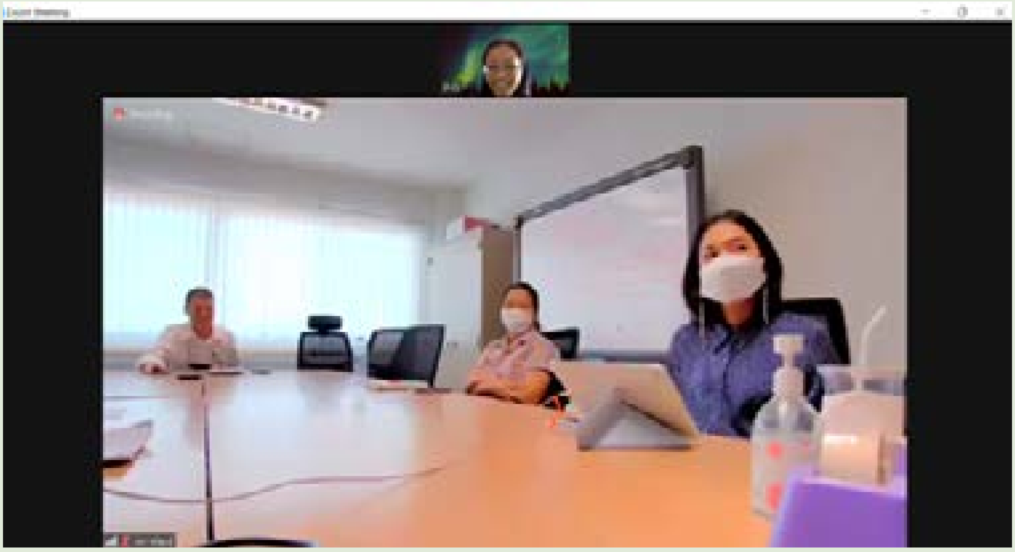


FIGURE A2

INTERVIEW WITH GEO-INFORMATICS AND SPACE TECHNOLOGY DEVELOPMENT AGENCY.

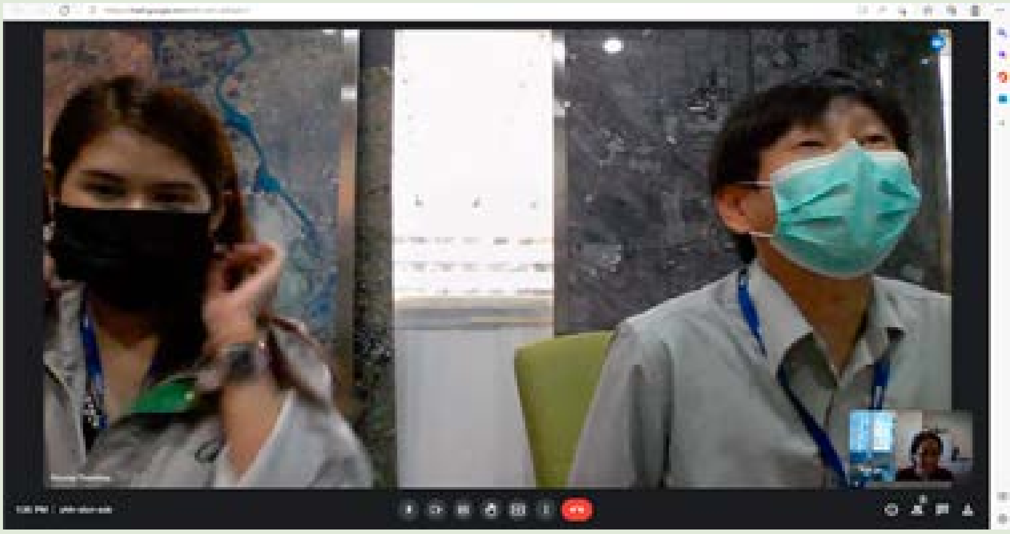


FIGURE A3

PARTICIPATION IN THE *END POVERTY SEMINAR* BY THE WORLD BANK GROUP.

FIGURE A4

INTERVIEW WITH THE OFFICE OF AGRICULTURAL ECONOMICS.

AHP Calculation

We take the comparative values of each pair of factors, and put them in a matrix table format showing comparisons. Based on the calculation of the pairs used for comparison, the values from each pair's comparison are put in the matrix table. If factor A is more important than factor B on a scale of three points, or more important than moderate, then A = 3B or B = A/3. Factor C is much more important than factor A on a scale of five or more important, so C = 5A or A = C/5. Factor C is more important than factor B on a scale of score seven or more important than most, so C = 7B or B = C/7, as shown in Table A2.

The comparison is from top to bottom in the same hierarchy. For example, compare, starting with the second hierarchy, followed by the third and fourth hierarchies, respectively, where the number of pairs used to compare is equal to

$$\frac{n^2 - n}{2} \tag{1}$$

where n is equal to the number of factors being compared, i.e., if three factors are used in the comparison, then the number of pairs used for comparison can be calculated as follows:

$$\frac{3^2 - 3}{2} = 3 \text{ pairs}$$

We define phrases in comparison that are appropriate to the nature of the factors. It is important to formulate a question phrase, asking the appropriate relationship between factors in the same hierarchy, where the phrase differs according to the nature of the comparison, i.e., to what extent this factor is more important than any other factor. Then, define numbers 1–9 instead of phrases in comparison so that the gauge can be displayed, as shown in Table A1.

TABLE A1

SCALE IN THE COMPARATIVE DIAGNOSIS OF AHP.

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	For compromises between above
Reciprocals of above	In comparing elements i and j (if i is 3 compared to j, then j is 1/3 compared to i)
Rationales	Force consistency, measured values available

Step 1: An expert compares the importance score of each pair of factors. Let us put it in a table showing comparisons in matrix table format, based on the calculation of the pairs used for comparison in Table A2. Then, the values from each pair's comparison are put in the matrix table. If factor A is more important than factor B on a scale of three points, or more important than moderate, then A = 3B or B = A/3. If factor C is much more important than factor A on a scale of five or more important, then C = 5A or A = B/5. If factor C is more important than factor B on a scale of score seven or more important than most, then C = 7B or B = C/7, as shown in Table A2.

TABLE A2

EXAMPLE OF PUTTING SCORES IN A MATRIX TABLE.

Goal	Factor A	Factor B	Factor C	Factor D
Factor A	1	3	1/5	1/9
Factor B	1/3	1	1/7	¼
Factor C	5	7	1	3
Factor D	9	4	1/3	1

After calculating the comparison of the factors in step 1, the same is done in step 2, i.e., a comparison of the alternatives, whereas if there are three comparative alternatives and three factors are compared, then there must be a total of three tables according to the number of factors compared, as shown in Table A3.

TABLE A3

EXAMPLE MATRIX TABLE TO COMPARE ALTERNATIVES.

Factor A	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Alternative 1	1	A	b	d
Alternative 2	1/a	1	c	e
Alternative 3	1/b	1/c	1	f
Alternative 4	1/d	1/e	1/f	1

Step 2: Priority calculation in AHP is computed after the expert puts the importance score in the matrix table format. Priority values can be calculated by doing a vertical sum of the matrix table and then finding the ratio obtained from the vertical sum. Next, the sum of the ratios in each row is averaged. An order of magnitude can be calculated as shown in Figure A5, where the table on the left is the calculation formula and the right table is the result of the calculation.

FIGURE A5

PRIORITY CALCULATIONS OF THE CRITERIA.

	C	B	R	A
Cost	1	0.33	5	7
Benefit		1	5	7
Readiness			1	3
Appropriatemess				1

Step–1

	C	B	R	A
C	1	0.33	5	7
B	3	1	5	7
R	0.20	0.20	1	3
A	0.14	0.14	0.33	1
Total	4.34	1.68	11.33	18

Step–2

	C	B	R	A	Average
C	0.23	0.20	0.44	0.39	0.31
B	0.69	0.60	0.44	0.39	0.53
R	0.05	0.12	0.09	0.17	0.11
A	0.03	0.09	0.03	0.06	0.05
					1

FIGURE A6

PRIORITY CALCULATIONS OF THE ALTERNATIVES FOR COST.

Cost	PF	CR&CM	F&IPM	BT
PF	1.000	5.000	0.200	0.200
CR&CM		1.000	0.143	0.143
F&IPM			1.000	1.000
BT				1.000

Step–3

Cost	PF	CR&CM	F&IPM	BT
PF	1.000	5.000	0.200	0.200
CR&CM	0.200	1.000	0.143	0.143
F&IPM	5.000	7.000	1.000	1.000
BT	5.000	7.000	1.000	1.000
Total	11.200	20.000	2.343	2.343

Step–4

Cost	PF	CR&CM	F&IPM	BT	Average
PF	0.09	0.25	0.09	0.09	0.13
CR&CM	0.02	0.05	0.06	0.06	0.05
F&IPM	0.45	0.35	0.43	0.43	0.41
BT	0.45	0.35	0.43	0.43	0.41
					1.000

FIGURE A7

PRIORITY CALCULATIONS OF THE ALTERNATIVES FOR BENEFIT.

Benefit	PF	CR&CM	F&IPM	BT
PF	1.000	7.000	1.000	5.000
CR&CM	0.143	1.000	0.143	0.200
F&IPM	1.000	7.000	1.000	3.000
BT	0.200	5.000	0.333	1.000

Step–5

Benefit	PF	CR&CM	F&IPM	BT
PF	1.000	7.000	1.000	5.000
CR&CM	0.143	1.000	0.143	0.200
F&IPM	1.000	7.000	1.000	3.000
BT	0.200	5.000	0.333	1.000
Total	2.343	20.000	2.476	9.200

Step–6

Benefit	PF	CR&CM	F&IPM	BT	Average
PF	0.43	0.35	0.40	0.54	0.43
CR&CM	0.06	0.05	0.06	0.02	0.05
F&IPM	0.43	0.35	0.40	0.33	0.38
BT	0.09	0.25	0.13	0.11	0.14
					1.000

FIGURE A8

PRIORITY CALCULATIONS OF THE ALTERNATIVES FOR APPROPRIATENESS.

Readiness	PF	CR&CM	F&IPM	BT
PF	1.000	3.000	0.143	3.000
CR&CM	0.333	1.000	0.143	1.000
F&IPM	7.000	7.000	1.000	7.000
BT	0.333	1.000	0.143	1.000

Step–7

Readiness	PF	CR&CM	F&IPM	BT
PF	1.000	3.000	0.143	3.000
CR&CM	0.333	1.000	0.143	1.000
F&IPM	7.000	7.000	1.000	7.000
BT	0.333	1.000	0.143	1.000
Total	8.667	12.000	1.429	12.000

Step–8

Readiness	PF	CR&CM	F&IPM	BT	Average
PF	0.12	0.25	0.10	0.25	0.18
CR&CM	0.04	0.08	0.10	0.08	0.08
F&IPM	0.81	0.58	0.70	0.58	0.67
BT	0.04	0.08	0.10	0.08	0.08
					1.000

FIGURE A9

PRIORITY CALCULATIONS OF THE ALTERNATIVES FOR READINESS.

Appropriateness	PF	CR&CM	F&IPM	BT
PF	1.000	5.000	5.000	7.000
CR&CM	0.200	1.000	1.000	3.000
F&IPM	0.200	1.000	1.000	3.000
BT	0.143	0.333	0.333	1.000

Step–9

Appropriate-ness	PF	CR&CM	F&IPM	BT
PF	1.000	5.000	5.000	7.000
CR&CM	0.200	1.000	1.000	3.000
F&IPM	0.200	1.000	1.000	3.000
BT	0.143	0.333	0.333	1.000
Total	1.543	7.333	7.333	14.000

Step–10

Appropriate-ness	PF	CR&CM	F&IPM	BT	Average
PF	0.65	0.68	0.68	0.50	0.63
CR&CM	0.13	0.14	0.14	0.21	0.15
F&IPM	0.13	0.14	0.14	0.21	0.15
BT	0.09	0.05	0.05	0.07	0.06
	0.65	0.68	0.68	0.50	0.63

FIGURE A10

PRIORITY CALCULATIONS OF THE ALTERNATIVES FOR ALL CRITERIA.

	Weights	PF	CR&CM	F&IPM	BT
Cost	0.315	0.128	0.047	0.412	0.412
Benefit	0.529	0.431	0.048	0.377	0.145
Readiness	0.105	0.179	0.076	0.668	0.076
Appropriatemess	0.051	0.628	0.154	0.154	0.064

Step–11

	PF	CR&CM	F&IPM	BT
Cost	0.040	0.015	0.130	0.130
Benefit	0.228	0.025	0.199	0.077
Readiness	0.019	0.008	0.070	0.008
Appropriatemess	0.032	0.008	0.008	0.003
SUM	0.319	0.056	0.407	0.218

Consistency Testing [30]

The AHP requires a consistency ratio with four computational variables: λmax (described below); the number of factors compared (n); consistency index (CI); and consistency ratio (CR) resulting from the calculation. There are two cases: one, there is a consistency (i.e., CR is less than 10% or 0.10); and two, there is no consistency (i.e., CR is greater than 10% or 0.10).

λmax = the summation of the multiplication of the priority value and the sum of the significance values. It should be equal to the number of factors or the number of alternatives used to compare.

From Figure A5,

	C	B	R	A
C	1	0.33	5	7
B	3	1	5	7
R	0.20	0.20	1	3
A	0.14	0.14	0.33	1
Total	4.34	1.68	11.33	18

Step–2

	C	B	R	A	Average
C	0.23	0.20	0.44	0.39	0.31
B	0.69	0.60	0.44	0.39	0.53
R	0.05	0.12	0.09	0.17	0.11
A	0.03	0.09	0.03	0.06	0.05
					1

$\lambda max = 4.34*0.31+1.68*0.53+11.33*0.11+18*0.05 = 4.36$

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (2)$$

$$CI = \frac{4.36-4}{4-1} = 0.12$$

Next, we calculate the random consistency index (RI) value as shown in Table A4, and then determine the CR, which varies with the value of n from the formula.

$$CR = \frac{CI}{RI} \quad (3)$$

$$CR = \frac{0.12}{0.9} = 0.133 = 13.3\ \%$$

According to the calculation, a CR of 0.133 is greater than 0.10, indicating that the diagnosis is not consistent within acceptable limits. Hence, the comparison should be reevaluated. If the CR is close to 0, then it indicates that the diagnosis is more consistent.

TABLE A4

RANDOM CI.

n	3	4	5	6
R.I.	0.58	0.9	1.12	1.24

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VIETNAM

Agricultural productivity is a key driver for the development of agricultural industry, since improving farmers' living standard is an important policy consideration. Increasing food supply to meet the challenges of the global population growth and changes in income and dietary is also important. Moreover, agricultural productivity is directly affected by food security, price, and poverty reduction, especially in developing countries like Vietnam. Therefore, a study of agricultural productivity in agriculture is always important, especially when it focuses more on sustainability and modernization.

Over the past years, Vietnam's agriculture has played an important role, contributing to the development of the country's economy. However, to achieve higher goals in future, Vietnam has realized the importance of sustainable development and therefore put the perspective of sustainable development into resolutions, strategies, and plans for socioeconomic development, including that of the agricultural sector. Sustainable agricultural and rural development requires a system of comprehensive solutions, from formulating macro-management policies to taking economic and social measures, human resource development, research, and application. It is about using science and technology to increase productivity and create more green products to meet the demands of large domestic and international consumption markets.

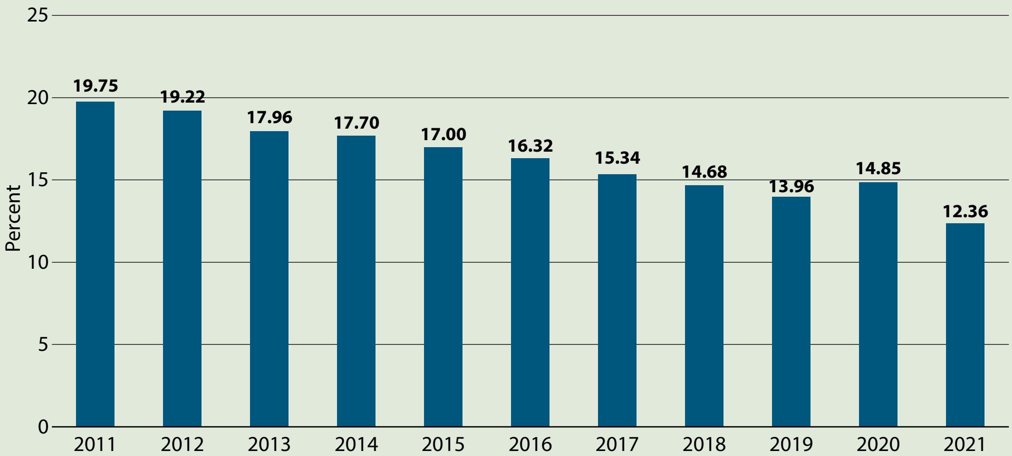
As productivity assessment tools for Vietnam's agriculture are lacking, this research has focused on the policy, orientation, and support of the Vietnamese government for the development of high-technology applications in agricultural production and providing a general overview of sustainable agricultural modernization (SAM) in Vietnam, with certain limitations.

Overview of Vietnam Agriculture

Overview of Agriculture Sector

FIGURE 1

GDP CONTRIBUTION OF THE AGRICULTURE, FORESTRY, AND FISHERY SECTOR IN VIETNAM, 2011–21.



Source: [1].

In 2021, Vietnam's agriculture, forestry, and fishery sector accounted for 12.36% of the country's gross domestic product (GDP). In 2020, this sector recorded the first growth in GDP share in recent years. Prior to 2020, the agriculture, forestry, and fishery sector had a decreasing GDP contribution due to the growing significance of Vietnam's industry and service sectors.

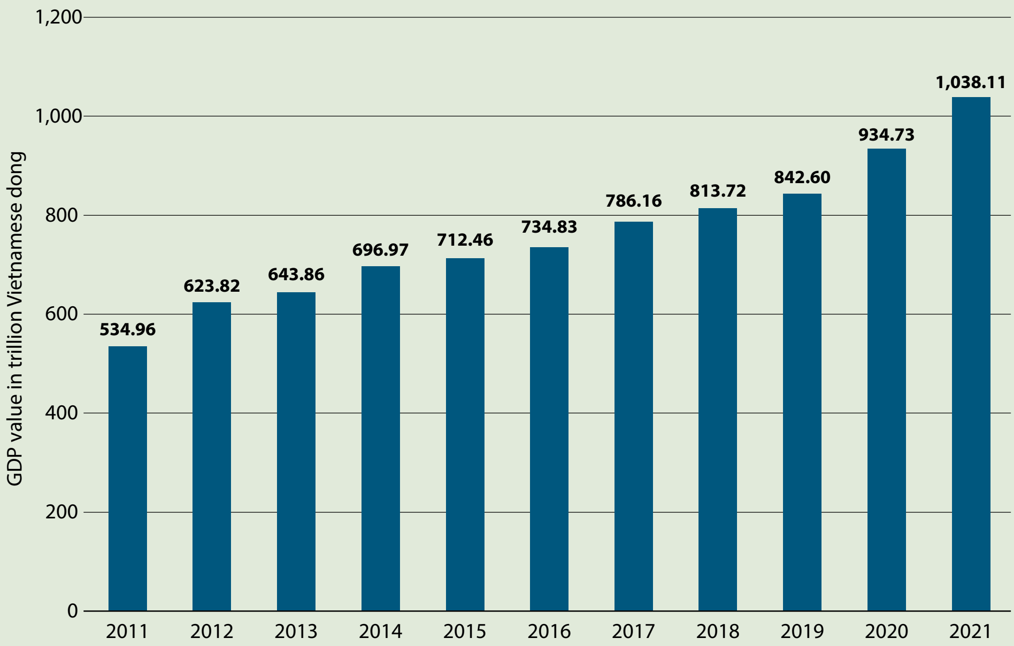
Vietnam has transformed from a net importer of agricultural products to a net exporter since its trade liberalization and agricultural reforms in the 1980s. The country has become a leading producer and exporter for many important commodities, such as rice, coffee, pepper, and cashew nuts. For instance, Vietnam has kept its place as the second-largest exporter of coffee after Brazil. On the other hand, with growing domestic demand, agricultural product imports have been increasing in the country, with fresh fruits, tree nuts, and fresh vegetables being the leading imported food products in value terms in 2020.

Outlook of the Agriculture Sector in Vietnam

Vietnam's agriculture sector is heavily subjected to climate change-related issues, such as annual droughts and increasing salination. This affects the production of many of its commodities, including rice, which is one of the most important agricultural export products. The volume of rice produced in the Mekong Delta, Vietnam's main rice-cultivating area, has been decreasing in recent years. Consequently, the government and farmers have been working on finding solutions to adapt agricultural production to the changing climate and land conditions.

FIGURE 2

GDP VALUE OF THE AGRICULTURE, FORESTRY, AND FISHERY SECTOR IN VIETNAM, 2011–21.

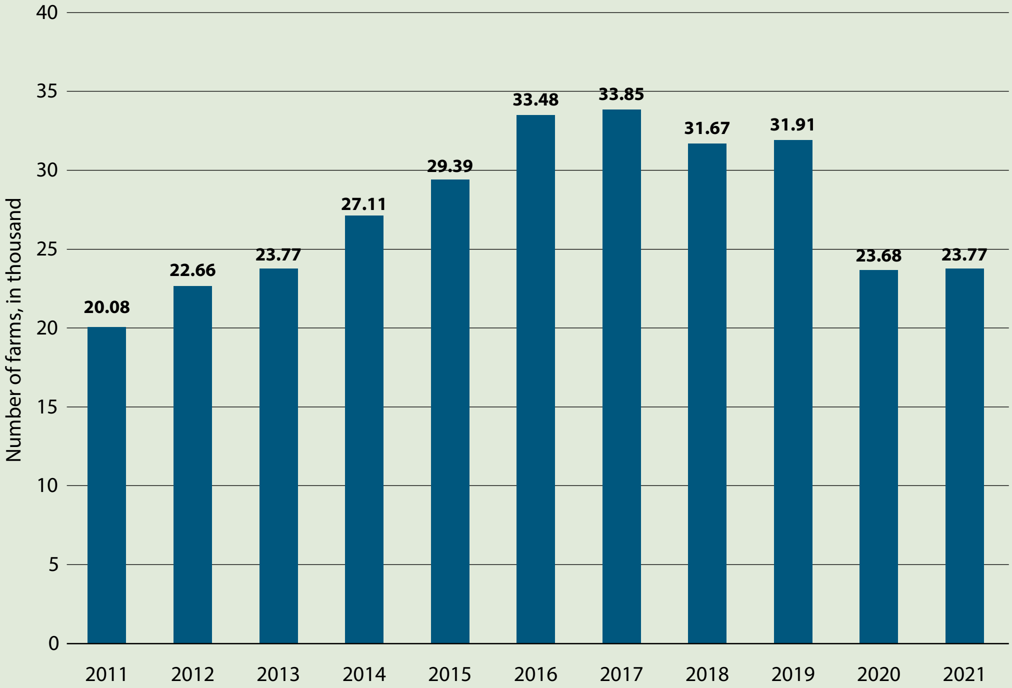


Source: [2].

In 2021, Vietnam's agriculture, forestry, and fishery sector contributed more than a thousand trillion Vietnamese dong to the country's GDP. The GDP value of this sector increased year on year in the observed period and accounted for 12.36% of Vietnam's GDP in 2021.

FIGURE 3

NUMBER OF FARMS IN VIETNAM, IN THOUSAND, 2011–21.



Source: [3].

In 2021, there were approximately 23.8 thousand farms in operation throughout Vietnam. Compared with the years before, the number of farms in the country had decreased significantly, though there was a minor increase in the number compared with 2020.

Overview of Productivity Indicators in Agriculture, Forestry, and Fishery

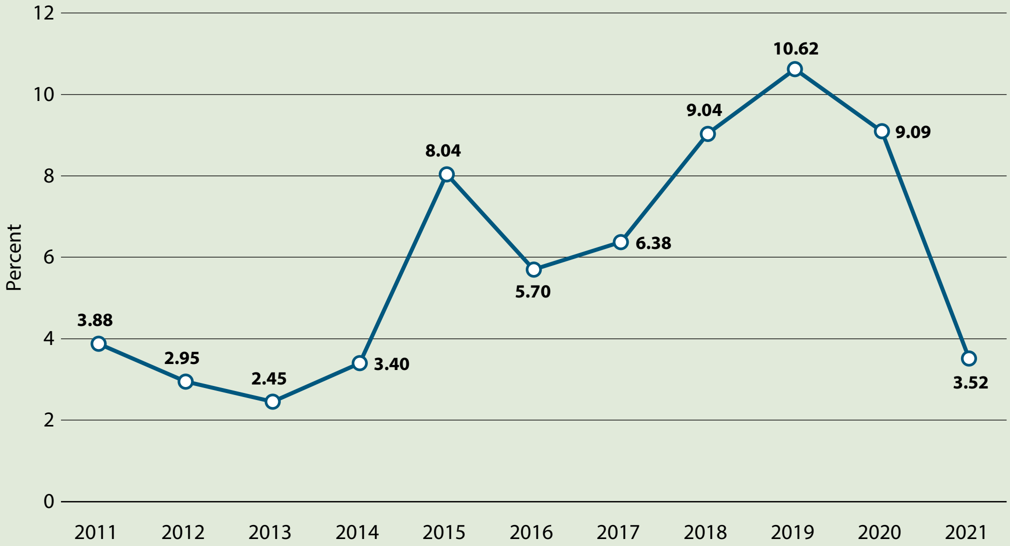
In 2021, the value of agriculture, forestry, and fishery increased by 2.9%, as the productivity of most crops was better than that in the previous year, ranching grew stably, and the export turnover of some farm products increased, thereby contributing to the growth rate. The added value of the agricultural sector increased by 3.18%, that of the forestry sector by 3.88%, and fishery by 1.73%, according to the General Statistics Office report on socio-economic situation in 2021.

In 2021, the labor productivity in agriculture, forestry, and fishery was VND63.1 million per labor, increasing by 3.52% compared with 2020. However, after a series of continuous increases, the growth rate of labor productivity in agriculture, forestry, and fishery slowed down in 2020 and came further down in 2021.

The growth rate of labor productivity quickly increased in the period from 2015 to 2020, due to the strong labor restructuring from agriculture to industry and services, while science and technology contributed to boosting the productivity of crops and livestock, thereby improving the quality and increasing the value of farm products. However, due to social distancing during the COVID-19 pandemic, from the end of 2020 and especially from April to August in 2021, labor restructuring tended to concentrate on the agricultural sector, thus slowing down the speed of labor productivity.

FIGURE 4

GROWTH RATE OF LABOR PRODUCTIVITY IN AGRICULTURE, FORESTRY, AND FISHERY IN 2011–21.



Source: Calculated on the basis of statistical data by the author (https://www.gso.gov.vn/so-lieu-thong-ke/) updated to 30 March 2022; [4].

From 2011 to 2020, the growth rate of TFP in the agriculture, forestry, and fishery sector was approximately 1.86% per year, reaching quite a high level, thanks to the conversion of high-value-added products and technologies in agriculture. Specifically, the growth rate of TFP in the period 2011–15 was 1.70% per year, while during 2016–20 it was 1.94% per year.

The added value of agriculture increased slowly. From 2011 to 2020, the average added value increased 2.83% per year. The capital investment still increased, but the labor force decreased rapidly due to economic restructuring. The contribution to increase in added value was mainly due to increase in capital and TFP compensating for the decrease in labor. In the period of 2011–20, the increase in TFP contributed 65.5% to the added value.

Based on an assessment by the Ministry of Agriculture and Rural Development, the production in agriculture, forestry, and fishery in 2021 was done in relatively good weather conditions, with good productivity of crops and livestock. However, because of the COVID-19 pandemic, especially in the third quarter of 2021, many localities applied prolonged social distancing, which affected the supply chain, processing, and consumption of products in agriculture, forestry, and fisheries. The agriculture sector received a timely response and effective implementation of Resolution No. 128/NQ-CP of the Government to stabilize and develop production, thereby reaching a high growth level. The performance of the sector in 2021 clearly demonstrates its role as a foundation for the economy. By ensuring supply of food and essential goods, it played an important role in applying social security during the pandemic.

In farming industry, the crop structure was transformed more efficiently, to strengthen intensive farming and apply science and technology, especially for key crops. The focus was on improving the breed structure, i.e., to control and increase the percentage for using new, high-quality breeds. Despite the COVID-19 epidemic, rice production in 2021 still reached 43.86 million ton, satisfying the demand for domestic consumption and export. The proportion of high-quality rice made up more than 89%, with the price of exported rice increasing from USD496 per ton in 2020 to USD503 per ton in 2021.

In 2021, the crop area was approximately 1.12 million hectare, and the output reached 18.6 million ton, increasing by 325,500 tons compared with 2020. The forest area reached 1.18 million hectares, increasing by 44.8 thousand hectare compared with 2020, with the output and quality of fruit trees stably increasing across the country and in all regions. The output of some key fruit trees increased from 5% to 19%.

In ranching, the organization of production and ranch farming clearly changed, focusing on clean, organic, and biosafety chains. The output of meat in all kinds reached 6.69 million ton, increasing by 3.2% compared with 2020; the output of fresh milk reached more than 1.2 million ton, increasing by 10.5%; and the output of eggs was 17.5 billion, increasing by 5.1%. This was achieved by strongly, synchronously, and effectively preventing and controlling diseases in livestock and poultry. The fishery also sustainably developed in terms of both farming and fishing. Total output of marine products reached over 8.73 million ton, increasing by 1% compared with 2020, of which, the exploited output reached over 3.9 million ton, increasing by 0.9%. The cultivation reached 4.8 million ton, increasing by 1.1%.

Forestry continues to implement the Forest Protection and Development Program, focusing on the project "Growing one billion trees in the period of 2021–25." The area of newly and concentrated forest was 278,000 hectare and 120 million scattered trees, and the revenue gained from forest environmental services was over 3,100 billion dong.

Sustainable Agriculture Modernization in Vietnam

The Concept about Sustainable Agricultural Development

Sustainable agricultural development is a close, reasonable, and harmonious combination between agricultural development toward economic, social, and environmental sustainability.

Agricultural development in the direction of economic sustainability is shown by improving the quality of agricultural growth and agricultural restructuring with a progressive and reasonable orientation.

Agricultural development in the direction of social sustainability is shown by improving employment and job restructuring in agriculture in a positive direction, and enhancing farmers' living standards.

Agricultural development in the direction of environmental sustainability is shown by economically and efficiently exploiting and using natural resources in agricultural production; and protecting, regenerating, and restoring natural resources.

To achieve sustainable agriculture development, it is necessary to achieve all three above factors; i.e., it is necessary to make the intersection between the three factors of economy, society, and environment more open.

Agricultural development in the direction of economic sustainability is shown in the quality of agricultural growth and agricultural restructuring suitable for the market and adapting to climate change, as discussed below.

The quality of agricultural growth is shown by three aspects: development, structure, and efficiency of agricultural growth.

The development of agricultural growth is shown by the speed and scale of agricultural growth in a certain period (at least five years). If the agricultural growth rate is high, and the growth scale is large and continuous for many years and stable, it shows the quality of agricultural growth in the direction of sustainable development. On the contrary, if the speed and scale of agricultural growth are both negative or develop slowly on a small scale, the quality of agricultural growth is not sustainable [5].

Structure of agricultural growth: For the input in production process, if agricultural growth mainly depends on increasing capital, labor, and natural resources, it is shown that the quality of agricultural growth is low and not in the direction of sustainable development. On the contrary, if the agricultural growth mainly depends on technological progress and TFP, it shows there is a sustainable agricultural development.

For the output in production process, if agricultural growth mainly depends on products with advantages, high labor productivity, and added value, it shows a high quality of agricultural growth and vice versa.

The effectiveness of agricultural growth is often considered by using the factors: capital, labor, land and the VA/GO ratio (an indicator reflecting production efficiency) of the agricultural sector.

If the incremental capital output ratio (ICOR), labor use efficiency (labor productivity), land use efficiency, and the VA/GO ratio of the agricultural sector reach high value levels, then it is considered that agricultural development is in the direction of sustainable development and vice versa [6].

Agricultural restructuring in a reasonable and progressive direction: The structure of agricultural sector must move in the direction of increasing the density of industries with high added value, science and technology, using little resources, and being less harmful to the environment, with the dual goal of economic efficiency associated with social efficiency and environmental protection.

Agricultural restructuring needs to closely associate with economical and efficient use of resources; promote its comparative advantages in accordance with the conditions of each sector, subsector, region, or locality for more added value; and positively contribute to the economic growth of the country and the locality. In this regard, one should clearly identify leading sectors and subsectors that are competitive, bring economic efficiency, and ensure continuous and stable agricultural growth in the long term.

Agricultural Development in the Direction of Social Sustainability

Agricultural development in the direction of social sustainability must be linked to farmers and rural areas, as follows:

(1) Progressively and reasonably create employment and job restructuring in the agricultural sector: When the agricultural sector develops sustainably, it means creating more new jobs and contributing toward solving the problem of underemployment in rural areas. The

employment quality needs to be improved to increase jobs with high value added and labor productivity and to decrease jobs with low value added and labor productivity, thereby reducing seasonal employment, and increasing long-term employment. Specifically, it should (1) increase employment for households specializing in fishery and decrease employment for households specializing in forestry and agriculture; (2) increase employment for households specializing in ranching and reduce employment for households specializing in farming; and (3) increase employment in areas of agricultural product processing and services for agricultural production.

(2) Farmers' living quality is increasingly improved: Farmers' living quality is reflected in many aspects, such as income, education, healthcare, medical examination and treatment, access to public services, etc. If farmers can improve their income with a life of comfort, without being affected by negative factors and market risks; gain education to improve qualification; and have equal access to essential public services such as healthcare, clean water, and electricity, it shows that the agricultural development is in the direction of social sustainability and vice versa.

Agricultural Development in the Direction of Environmental Sustainability

(1) Reasonably exploit, and economically and efficiently use natural resources: While exploiting land and water resources, there should be attention to maintaining soil quality, avoiding pollution and land degradation. It is necessary to protect water sources, discourage unplanned exploitation, and develop a model of low input.

(2) Protect, restore, and regenerate resources and biodiversity: The process of agricultural development must maintain diversity, integrity, and sustainability of the ecological environment and protect the function of the ecological system. Therefore, it is necessary to safely and effectively use chemicals and inorganic fertilizers and use plants and animals suitable for the locality's ecological condition, to meet the need of market and to adapt to climate change. Moreover, it is necessary to save on inputs by applying science and technology and cultivation techniques such as drip irrigation in the production process and by developing ecofriendly agricultural models such as organic agriculture model and eco-agriculture model.

(3) Agricultural development suitable for climate change: The agricultural development process must (1) aim at industries and technologies that mitigate climate change, i.e., reduce greenhouse gas emissions and toxic waste; and (2) adjusted to climate change in order to reduce losses and enhance adaptation to climate change.

Vietnam's Characteristics in Agricultural Development

In a mid-2020 survey of the General Statistics Office, the results showed that the overall picture of rural socioeconomic and agricultural, forestry, and fishery production in rural areas in the years 2016–20 had many bright spots and outstanding achievements. First, rural infrastructure, including economic infrastructure, social infrastructure, and environmental sanitation infrastructure had been supplemented and completed in both quantity and quality. Second, the rural economic structure had a positive shift in the direction of gradually increasing the proportion of non-agriculture, forestry, and fishery sectors. Third, agricultural, forestry, and fishery production had overcome difficulties in natural disasters, COVID-19 epidemic, African swine fever, and avian influenza to maintain and develop stable production.

The survey results also reflect more clearly some limitations and inadequacies, including three major issues: (1) there has not been a real breakthrough in exploiting and using potential advantages, labor resources, land, market and other resources in large rural areas in general and the fields of agriculture, forestry, and fishery in particular, with many bottlenecks continuing to exist; (2) the economic structure of rural, agro-forestry-fishery and fishery has been slowly shifting, with small production still being popular and agriculture still being the mainstay; and (3) the ecological environment pollution tends to increase, thereby negatively affecting the process of socioeconomic development and social security in rural areas [7].

In the coming period, it is necessary to have a system of synchronous, practical, and effective solutions to handle and overcome the above-mentioned limitations and inadequacies, thereby enabling the country's countryside and agriculture to continue developing in the direction of modernity and sustainability.

Overview of Smart and Sustainable Agriculture Development in Vietnam

The modern scientific and technical revolution is creating completely new technologies to become the driving force for the development of smart agricultural production in the world, and Vietnam's agricultural industry is not out of this trend. However, depending on the ecoregion, the types of crop and livestock, and the scale of production, the development of smart agriculture in Vietnam requires smart approaches to promote efficiency in accordance with the conditions in Vietnam.

According to agriculture experts, participating in smart agricultural production will help Vietnam's agriculture sector to increase the ability to connect producers with information, better manage production, and reduce the complexity of multi-level administrative procedures to directly use the State's public services for agriculture. This shows the benefits and values that smart agriculture brings to Vietnam's agricultural production. However, in order to develop smart agriculture, Vietnam needs to take a smart and appropriate approach based on many different factors to ensure the most optimal and harmonious production methods that are effective not just economically but also socially and environmentally.

In order to smartly access the agricultural export market, Vietnam's agricultural production needs to invest in deep processing with agricultural products that do not have much room for exports, instead of increasing volume. On the contrary, for products that still have a lot of room for export development, Vietnam can increase output in the coming times to meet the demand of the world market. In addition, continuing to develop a variety of markets, including the domestic market, will also help agricultural products have a higher safety.

Apart from having smart access to the market, smart agricultural production also has a smart approach to using agricultural land resources. Depending on the specific conditions of nature, the use of land suitable for each type of crop and crop system has been reviewed by localities for transforming the crop structure in accordance with the advantages of the regions, localities, market demands, and climate change conditions. Since then, it has helped the agricultural industry harvest specialty agricultural products, with geographical indications such as Fragrant Rice (Hai Hau, Nam Dinh); Lo Ren star apple (Vinh Kim, Chau Thanh, Tien Giang); and green skin grapefruit (Ben Tre). By approaching alum soils and saline soils with smart farming methods such as grading and combining irrigation to sweeten the soil have not only served to grow rice but also fruit trees, vegetable crops, and colors. In places where land is difficult to improve, e.g., coastal areas, to achieve effective land use, smart agricultural production has changed farming methods according to models of combination such as rice-shrimp, shrimp-forest, and rice-fish. In addition, the smart approach to shifting from land-based production to technology-based production has also contributed to a significant increase in agricultural land use efficiency.

The water resource is considered an important factor in agricultural production. For a smart approach, Vietnam has adjusted its production structure from water-intensive crops to crops with less water demand. In economical use of water resources, Vietnam has gradually put technology into production. Examples include irrigation equipment connected to the internet operated via telephone and water storage technologies for saving water.

Agriculture is a sector directly affected by the weather, so climate-smart agriculture approach is a mode of agricultural production capable of mitigating and adapting to extreme changes of weather using the most optimal techniques in terms of economic, social, and environmental aspects accepted by farmers. Vietnam is currently applying an automatic warning system for earthquakes, floods, flash floods, and landslides; building a system of dikes to prevent floods and saltwater culverts; and leveraging adaptation solutions to switch seasonal frames to minimize damage caused by weather changes and extreme climates due to drought, salinity, floods, etc.

Combined with the warning system, using materials to reduce greenhouse gas emissions, or limit the leaching of nutrients that pollute and eutrophicate water sources such as biochar and organic fertilizers are also very smart farming methods that bring efficiency to agricultural production over time [8].

The smart agricultural production model with a smart approach applied in practice is bringing significant benefits to farmers, including smart and safe agricultural production models according to the cooperative chain of Muong Dong Cooperative, Kim Boi district, and Hoa Binh province. With a scale of 125 ha, the joint project of producing and consuming fruit trees in communes of Tu Son, Da Sang, Vinh Tien, Binh Son has helped farmers have land when participating in the project. The cooperative provides plant varieties, care techniques according to standards, while Vietnamese Good Agricultural Practices (VietGAP) help improve product quality during and after the harvest. In addition, many other cooperative units of Hoa Binh province have also implemented agricultural development according to the trend of linking production along the value chain and applying models such as growing organic vegetables and developing fruit trees in the direction of VietGAP. As a result, products of cooperatives and enterprises have been stamped with traceability. Dalat is known as a leader in building a fully automated hydroponic vegetable growing system, serving the supply of clean agricultural products and tourist attractions. The watering of Dalat flower gardens is using a completely pre-established automatic system including sensors that indicate humidity, the amount of water for irrigation, and the time of irrigation.

As a place that fully converges socioeconomic conditions to develop smart agriculture and apply high technology, Hanoi has now built 164 models of agricultural production applying high technology. The value of high-tech agricultural products accounts for about 35% of Hanoi's total agricultural production value. Hanoi's technologies and equipment for application selection are mainly smart in managing and controlling the farming environment to help reduce labor and increase the quality and output of agricultural products from the application of building membrane houses (net houses with automation systems in irrigation system control, fertilizing, adjusting humidity, temperature, and lighting). The monitoring system can analyze land, forecast yields, detect pests and diseases by applying technologies such as IoT, land-free technology, blockchain, and industrial-scale plant cell farming using drones for fertilization and disease prevention [8].

To develop smart agriculture, Vietnam needs to have a smart approach to the market, which is considered the most important requirement in agricultural production, because changes in market demand such as quality, volume, and time all directly affect production. Therefore, with a smart approach to the market, agricultural production must meet the criteria of what to produce, when and how much to produce, and where to sell it, on the basis of maximizing comparative advantages in terms of natural resources, climate, and people. In addition, when exporting to other markets, agricultural products also need to meet the requirements of the specific quality indicators of those markets. These are considered factors that play a decisive role in the orientation and production planning of each type of product.

In terms of global trade relations, in order to intelligently access the agricultural export markets, Vietnam's agricultural production, instead of increasing volume, needs to invest in deep processing for agricultural products that do not have much room for export. On the contrary, for products that still have a lot of room for export development, Vietnam can boost production and increase output in future to meet the demand of the world market. In addition, continuing to implement a variety of markets, including the domestic market, will also help agricultural products have a higher safety.

Currently, Vietnam is pursuing the trend of developing smart agriculture by using advanced techniques from Industrial Revolution 4.0 for high-tech agricultural production. Vietnam has already realized benefits of earlier developments such as mechanization, electrification, automation, nanotechnology, molecular biology, microbial technology, gene transfer, new materials, and new energy. New technologies being used in smart agriculture include IoT using sensors that collect accurate data on climate, growing conditions, and health of crops/animals; intelligent automation technology using robots and unmanned aerial vehicles to gradually replace humans in farming activities; and artificial intelligence (AI) and blockchain that have been applied to help improve productivity and control product quality throughout the supply chain. These technologies are not only geared to increased production and optimize resource usage, but also for reducing waste and ensuring traceability and food quality [9].

Results

According to a report by Ministry of Science and Technology (MOST), advances in science and technology contribute over 30% of added value in agricultural production and 38% in the production of plant varieties and livestock. The level of loss of agricultural products has decreased significantly (less than 10% in case of rice). The degree of mechanization at the stage of tillage for annual crops (rice, sugarcane, maize, vegetables) is about 94%; the rice harvest stage reaches 50% (the delta provinces reach 90%) [9].

On the contribution of science and technology to the development of the country's agriculture, many experts and scientists generally agree that science and technology play an important role in making effective contributions, creating breakthrough changes in agricultural production development, serving agricultural restructuring, and improving people's living standards.

According to a MOST report in 2019, thanks to the application of science and technology, the structure of agricultural production continues to be adjusted in the direction of promoting the advantages of each locality and region as well as the country as a whole, associated with domestic and international market demand, adapting to climate change. Many enterprises have invested in large-scale concentrated production zones with modern technologies associated with factories, storage, and processing facilities for agricultural products with high export value.

In the field of horticulture, the transformation of crop structure has been accelerated, and the application of advanced production processes has been promoted. Due to the good work in pest control, the output and quality of many crops have increased in economic value. The proportion of high-quality rice accounts for over 80% of exported rice, helping to raise the average export price of rice from USD502 per ton in 2018 to USD510 per ton in 2019. In particular, the ST25 rice variety was recognized as best rice in the world in 2019 at the 11th World Rice Trade Conference held in the Philippines.

The application of VietGAP is increasingly expanding and effective in bringing safe, good quality, and high yielding products. In addition, the expansion of application of scientific and technological advances to production, along with the results of research, evaluation, and deployment of a large sample field model, has boosted agricultural production and linked production and consumption of agricultural products along the value chain.

The forestry sector has had a remarkable development with a stable growth rate; mastered many advanced technologies; and created processing and preservation lines with quality equivalent to imported products. The forest product processing industry of Vietnam is ranked second in Asia and fifth in the world.

The livestock sector has seen a clear change in the organization of production, raising farms and ranches, focusing on closed chains, and applying advanced science and technology and high technology. Many organic farming models have been formed and are being popularized and replicated. Seafood processing technology is increasingly invested in modern technologies to meet the requirements of the international market.

Science and technology are being applied at all stages of the agricultural production process ranging from research, selection, and breeding of plants and animals to planting, tending, and cultivation techniques; use of fertilizers, plant protection drugs, and veterinary drugs; and processing and post-harvest preservation techniques. This has created new value for agricultural products, helping products to be fresh and safe, improving productivity, and ensuring quality standards.

These results have contributed to the rapid increase in Vietnam's agricultural export turnover over the years. In 2019, the total export turnover of agricultural, forestry, and fishery products was estimated at USD41.3 billion and the trade surplus of the whole industry was estimated at USD10.4 billion [10].

Limitations

However, Vietnam's agricultural labor productivity is very low, being only one-third of the industry's. The causes are discussed below:

(1) **The formulation of mechanisms and policies is generally slow and inconsistent, so the implementation faces many difficulties:** The work of developing specific guiding documents to implement the guidelines and policies of the Party and State is still slow, therefore it also slows down the actualization of the Party and State's guidelines and policies into actual production and life.

(2) **High-quality human resources are declining and the phenomenon of "brain drain" is increasing:** Human resources for science and technology in general and agriculture in

particular tend to decline in quality due to the lack of preferential policies for researchers, especially in the field of agriculture, where it is difficult for researchers to earn high income. As a result, the number of leading science and technology staff in the industry is increasingly lacking.

The slow implementation of transforming the operating mechanism of public science and technology organizations in the agricultural sector to a mechanism of autonomy and self-responsibility also has certain negative impacts, and contributes to this brain drain.

Moreover, a mechanism to attract oversea Vietnamese experts or foreigners to do R&D work at science and technology organizations in Vietnam is lacking.

(3) **The level of science and technology in agriculture in Vietnam is still low compared to the world, with insufficient attention to rural development research:** Although the technological level in the agricultural and rural areas of Vietnam is constantly being elevated (in some areas the development has been rapid to reduce the gap with the region), in general, the level is still low, especially in the field of mechanization and post-harvest technologies. The development and application of high technology in agricultural production is still limited.

(4) **Household economy with fragmented land in agriculture is a hindrance to the process of investment and application of science and technology in agricultural development:** In the early period of renovation, the household economy worked well for agricultural production. Today, when commodity agricultural production is increasingly developing, requiring high productivity, good quality, and high output, the household-economy model has become a hindrance to the investment and application of scientific and technological advances. This is due to fragmented land resources and lack of linkages in the organization of production and business. Due to the small portions of land, farmers are not interested in investing in applying science and technology advances. As the land is fragmented, the effectiveness of applying science and technology advances is also low, especially in the field of farming.

This is a major obstacle in terms of policy mechanisms that needs to be removed in the near future. There need to be policies on land accumulation for commodity agricultural production, stronger incentives for enterprises to invest in rural agriculture, and promotion of linkages between household economy and enterprises.

(5) **Funding for research is still low, yet spread out, so the efficiency is not high and technological breakthroughs have not been made:** The total funding for scientific research and technological development under state-level science and technology tasks in five years was only about USD100 million (USD20 million per year); the tasks of the Ministry of Agriculture and Rural Development reach USD22 million per year; and local-level tasks (63 provinces and cities) also only reach about USD30 million per year. Each state-level science-and-technology task is only VND3.8–4.0 billion on an average, while the tasks at ministerial, provincial, and city levels are many times lower.

Recently, many enterprises in the field of agriculture and rural areas have boldly invested in research of technology innovation to serve their business and production strategies.

However, the funding for research and implementation has not yet met their development requirements. The issue of mobilizing investment to increase funding for research and implementation in agriculture is still very limited.

Due to the lack of investment funds, the technical facilities in many agricultural research institutes are very outdated and do not meet the research requirements, especially for research in biotechnology and high technology in agriculture. This makes it very difficult to go strong in researching new and high technologies in agriculture.

Development of High-technology Applications in Agricultural Production in Vietnam

In implementing the Law on High Technology (2008), the Prime Minister had approved the National High-Tech Development Program until 2020 (Decision No. 2457/QĐ-TTg dated 31 December 2010, of the Prime Minister). The program consists of three components (Research, Training and Construction Program of high-tech infrastructure assigned to the Ministry of Science and Technology; Development Program for a number of high-tech industries assigned to the Ministry of Industry and Trade; and the High-Tech Applied Agriculture (HTAA) development program assigned to the Ministry of Agriculture and Rural Development).

The HTAA development program under the National High-tech Development Program until 2020 was approved by the Prime Minister in Decision No. 1895/QĐ-TTg dated 17 December 2012. The program includes the following main objectives: creating and developing high technology in agriculture; applying high technology in agriculture; and constructing and developing HTAA parks, forming and developing HTAA areas, and developing HTAA enterprises [11].

Implementation Results of the Prime Minister's Decision 1895/QĐ-TTg

For implementing the State's policy on promoting the application of high technology in agriculture for the modernization of rural agriculture, and for implementing the Law on High Technology, the Ministry of Agriculture and Rural Development has presided over and coordinated with ministries to review and finalize the legal framework, mechanisms, and policies. The goal is to attract organizations and individuals to apply high technology in agriculture, specifically as follows:

- Promulgate Circular No. 50/2011/TT-BNNPTNT dated 15 July 2011 on Guiding the implementation of Decision No. 69/2010/QĐ-TTg dated 3 November 2010 on authority, order of sequence, and procedure for recognition of high-tech agricultural enterprises;

- Formulate and submit to the Prime Minister for approval Decision No. 575/QĐ-TTg dated 4 May 2015 Master plan for high-tech agricultural parks and areas up to the year 2020, with orientation to 2030;

- Formulate and submit to the Prime Minister the Decision No. 66/2015/QĐ-TTg dated 25 December 2015 stipulating criteria, authority, order of sequence, and procedure for recognition of high-tech agricultural areas;

- Formulate and submit to the Prime Minister the Decision No. 19/2018/QĐ-TTg dated 19 April 2018 stipulating criteria, authority, order of sequence and procedure for recognition of high-tech agricultural enterprises (annul Circular 50/2011/TT-BNNPTNT, assigning the authority to recognize high-tech agricultural enterprises to the People's Committees of provinces and central cities);

- Formulate and submit to the Prime Minister the Decision No. 34/2019/QĐ-TTg dated 18 December 2019 stipulating criteria for determining projects, production and business plans for applying high-tech agriculture and supplementing list of high technologies prioritized for investment and development promulgated in conjunction with Decision No. 66/2014/QĐ-TTg (dated 25 November 2014) of the Prime Minister;

- Promulgate Resolution No. 499-NQ/BCSĐ dated 11 April 2018 of the Party Personnel Committee of the Ministry of Agriculture and Rural Development on promoting the application of high-tech agriculture for sector restructuring, toward improving added value and sustainable development;

- Promulgate Decision No. 1563/QĐ-BNN-KHCN dated 4 May 2018 of the Minister of Agriculture and Rural Development on the implementation plan of the Resolution of the Party Personnel Committee for promoting the application of high-tech agriculture for sectoral restructuring, toward improving added value and sustainable development.

- In order to continue promoting the development and application of high technology in agriculture, the Ministry has coordinated with the Ministry of Science and Technology to formulate and submit to the Prime Minister the Decision No. 130/QĐ-TTg dated 27 January 2021 promulgating the National High-tech Development Program to 2030. The Minister of Agriculture and Rural Development has approved the framework of the component programs for developing high-tech agriculture (Decision No. 3070/QĐ-BNN-KHCN dated 14 July 2021).

- Participate in and coordinate with ministries formulating relevant documents to promote the development of high-tech agriculture.

Implementation Results of the HTAA Development Program

Regarding the development of high-tech agricultural areas: In implementing Decision No. 66/2015/QĐ-TTg dated 25 December 2015 stipulating the criteria, authority, order of sequence, and procedure for recognition of hi-tech agricultural areas, local authorities have recognized 18 such areas, including Van Thanh high-tech flower production area; Thai Phien high-tech flower production area; Lac Xuan high-tech vegetable production area; Lac Lam high-tech vegetable production area; Don Duong District high-tech dairy farming area; Trung An Kien Giang high-tech rice area for rice cultivation and export; Trung Son Kien Giang high-tech agricultural area for aquaculture and seafood processing; Minh Phu Kien Giang high-tech aquaculture area; Vifaba banana high-tech agricultural area; high-tech agricultural area of Nam Viet-Binh Phu Aquaculture One Member Company Limited; Loc An high-tech shrimp farming area; high-tech aquaculture breeding production area in Xuan Hai commune, Song Cau town, Phu Yen province; high-tech rice production area; high-tech coffee production area; high-tech black pepper production area of Thuan Hanh, Dak Song, Dak Nong; high-tech black pepper production area of Thuan Ha, Dak Song, Dak Nong; high-tech tea production area; and high-tech agricultural area of Ea Tan-Krong Nang-Dak Lak.

Planning and construction of high-tech agricultural parks: In implementing Decision No. 575/QĐ-TTg of the Prime Minister on the master plan for high-tech agricultural parks and areas up to

2020, with a vision for 2030, out of 11 HTAA parks approved by the Prime Minister till 2020, five were established by the Prime Minister's decision. These included Hau Giang high-tech applied agricultural park, Phu Yen high-tech applied agricultural park, Bac Lieu high-tech shrimp development park, Thai Nguyen high-tech applied agricultural park, and Quang Ninh high-tech applied agricultural park. Also, the Prime Minister approved the establishment of the North Central High-tech Applied Forestry Park according to the development strategy of the forestry sector.

Some regions (Ho Chi Minh City, Khanh Hoa in the plan according to Decision 575/QĐ-TTg) have proactively invested in park infrastructure, put it into operation effectively, and have not submitted to the Prime Minister to establish the park with capital from the central budget.

According to the Master plan (Decision 575/QĐ-TTG), only five out of 11 parks had been approved and established by 2020, of which two parks had been approved before planning. Some parks were established early, but could not be deployed and have not been able to attract investments so far.

Developing high-tech agricultural enterprises: In implementing the Prime Minister's Decision No. 69/2010/QĐ-TTg and Decision No. 19/2018/QĐ-TTg of the Prime Minister, up to now, 68 agricultural enterprises have been recognized as HTAA enterprises in fields including crop, breeding, and aquaculture.

In response to the policy of the Party and the Government on the application of high technology in agriculture, many cooperatives have deployed high-tech agriculture. By the end of May 2021, the country had established 1,916 high-tech applied cooperatives.

Current status of carrying out science and technology tasks for the development of high-tech applied agriculture: The program has conducted research, transferred to production, focused on application of new technologies (automation technology, semi-automation technology, biotechnology, and information technology) on key plantlets. By implementing the project with partial financial support from the State, enterprises have proactively mobilized their capital to apply advanced technologies at each stage of the production process, imported technologies in processing and preserving agricultural products, and formed a chain of connections with farmers to build a product value chain that meets quality standards. Many projects have created a ripple effect in the province and in the region.

Under the program, 21 technical advances have been created and many technological procedures have been effectively applied and transferred into production. By participating in the program, many HTAA enterprises and farms have mastered technological procedures, reduced their product costs, replicated technological procedures, transferred to producers in all fields on key plantlets, increased productivity, and enhanced production on industrial scale:

- In cultivation, the hot steam treatment to get rid of Tephritidae fruit flies on star apples has allowed the star apple export to expand to rigorous markets such as Europe, Japan, and New Zealand; strawberry breeding and production has helped reduce costs and replace imported strawberry products for domestic consumption; and advanced rice farming techniques have helped farmers reduce costs, save production costs, improve quality, and increase income for rice farmers in the Ca Mau peninsula. There have been improvements in production procedures of cantaloupe, cucumber, lettuce, and chrysanths using semi-automation technology in the greenhouse; production procedures of cantaloupe, cucumber, lettuce using automation and semi-automation technology in Dak Lak and Dak Nong; breeding procedures of disease-free sugarcane at three industrial levels; sugarcane production procedure using economical watering technology combined with automatic fertilization; asparagus propagation, cultivation, and harvest procedure with high technology application; and disease-free citrus fruit breeding procedure with increased yield and fruit/vegetable quality. At the trial production scale, over 175 ton of certified high-quality rice varieties have been produced and sold; over 1.58 million disease-free strawberry varieties have been produced and sold; over 10 million eucalyptus-acacia hybrid trees have been produced and sold using tissue culture technology; over 4 million chrysanthemum seedlings, 2.4 million lettuce seedlings, 258,000 cantaloupe seedlings, and 166,000 cucumber seedlings have been produced and sold; and 140,000 green asparagus seedlings qualified for export have been produced and sold at a reduced cost of 50% and more, utilizing advanced technology to produce over 120,000 disease-free citrus fruit trees for production. Two new maize varieties have been created with double haploid technology (thịnh vượng 9999 maize variety, VS89 maize variety, both of which have been licensed to enterprises), and over 90 hectares of new varieties have been produced to expand production.

- In forestry, eucalyptus-acacia hybrid breeding procedure has resulted in 3 million trees per year.

- In animal husbandry, the artificial insemination technology using sex-sorted sperm has achieved a conception rate of 47% for imported frozen sperm, 44% for self-produced frozen sperm, and 52% for fresh sperm; 2000 sex-sorted embryos have been produced and 600 calves were born from sex-sorted embryos, of the same quality as imported embryos, with a selling price at least 15% lower than that of imported embryos; 100 sows and 10 males of two purebred yorkshire and landrace sow lines have been created with the number of live newborns per litter being 12.5 or more and the number of weaned newborns being 27 calves/sow or more per year; 50 sows and 10 duroc purebred males have been created with a growth rate of 30–100kg $\geq$ 1,000g per day; and 100 sows have been mated between yorkshire and landrace.

- In fishery, tuna preserving procedure with UFB nanotechnology was implemented on fishing vessels, transferring UFB technology application on nine ocean tuna fishing vessels, thereby improving the value of Vietnamese tuna. Super-intensive two-level farming procedure of commercial whiteleg shrimp combined with biofloc led to a yield of 100 ton and more per ha per year (FCR $\leq$ 1.0, survival rate $\geq$ 80%). With intensive shrimp farming procedure using micro-nano bubble oxygen technology, survival rate increased by $\geq$10%, FCR decreased by 15%, and production cost decreased by at least 10%. Around 800 ton of commercial whiteleg shrimp have been produced using multi-level farming technology combined with biofloc technology, with food safety ensured. Application of micro-nano bubble oxygen technology has led to a production of 220.57 ton of commercial whiteleg shrimp and 60.4 ton of pangasius catfishes, with food safety ensured.

- In preservation and processing, there has been design and manufacture of equipment system and procedure for banana ripening by ethylene gas to ensure nutritional quality, appearance, and food safety, with technological ripeness of 97% and above. With design and manufacture of equipment system and procedure for banana puree production using synchronous equipment line, with a capacity of 3 ton of raw material per hour, over 500 ton of banana puree have been produced that meets EU standards.

At the same time, the Ministry of Agriculture and Rural Development has integrated the task of developing and applying high technology in agriculture through program such as biotechnology in agriculture and aquaculture, biotechnology application in processing, the State's Science and Technology Program, and several ministerial-level tasks of research and development of high technology in agriculture [11].

Program Implementation Result Evaluation: Pros

- After the Law on High Technology, Decision 2457/QD-TTg, and Decision 1895/QD-TTg were promulgated, the Party and Government have continued to direct and finalize the support policy system to attract enterprises, organizations, and individuals investing in the development of high-tech agriculture. Local regions have proactively developed mechanisms and policies specific to the province to attract investment from HTAA development enterprises for agricultural production with high efficiency and sustainability. Mechanisms and policies have contributed to the growth and development of the agricultural sector during 2015–20.

- In fact, the HTAA development program has brought about very high efficiency and pervasiveness and various HTAA production areas have been formed, though not yet been recognized by local authorities. Many regions have proactively attracted enterprises, individuals, and farms to invest in high-tech applications to reduce costs and increase agricultural product value; and several enterprises have connected with farmers, cooperatives, and cooperative groups to expand the HTAA production model on a larger scale.

- Advanced technologies have been utilized at each stage or in the entire production chain to bring high added value to agricultural products, thereby promoting the construction of HTAA areas. Specifically, the use of biotechnology has contributed to the creation of various high-yielding and high-quality resistant varieties of plants and animals; in-vitro technology in industrial-scale plant breeding has helped reduce the cost of plantlets; many biological products have been researched and applied to agricultural production to provide nutrients for plants and animals and to limit disease outbreaks; and multiple enterprises and individuals have taken the initiative to approach, import, and master new technologies, and to apply automation, semi-automation, and information technologies to bring high economic efficiency to agricultural production (vegetable and flower production in greenhouses for vegetables, revenue reached 2.5 billion to 9 billion dong per ha, profit reached 1.6 to 4.9 billion dong per ha, for flowers, revenue reached 0.5 billion to 9.9 billion dong per ha, profit reached 0.3 to 5.4 billion dong per ha). These technologies have also helped improve productivity and quality of whiteleg shrimp (yield reached 40 ton per ha, 40 times higher than mass production, while production cost reduced by 30–35%) as well as that of dairy production (milk yield of over 30 liter per cow per day, with good quality) [11].

Program Implementation Result Evaluation: Cons and Causes

- Legal documents are inconsistent and unable to keep up with the development of practical requirements. The Law on High Technology was promulgated in 2008 and has not been amended or supplemented after 13 years of implementation. Besides this law, there are no guiding documents of high legal status like decrees but mainly individual Decisions of the Prime Minister. There are no documents specifying the order of sequence and procedures for the establishment of parks or recognition of areas and enterprises. There are no specific guidelines and mechanisms for preferential policies for parks established by local regions and enterprises with local budgets and socialization sources.

- High technologies' applications in agriculture are mainly concentrated in a few areas, in some strategic products, and in some large enterprises. High-tech agricultural parks have been decided by the Prime Minister (four parks) mostly focusing on production; and other functions such as research, transfer, and product promotion have not received proper attention. Thus, they are unable to promote their roles as centers of ripples, i.e., to promote the development of science and technology applications in agricultural production of the regions.

- At present, many provinces wish to establish their own HTAA parks (e.g., Gia Lai, Kon Tum, Long An, Binh Duong, and Quang Ninh province with three parks). HTAA parks are diverse in form (e.g., state-invested, enterprise-invested), some of which are invested and assigned to enterprises before they are established. The capital for investment in general infrastructure of the parks comes from a mix of central budget, local budget, and enterprise capital. Most regions have prepared to build on land planned for agricultural and forestry and not yet planned to build HTAA parks. Moreover, local HTAA parks are functionally insufficient as prescribed by the Law on High Technology to ensure the desired objectives.

- Some regions have confused the construction of HTAA parks according to the Law on High Technology with the formulation of production investment projects according to the Law on Investment, thereby leading to low feasibility of land and investment in planning in Decision 575/QĐ-TTg.

- The State has various policies on taxes, land use levies, and credit incentives to encourage enterprises to develop high-tech applications and production and concentrated commodity production areas (the HTAA areas). However, at present only 12 HTAA areas and 49 enterprises are recognized as HTAA enterprises (according to the decentralization of the Prime Minister). Recognized HTAA areas and enterprises may enjoy policies on the basis of existing production, based on the needs of production, but policies specific to high-tech applied agriculture have not been distinctive, i.e., not much different from investments in agriculture and rural areas in general.

- Newly established HTAA parks have insufficient resources for scientific and technological research, and other public scientific organizations have been unable to create many highly efficient products and technologies transferrable to agricultural production. There have not been many high technologies owned and imported by institutes and universities abroad. On the other hand, the transfer of scientific and technological results into production is still inadequate, limiting the effect of science and technology on production. There is a lack of close connection between scientists, enterprises, and the people, so it is necessary to establish a binding and cohesive mechanism for the harmonious interests of the parties in their common interest.

- The high-tech application models in agricultural production are still small-scale and unevenly distributed, and the production scale is not large enough to create centralized administration, thus causing difficulties in investment and management.

- Although the State and the Government have established various preferential credit policies for agriculture and rural areas in general, and high-tech agriculture in particular (Decree 55/2015/NĐ-CP and Decree 116/2018/NĐ-CP), agricultural production has always faced a multitude of potential risks due to natural disasters, epidemics, unstable markets, small production scale, limited production, and financial capacity, while still lacking instruments to prevent and limit risks (such as agricultural insurance). The access to credit capital of organizations and individuals in agricultural production still encounters multiple difficulties and challenges in terms of loan procedures, unsecured loans, and loans with collaterals [11].

Program Planned for 2022–30

In implementing Decision 130/QĐ-TTg, the Department of Science, Technology and Environment has prepared the High-tech Applied Agriculture Development Program under the National High-tech Development Program to 2030 and submitted it to the Minister of Agriculture and Rural Development in Decision No. 3070/QĐ-BNN-KHCN.

Objectives

General objectives: Research, master and develop high technology; effectively apply high technology in agriculture; contribute to the successful implementation of agricultural sector's restructuring plan; and develop a comprehensive agricultural plan toward modernization and mass production with added value and high competitiveness. Also, form and develop a number of high-tech applied agricultural parks, areas, and enterprises.

Specific objectives:

- Develop and master several high technologies on the list of high technologies prioritized for development and investment in agriculture and effectively apply them to high-tech agricultural production on a large scale. Create and put into production at least 8–10 key plant and animal varieties with high yield, good quality, and outstanding resistance; 8–10 advanced technological procedures; and 8–10 new biological products, materials, machinery, and equipment for agricultural production.

- Promote the application of advanced technologies to produce several agricultural products with high added value; contribute toward bringing the value ratio of agricultural products utilizing high technology to over 20% by 2025 and 30% by 2030; and accelerate the growth rate of productivity in agriculture, forestry, and fishery to an average of 7–8% per year.

- Contribute to the construction and development of 200 high-tech applied agricultural enterprises with cooperation and connection in production chains from production to processing and consumption of agricultural products nationwide.

- Contribute to the construction and development of 30 high-tech applied agricultural areas in agro-ecological parks.

Main Content and Tasks

Research, master, and develop high technologies prioritized for development and investment and the high-tech products recommended for development:

- Research, master, and develop high technologies prioritized for investment and development in the selection and breeding of key plants and livestock as well as diagnosis, assessment, forecast, and control of pests in plants, livestock, and aquatic products.

- Research, master, and develop agricultural production procedures in a closed chain on the basis of information technology and automation technology applications. Research and apply high technology in the production of additives and for processing and preserving agricultural, forestry, and fishery products with high added value on industrial scale.

- Research, master, and create supplies for high-tech agricultural production in cultivation and forestry (fertilizers, biological plant protection drugs, growth regulators, agricultural/forestry product preservative preparations, treatment of waste byproducts, and growing media); and in animal husbandry and aquaculture (disease diagnostic kits, vaccines, animal feeds, aqua feeds, disease prevention/treatment preparations, and environmental treatment).

- Research, master, and manufacture machinery and equipment substituting imports for cultivation (agricultural machinery suitable to Vietnam's production scale and conditions, greenhouses, cover nets, irrigation systems, equipment for care, harvesting, preliminary processing, preservation, ventilation system in preliminary processing and preservation of products, etc.); forestry (machinery for planting, tending, harvesting, processing and preserving timber, non-timber forestry products, etc.); and livestock and aquaculture (house frame, lighting system, food distribution system, harvesting, preliminary processing, cold storage, automatic control system, waste treatment system, circulating water regulation system, etc.).

- Research, master, and develop technologies for forecasting, storing, and making use of water sources; water storage to provide stable, efficient water for multiple purposes; filtering and supplying fresh water to saline soil, coastal soil, and islands; managing and operating irrigation works and rural water supply system; and safely managing dams and water reservoirs in forecasting and warning about water quality changes in irrigation works [11].

Application of High Technology in Agriculture

(1) Develop and implement transferring and mastering high-tech agriculture technologies prioritized for development and investment and high-tech products recommended for development.

Focus on supporting the application of high technology in projects (of varied scales) for the development of brands of national key agricultural products, provincial key products, and local specialty products; creating agricultural products with high quality, outstanding features, high added value, environmental friendliness, and traceability; and supporting applications of high technology to develop products that can replace imported products. Specifically, in cultivation, focus on industrial-scale plant variety production and wide application of new plant varieties with high yield, good quality, and resistance to pests and diseases; breeding and production of edible mushrooms and medicinal mushrooms on industrial scale; production and application of biological products, diagnostic kits, new generation fertilizers, biological pesticides, and growth stimulants on industrial scale; and application of automation and information technology in high-tech agricultural production, focusing on a number of key subjects with high competitive advantages.

In forestry, focus on rapid propagation and industrial-scale production of several new varieties of forestry plants, non-timber forest products, and new medicinal herbs; economic forestation by intensive farming method utilizing high technology; application of materials and nanotechnology to improve the mechanical and biological durability of fast-growing plantation timber; production of new bio-composite materials from wood and fibrous plants; application of information technology and remote sensing technology in forest management and protection.

In animal husbandry and veterinary medicine, focus on development of new high-yield and high-quality key livestock lines and breeds, such as cows, pigs, and poultry; application of automation technology, information technology, and artificial intelligence in raising poultry, pigs, and cows; production and application of biological products, animal feeds, vaccines, and new kits used in animal husbandry and disease prevention.

In aquaculture, focus on rapid propagation and production of key aquatic breeds with high productivity and quality such as black tiger shrimps, whiteleg shrimps, freshwater fishes, marine fishes, and bivalve molluscs; intensive farming, super-intensive farming, automatic control, and environmental treatment with advanced technologies (chemical fog, biofloc, bio filtration, etc.); production of feed, sex hormones, medicines for prevention and treatment of aquatic diseases, as well as production of quick diagnosis kits; application of information technology in planning, management and exploitation of marine resources and aquaculture areas; long-term preservation of aquatic products on fishing vessels; and aquatic product processing with high added value.

In the production of supplies and machinery for agriculture, focus on application of automation technology to produce all kinds of supplies, machinery, and equipment for agricultural, forestry, and aquaculture production.

In irrigation and disaster prevention, focus on application of automation technology and information technology in management, exploitation, and operation of irrigation works, rural water supply system, and safety management for dams and reservoirs; natural disaster forecast related to water (drought, saltwater intrusion, flood, inundation, waterlogging); forecast and warning of water quality changes in irrigation works; and production of new supplies, equipment, and construction of irrigation works.

(2) Assist enterprises and science and technology organizations in deploying high-technology applied agricultural projects based on research results of scientific and technological tasks at all levels that have been accepted; technology transfer agreements or science and technology cooperation agreements; and manufacturing products in the list of high-tech products recommended for development in agriculture. Assist in research activities, technology transfer, and intellectual property rights to use research results and promote close connection between enterprises and science and technology organizations.

Build and Develop High-tech Applied Agriculture

(1) Coordinate and assist provinces and central cities in implementing Decision No. 19/2018/QĐ-TTg of the Prime Minister, dated 19 April 2018, stipulating criteria, authority, and order of sequence; implementing procedure for recognition of high-tech applied agricultural enterprises; and promoting the development of high-tech agricultural enterprises.

(2) Coordinate and assist provinces and central cities in implementing Decision No. 66/2015/QĐ-TTg of the Prime Minister, dated 25 December 2015 stipulating criteria, authority, and order of sequence; procedure for recognition of high-tech applied agricultural areas; and effective application of research results in the development of high-tech applied agricultural areas.

(3) Coordinate and assist provinces and central cities to create favorable conditions for agricultural enterprises utilizing high technology to participate in the global supply chain and build and develop high-tech applied agricultural areas.

(4) Coordinate and assist provinces and central cities in developing high-tech applied agricultural parks according to regulations; operating them effectively; and promoting the core role of high-tech applied agricultural parks.

(5) Integrate agricultural development tasks with high-technology applications in science and technology programs at ministerial levels, variety production, research and development programs for agricultural sector restructuring in the 2021–30 period, and other science and technology programs.

Implement High-technology Tasks and Solutions

Implement high-tech tasks and solutions to promote the application of high technology in agriculture specified in Section III of the Prime Minister's Decision No. 130/QĐ-TTg dated 27 January 2021:

(1) Create process documents: Continue to review and finalize legal documents in order to promote research, mastery, and development of high technology and effective application of high technology for the development of high-tech applied agriculture.

(2) Promote international cooperation in high technology, and assist science and technology organizations and agricultural enterprises in international cooperation activities for research, mastery, application, and development of high technologies.

(3) Raise social awareness about the role and impact of high technology: Coordinate with ministries and local authorities in organizing activities to disseminate and raise awareness in the society, organizations, and enterprises on research results and achievements and high technology's application in agricultural development; and organize conferences, seminars, and forums on agricultural development through high-technology applications with the participation of domestic and foreign organizations and individuals.

Recommendations

Laws and policies on development of high-tech agriculture (Law on High Technology) should be reviewed and amended to promote application of technology to create high-value products:

(1) High-tech agricultural areas have not been institutionalized in the Law on High Technology. So, it is necessary to categorize the type of HTAA areas in the Law to provide policies to support and promote the formation of high-tech applied agricultural areas with production scale suited to the characteristics of the region. This should be based on the principle that the state invests in general infrastructure, while organizations and individuals invest in production, thereby ensuring coherence in large-scale production.

(2) Limit construction of HTAA parks going rampant, aimless, and unable to create breakthroughs or promote large-scale production, productivity, and high quality according to regional scale, thereby causing wastage of resources.

(3) Financing capital for high-tech agriculture is very important. Therefore, it is necessary to establish policies to create favorable conditions for organizations and individuals engaged in high-tech agricultural production to get access to capital associated with insurance policies. This will balance and share risks and interests between credit institutions and organizations and individuals engaged in high-tech agricultural production.

(4) It is necessary to develop appropriate mechanisms and policies to encourage individuals and enterprises to invest capital in HTAA business compared with general agriculture and rural areas in tax, land, development planning, etc.

(5) Establish proper sanctions to ensure compliance with planning for high-tech agricultural development, in line with national general planning, regional planning, provincial planning, stability, and sustainability.

(6) Adopt policies to encourage import, transfer, and mastery of new and advanced technologies from abroad that are unavailable in Vietnam.

(7) Apply productivity indicators to promote sustainable agricultural modernization policies.

These measures include investing in research and development and agricultural encouragement. Science-based technology gives producers the tools to prepare for and recover from pest outbreaks, extreme weather events and market volatility. Physical infrastructure, information infrastructure, and efficient financial infrastructure provide producers with fair and equitable market access and facilitate economic growth. Also, public–private partnerships transfer technologies and knowledge that are appropriate to the environment and the society for producers.

Reducing post-harvest losses and food wastage can increase food availability, lower food prices, and support healthy ecosystems. Specific guidelines and solutions will be needed to better implement the goal of bringing science and technology into agricultural production and rural development in the coming period.

Case study: High-tech Criteria for Rice and Vegetable Production in Two Districts of An Giang

Research Summary

An Giang is one of the provinces with the largest agricultural production areas for rice and vegetables in the Mekong Delta. In recent years, the province has promoted development of high-tech applications in agricultural production and obtained very positive results. However, high-tech application in agricultural production still has many difficulties and inadequacies such as large initial investment costs; problems of land accumulation and infrastructure in rural areas; resources; unstable product consumption market; and limited production experience.

Therefore, the Research Institute for Climate Change did a study to evaluate the importance of criteria in production of rice (Thao Son District) and vegetables (Chau Phu District) with high-tech application in An Giang province.

According to the study by the Research Institute for Climate Change (2017), main research methods such as farmer interviews, document synthesis and inheritance, MCE multi-criteria assessment, etc., have been applied to find out high-tech criteria and targets that farmers focus on the most [12].

This can be a reference for the APO to do a review of the productivity tool for sustainable agricultural development.

System of Theoretical Bases

The first basis for development of high-tech rice and vegetables production areas for Thoai Son District and Chau Phu District is formed of the policies and legal documents that stipulate standards and criteria for agricultural production areas with high-tech application. The criteria are provided in documents specified in Table 1.

The results of synthesis and evaluation of criteria for high-tech agricultural production show that regulations that are the criteria in high-tech agricultural production (see Table 1) have not been concretized. For example, products must be linked with value chains, cooperatives, or cooperative unions; high-tech agricultural production areas must be specialized cultivation areas with contiguous areas and land plots; the minimum area for rice and safe vegetables should be 100 ha, but, for the current practical conditions, the area for cultivation is of a small scale; infrastructure has not been completed; conditions of production organizations and operation of cooperatives are inefficient; and technology is not highly developed, especially in the post-harvest stage. In addition, regulations on quotas also affect implementation of criteria on high-tech agriculture, while suitability of natural conditions has not been used. Regarding varieties, at present, places that produce good-quality varieties are limited, and have not been developed and spread. Therefore, in order to develop high-tech agriculture for rice and vegetable production, it is necessary to have specific development criteria in terms of nature, technology, economy, society, and environment, having influences on production.

Based on the system of theoretical bases and synthesis of studies, the results have identified criteria for high-tech application in production of rice in Thoai Son District and vegetables in Chau Phu District, and are classified by levels (see Table 2).

TABLE 1

CRITERIA FOR HIGH-TECH AGRICULTURE IN LEGAL DOCUMENTS [12].

No.	Targets of high-tech agriculture	Regulation
1	Technologies that are prioritized for development, e.g., information technology, biotechnology, new material technology, and automation technology. Developments in varieties selection, disease prevention, efficiency improvement in agricultural production, agricultural equipment creation, and preservation and processing. Also, development of high-tech application enterprises, and development of agricultural services. Agricultural products with high quality, productivity, value and efficiency. Application of environmentally friendly, energy-saving measures. Development of human resources.	Law No. 21/2008/QH on High Technology dated 13 November 2008. Decision No. 1895/ND-TTg dated 17 December 2012.

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No.	Targets of high-tech agriculture	Regulation
2	Determination of criteria for high-tech agricultural production areas. Organized production and consumption of products that are linked as per the value chain; focal organizations such as enterprises, cooperatives, and cooperatives unions that operate in the area and sign contracts to implement value chain linkages in agricultural production in the area. Products produced in the area (commodity products with advantages of the area), with product groups focused on: Plant varieties, livestock breeds, aquatic breeds with high yield, quality and outstanding tolerance. Agricultural, forestry, and fishery products with added value and high economic efficiency, with quality meeting international, regional, or national standards (Viet GAP). Applied technologies include biotechnology for selection, breeding, and disease prevention of plants and animals; technology of intensive farming, super intensive farming, and deep processing to increase added value; automation/ semi-automation technologies; and information technology, remote sensing, etc. Technology is applied on an industrial scale, improving production efficiency, increasing product value, and increasing labor productivity. High-tech agricultural area is a specialized cultivation area with contiguous area and land plot within the administrative boundaries of a province; has suitable natural conditions; relatively complete technical infrastructure in terms of traffic, irrigation, and electricity; and is convenient for commodity production, in line with the master plan for agricultural production development of the sector and locality. Objects of production and scale of the area include production of flowers with minimum area of 50 ha; production of safe vegetables with minimum area of 100 ha; production of rice varieties with minimum area of 100 ha; breeding and production of edible and medicinal mushrooms with minimum area of 5 ha; and production of perennial fruit trees with minimum area of 300 ha.	Decision No. 66/ QD-TTg dated 25 December 2015.

Source: [12].

TABLE 2

LEVEL 1 AND LEVEL 2 CRITERIA FOR PRODUCTION OF RICE AND VEGETABLES WITH HIGH TECHNOLOGY IN THOAI SON AND CHAU PHU DISTRICTS.

No.	Level 1 criteria	Level 2 criteria
1	Technical	Plant varieties
		Land preparation
		Cultivation method
		Water management
		Applied technique
		Production type
		Processing and preservation
		Harvesting method

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No.	Level 1 criteria	Level 2 criteria
2	Economy	Consumption market
		Investment cost
		Profit
3	Society	People's knowledge
		Management capability
		Social infrastructure
		Consultants
		Land ownership
		Labor force
		Environment treatment
		Supporting policies
4	Environment	Land degradation
		Biodiversity
		Pandemic

Determination of Interest Level in Basic Criteria for Rice and Vegetable Production

The importance of technical, socioeconomic, and environmental aspects for rice and vegetable production in the research region is evaluated using the multi-criteria evaluation (MCE) method. With this approach, the assessment of the significance of the components is done on weight (W) value. The weight increases as the criteria become more significant. W has a value between 0 and 1, with 1 denoting the most significant and 0 the least. There are five classifications for significance levels: very low, low, moderate, high, and very high.

In the production of rice and vegetables with high-technology application, the factors that are concerned and identified are applied technique, economic level, social requirements, and environmental impact factors. Each factor and the components of each factor are examined and evaluated according to each level of influence through an assessment of experts, direct farmers, and farm workers in the area. The results of expert interviews including managers, scientists, and people directly involved in rice and vegetable production and knowledgeable about high-tech agricultural production in Thoai Son and Chau Phu districts show that technical factors are considered to be the most important for both rice and vegetable production models (w=0.52 and w=0.5), followed by economic, social, and environment factors (see Table 3).

TABLE 3

IMPORTANCE OF TECHNICAL, ECONOMIC, SOCIAL, AND ENVIRONMENTAL FACTORS.

No.	Model	Technical	Economy	Social	Environment
1	Rice production (Thoai Son)	0.52	0.25	0.15	0.08
2	Vegetables production (Chau Phu)	0.50	0.31	0.12	0.07

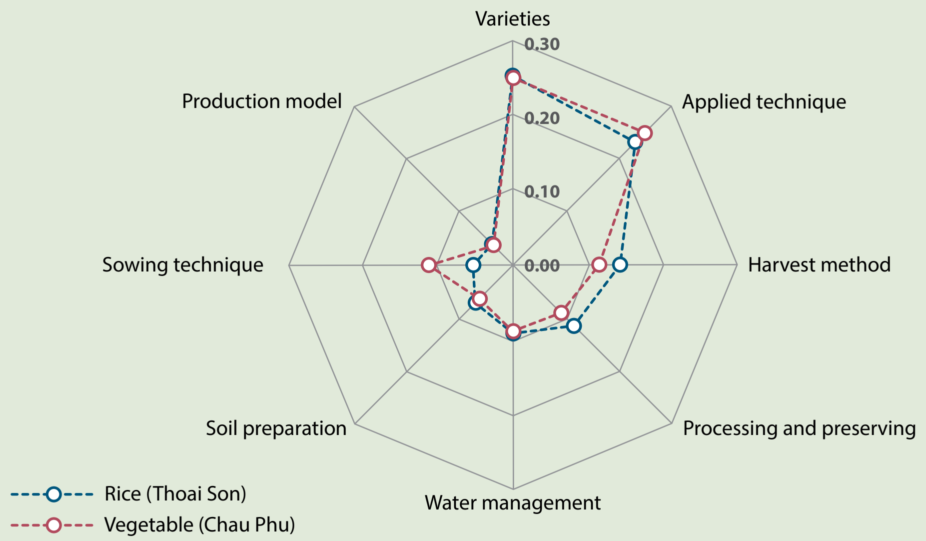
Source: [12].

The results of expert interviews show the importance of factors affecting high-tech rice and vegetable production models in Thoai Son and Chau Phu districts of An Giang province. Regarding the technical factors, the experts rated the "seeds" factor as having the highest importance and the "production type" factor as having the lowest importance for both types of rice and vegetable high-tech applications.

Regarding economic factors, interview results show that the consumption market factor in high-tech rice and vegetable production will have the highest importance, if the market is stable. The decision will help people feel secure to cultivate and not be afraid of losses when the initial investment is large.

FIGURE 5

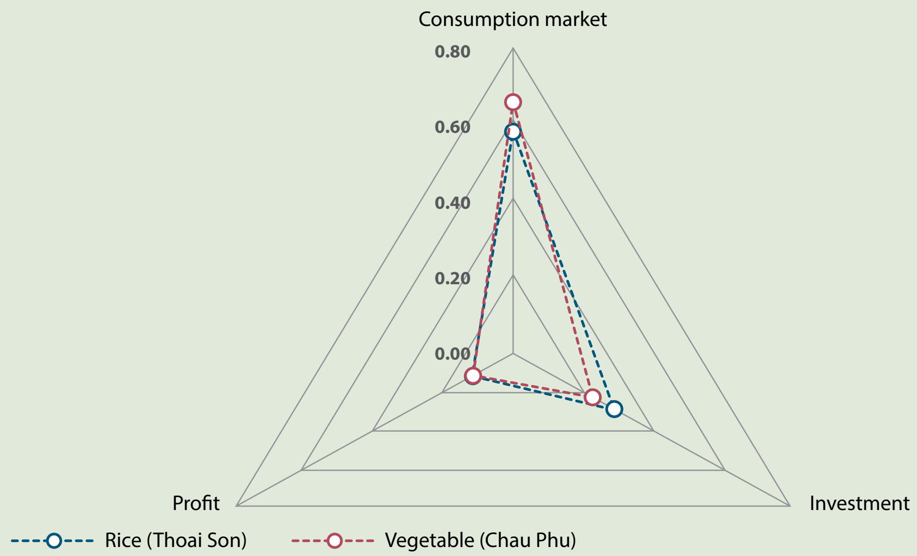
EVALUATION OF PARAMETERS PERTAINING TO TECHNICAL CONDITIONS.



Source: Research Institute for Climate Change.

FIGURE 6

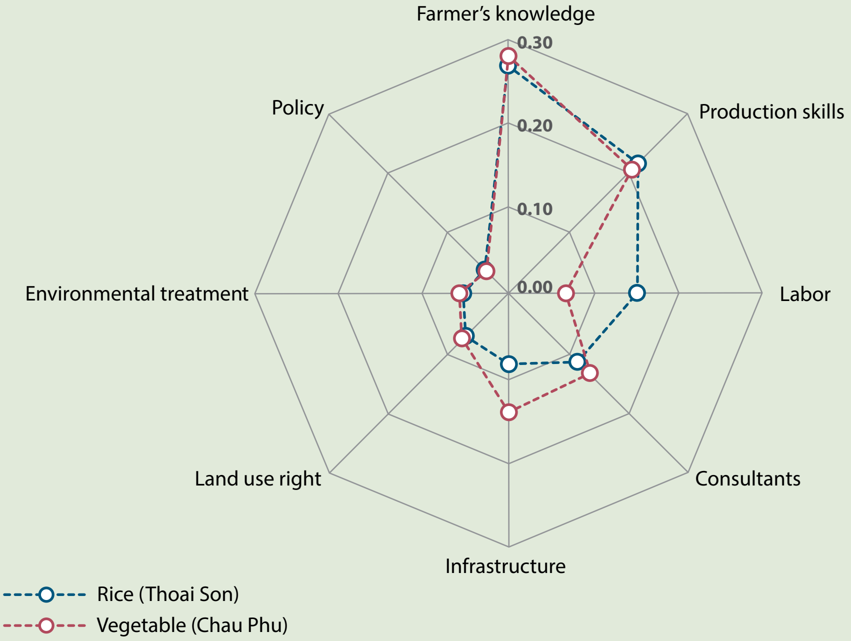
EVALUATION OF PARAMETERS PERTAINING TO ECONOMIC CONDITIONS.



Source: Research Institute for Climate Change.

FIGURE 7

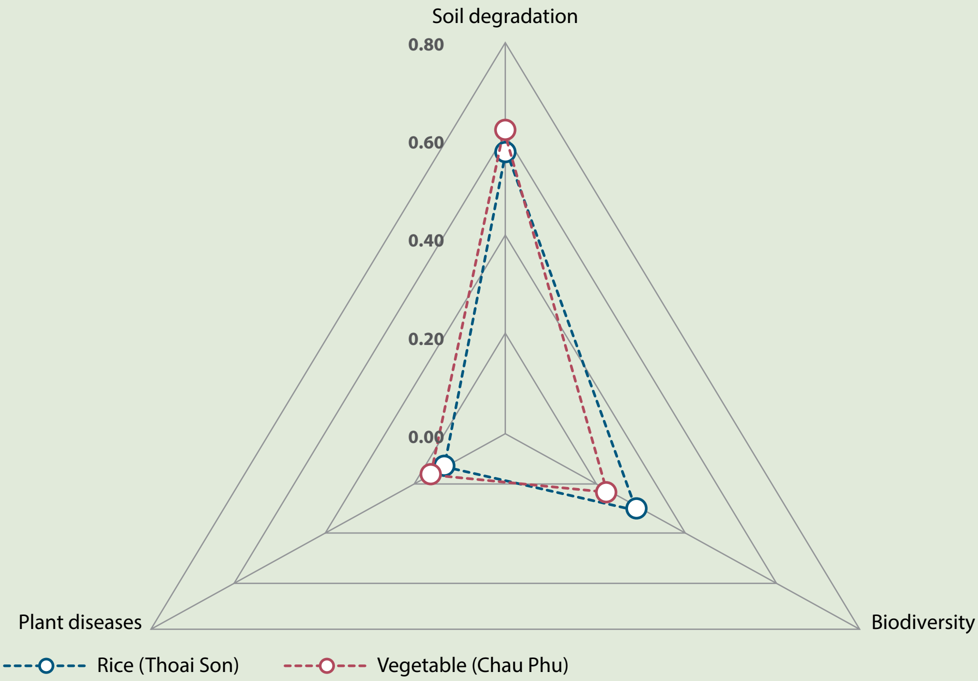
EVALUATION OF PARAMETERS PERTAINING TO SOCIAL CRITERIA.



Source: Research Institute for Climate Change.

FIGURE 8

EVALUATION OF PARAMETERS PERTAINING TO ENVIRONMENTAL INDICATORS.



Source: Research Institute for Climate Change.

TABLE 4

WEIGHTS OF FACTORS AFFECTING HIGH-TECH RICE AND VEGETABLE PRODUCTION.

No.	Level 1 factor	Level 1 factor weight (W1)		Level 2 factor	Level 2 factor weight (W2)		Overall factor weight (W=W1*W2)	
		Rice	Vegetable		Rice	Vegetable	Rice	Vegetable
1	Technique	0.52	0.50	Soil preparation	0.07	0.06	0.04	0.03
2				Varieties	0.26	0.25	0.13	0.13
3				Sowing technique	0.05	0.11	0.03	0.06
4				Water management	0.09	0.09	0.05	0.04
5				Applied technique	0.23	0.25	0.12	0.13
6				Production model	0.04	0.04	0.02	0.02
7				Processing and preserving	0.11	0.09	0.06	0.04
8				Harvest method	0.14	0.11	0.07	0.06
9	Economy	0.25	0.31	Consumption market	0.59	0.65	0.15	0.20
10				Investment cost	0.29	0.23	0.07	0.07
11				Profit	0.12	0.12	0.03	0.04
12	Society	0.15	0.12	Farmer's knowledge	0.27	0.28	0.04	0.03
13				Management capacity	0.21	0.21	0.03	0.02
14				Social infrastructure	0.08	0.14	0.01	0.02
15				Consultants	0.12	0.13	0.02	0.02
16				Land use right	0.07	0.08	0.01	0.01
17				Labor force	0.15	0.07	0.02	0.01
18				Environmental treatment	0.05	0.06	0.01	0.01
19				Support policy	0.04	0.04	0.01	0.00
20	Environment	0.08	0.07	Soil degradation	0.57	0.61	0.04	0.04
21				Biodiversity	0.30	0.23	0.02	0.02
22				Plant diseases	0.13	0.15	0.01	0.01

Sources: Research Institute for Climate Change [12].

The research team at the Research Institute for Climate Change used the MCE method to evaluate the significance of technical, socioeconomic, and environmental aspects for the production of rice and vegetables in the study region after establishing the fundamental target.

The results demonstrated that the ability to apply high technology in farming will depend on the technical understanding of those directly involved in agricultural production. When technology is shared, those with more understanding will have easier access to new science and technology. The production of rice and vegetables in the districts of Thoai Son and Chau Phu, however, does not significantly depend on the supporting policy factor. Regarding environmental concerns, it has been demonstrated that soil degradation will have a significant influence on farming, hinder the development of crops, and be very expensive to remediate. When using high technology to cultivate rice and vegetables, it becomes clear that factors such as the use of technical measures, the use of pest- and disease-resistant varieties, and the application of measures to prevent ecological diseases (fields, flower banks) are no longer significant in the process of high-tech rice and vegetable production.

The objective of identifying critical factors in the production of rice and vegetables and the advancement of high-tech applications is to direct attention toward the critical factors and to advance in line with the actual circumstances of the production area. The evaluation's results show that before high technology can be applied to agricultural production in the Thoai Son and Chau Phu districts, it is necessary to develop the first technical stage, then implement new technologies and techniques, before moving on to economic, social, and finally environmental issues.

Consumer market, according to the survey, is the first concern and has the highest relevance in the development of high-tech applications for rice and vegetables. The weight of this factor is 0.15 for rice and 0.2 for vegetables, out of 22 technical, economic, social, and environmental factors. Finding a market for the product is essential in order to properly develop the application of high technology since the results also demonstrate the requirement in agricultural production at the output stage. Then, production will be more practical and satisfy the need for high-productivity, high-quality agricultural products in large quantities.

The initial research has generally identified 22 criteria across (1) technical conditions (soil and seed preparation, cultivation, water management, farming techniques, model design, product consumption, and production scale); (2) economic conditions (consumption market, investment costs, and profits); (3) social criteria (people's knowledge, management ability, infrastructure, agricultural consultants, land ownership, labor resources, environmental treatment, policies); and (4) environmental indicators (land degradation, biodiversity, and disease). When putting into practice, it is required to examine the region's agricultural, industrial, and farming potential by considering the current situation and the application of the aforementioned criteria.

After determining these criteria and the region's present high-tech application situation, enterprises and farms in the province of An Giang support the creation of high-tech agricultural models for the production of rice and vegetables, with the following initial positive outcomes:

The An Giang Provincial People's Committee collaborated with Loc Troi Group Joint-Stock Company to carry out the project of developing 200 new agricultural cooperatives between 2020 and 2025 (50 cooperatives between 2020 and 2021, and 150 cooperatives between 2022 and 2025). These were linked to the construction of raw rice areas, sticky rice, vegetables, and fruit trees, providing agricultural services, and carrying out high-tech agriculture development projects. The implementation phase was to begin in 2020, with focus on developing and proposing the Project and Action Program on developing the An Giang rice brand. It proposed the creation of a Steering Committee "Together with Farmers" to coordinate with local agricultural sector units to develop a thorough cooperative action program based on technical and integrated activities, associated with local programs on SRP, IPM, organic, and high-tech production.

A goal was set to develop "Big Field," produce rice in accordance with GlobalGAP standards, and produce specialty rice varieties including fragrant Jasmine and Japonica as well as high-quality rice seeds. Additionally, the region used for the production of fruits and vegetables was to be developed in accordance with regions of concentrated production.

In particular, the district also implemented activities to upgrade and develop products proposed to participate in the OCOP project, such as longan (My Duc commune); dried products; white radish; green asparagus (Binh Thuy commune); Dinh Lang wine (Binh Long commune); Jasmine rice according to GlobalGAP standards; durian (Binh Chanh commune); apple (My Phu commune); pomelo and longan (Khanh Hoa commune); safe vegetables (Thanh My Tay commune), etc.

Chau Phu will continue to invest in the construction of a complete and synchronous agricultural infrastructure system to satisfy the requirements of concentrated production. It will also invest in irrigation works combined with intra-field traffic to serve the renovation of mixed gardens and convert inefficient rice-growing areas to vegetables or fruit trees in order to effectively carry out the goal of developing high-tech agriculture. [12]

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CONCLUSION AND RECOMMENDATIONS

The agrifood system landscape in APO member economies are characterized by both significant modernization and also growing challenges of emerging nature, including resource scarcity, environmental degradation, and climate uncertainty. The discussions in previous chapters collectively highlight diverse set of tools that can contribute toward sustainable modernization of the agricultural sector in APO member economies. Effective mobilization of these tools, however, requires key support from the public sector, as well as the APO. This concluding chapter briefly summarizes key recommendations for policymakers and the APO, as well as brief checklists.

Policy Recommendations

Key policy recommendations include, but are not limited, to the following sets of support:

A. **Encourage information and data sharing, with adequate safeguards and protection of intellectual property rights for**

- data/statistics on natural resource stock, quality (soil, water, and environmental quality);
- data/statistics related to economic, environmental and social vulnerabilities;
- data/statistics related to adaptive capacity, gender equality/inclusiveness, and collective actions; and
- offer incentive mechanisms to public research institutions to collect/publish data/indicators.

B. **Build capacity for better data collection and assessment through**

- better business accounting system to measure sustainability (e.g., proper accounting of waste materials);
- encouraging ICT applications for SAM monitoring; and
- encouraging public–private partnerships.

C. **Encourage private investments in affordable, low-cost SAM methods, technologies and services through**

- business models for collective action on natural resource managements;
- training on SAM practices through field schools and extension;
- promotion of specialized service providers for SAM;

- encouraging the private sector to develop social benefit technologies in exchange for support from public research/funding;
- developing technologies to lower costs of environmental quality improvement;
- developing technologies to transfer farming knowledge/skills to younger generation;
- offering tax incentives and other financial support to the private sector for pilot testing and developing/promoting technologies;
- strengthening property rights to natural resources; and
- creating other risk-sharing mechanisms in new technology development.

D. Prioritize sustainable modernization as part of national agricultural development strategies by

- expanding focus on longer-term agricultural sector development goals;
- developing capacity for identifying key SAM criteria and selecting viable options;
- investing in development of both applied research and longer-term basic research related to SAM; and
- promoting multisector approach with other government agencies in charge of environmental management, land and transport, science and technologies, consumer affairs, gender, and youth issues.

E. Governments should create public goods related to sustainable agricultural modernization that benefit the majority of players, including smallholders through

- public awareness of the importance of sustainability attributes;
- strategic, long-term investments that the private sector cannot make;
- data and statistics platforms;
- public support for certification of environmental-friendly production practices;
- support and facilitate rural infrastructure development for efficient natural resource management; and
- coordination role.

F. Enhance capacity for environmental regulations and enforcement

G. Support initiatives and encourage early adopters, as well as encourage cross-country collaboration and cooperation for knowledge, experience, best practice, and appropriate technology sharing (e.g., APO programs)

Recommendations for the APO

The APO will continue to play critical roles in mobilizing sustainable agricultural modernization tools. Specifically, it is particularly important that the APO provide the following support:

- develop country-specific SAM productivity tools;
- facilitate dissemination and exchange of information on sustainable agricultural modernization technologies through programs like demonstration projects;
- set up training courses/programs for SAM productivity assessment;
- support national agricultural productivity efforts and priority areas through consultancy services under the Specific National Program;
- assess scenarios of alternative future SAM and implications for specific member economies;
- hold country-based consultation meetings on SAM with various stakeholders;
- develop detailed country-based manuals on SAM productivity tools;
- offer advisory services to NPOs and related ministries in SAM;
- assist in developing country-specific action plans to develop/use SAM productivity tools; and
- build the capacity to monitor the progress of SAM;

Checklist

Lastly, the checklist below summarizes key elements of suggested approach for using productivity tools for SAM, based on the overall syntheses of the discussions in this report:

- Identify attributes of SAM:
  - productivity;
  - stability, resilience, and reliability;
  - adaptability;
  - equity; and
  - self-reliance.
- Identify indicators and measurement methods:
  - survey;
  - census;
  - registry; and
  - index.

- Identify suitable analytical tools:
    - direct TFP estimation
    - impact evaluation methods
    - production functions
    - expert opinions
    - composite indicators
- Share SAM-related statistics with the public.
- Assess policy/program effects on SAM related productivity indicators.
- Select/prioritize among different SAM strategies using the productivity tools.

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