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Analyzing the Effect of E-Farming Implementation on Supply Chain Performance in Sugarcane Plantations

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Abstract

Purpose: The purpose of this study is to assess the impact of e-farming implementation on the supply chain performance of sugar cane commodities in a plantation company, specifically focusing on PT. Perkebunan Nusantara (PTPN) X.
Research Methodology: This research used a quantitative method using survey methods by distributing questionnaires to e-farming actors/users at PTPN X. Survey research is research conducted on large and small populations, but the data studied are 352 samples from the population. The analysis was performed using Structural Equation Modeling (SEM) with Smart PLS 3.0 software.
Results: The results show that e-farming implementation positively and significantly affects supply chain performance. This means that to improve Supply Chain Performance, it is necessary to increase the role of the application of e-farming technology, especially application tools that can be developed to increase the effectiveness of the company's business processes.
Conclusions: E-Farming Implementation has a positive and significant influence on Supply Chain Performance.
Limitations: This study has several limitations. It focuses only on e-farming implementation at PTPN X, limiting generalizability. The sample of 352 respondents may not represent the broader agricultural sector, and reliance on self-reported data may introduce bias.
Contributions: This study contributes theoretically by confirming the positive effect of e-farming on supply chain performance using SEM-PLS, and practically by highlighting the importance of digital technologies to improve efficiency, monitoring, and decision-making in the sugar plantation industry within the Industry 4.0 context.

Keywords: *E-Farming Implementation, SEM, Supply Chain Efficiency, Supply Chain Performance*

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1. Introduction

Smart farming 4.0 is an artificial intelligence product that has been used as a mainstay tool by the Ministry of Agriculture in the current digital era. Smart farming 4.0 will encourage farmers' work so that agricultural cultivation becomes efficient, scalable, and integrated (Lumi & Yosef, 2022; Parmenas, 2022; Raj & Prahadeeswaran, 2025). This is beneficial for farmers to carry out cultivation planning properly and appropriately through mechanization to avoid seasonal dependence. The implementation of cultivation from planting to harvest is carried out with precise and accurate planning, including labor, cropping patterns, and harvesting (Balkrishna et al., 2023; Batra et al., 2025). Several smart farming technologies, such as blockchain, can facilitate the traceability of the supply chain of agricultural products for modern off-farm agriculture, agri-drone sprayer (drones spraying pesticides and liquid fertilizers), drone surveillance (drones for land mapping), soil and weather sensors (soil and weather sensors), smart irrigation (smart irrigation system), Agriculture War Room (AWR), and Siscrop (information system) 1.0 have been implemented in several areas (Nuraeni et al., 2022; Rachmawati, 2021).

Precision agriculture is a modern approach to agricultural management that exploits cutting-edge technology to monitor and optimize agricultural production (Martos et al., 2021; Naqvi et al., 2021). The concept of precision agriculture was born in the United States in the early 1990s, where the House of Representatives (1997) defined it as "an integrated production and information-based farming system designed to improve long-term, site-specific, and overall agriculture., production efficiency, productivity, and profitability while minimizing unwanted impacts on wildlife and the environment (Hernawan et al., 2022; Trivelli et al., 2019). One of the novel technologies developed for agriculture is E- Farming. An important program is the development of technology and innovation, especially in terms of the creation of local superior varieties (site-specific location), weather and climate information systems, the implementation of precision farming, and increasing management effectiveness to increase crop productivity and control the cost of production (Abidin et al., 2022; Klerkx et al., 2019; Vijayarajan et al., 2018). Funding support is needed for technology and innovation development institutions (research and technology institutions and HR development institutions, including P3GI, LPP, & Universities) for technology development and innovation. State-owned sugar companies must be able to transform themselves into superior companies in terms of production, human resources, marketing, IT, finance, and various aspects of the organization. To carry out this transformation, changes are needed, starting from the perspective of the sugar business going forward, running a business, and the competencies that must be built.

Plantation is an agricultural sub-sector that contributes to the state (Araújo et al., 2021). The contribution of the plantation subsector in 2019 was 3.27 percent of the total GDP and 27.75 percent of the Agriculture, Forestry, and Fisheries sector, or was the first in the sector (BPS). Sugarcane is one of the most widely developed and cultivated plantation crops by large plantation companies, both private and state-owned (Kenney-Lazar & Ishikawa, 2019; Smith & Lawrence, 2021). Large plantations are commercially organized or managed by a company that is a legal entity. Large plantations consist of State Large Plantations (PBN) and National/Foreign Large Private Plantations (PBS) plantations. The production performance of the PTPN Group, the achievement of sugarcane production, has decreased. In the development of the new digital era in the fourth industrial revolution, Information and Communication Technology and cyber-physical systems (CPS) based on Internet of Things (IoT) architecture for production logistics and Supply Chain applications have led to the implementation and acceleration of innovations needed for industrial digitization (Tu et al., 2016). This also influences the direction of national development, which was previously based on the agricultural sector to become an industry, which then has an impact on the face of the Indonesian agricultural system.

Holding Perkebunan Nusantara has started implementing E-farming for all PT Perkebunan Nusantara (PTPN) sugar. E-farming provides several benefits, including ease of land registration in several sugar factories, accuracy of land verification to avoid overlapping areas, ease of monitoring land, and ease of communication between farmers and sugar factory officers. E-farming is an application for land registration and monitoring the progress of plantation work through web and mobile applications (Android) supported by GIS and satellite technology. This application has been implemented at PTPN X since 2016 and continues to be developed every year (PTPN). PTPN X has implemented the digitization of land management through e-farming, where features continue to be developed to improve supply chain performance from land registration to land management, mainly on their own land. The obstacles faced by the PTPN sugar industry in achieving the feasibility of a sugarcane-based industry, from the on-farm aspect, include limited land area and marginal land, climate change and frequent occurrence of extreme weather, limited use of agro inputs, irrigation facilities, labor and technology, and high production costs. The high sugarcane land owned by farmers increases the uncertainty of the fulfillment of raw materials; therefore, it is necessary to take a precise and measurable inventory of the farmers' sugarcane land. Initially, land records were carried out by each sugar factory, so the potential for overlapping land records between sugar factories was very high because they were not integrated.

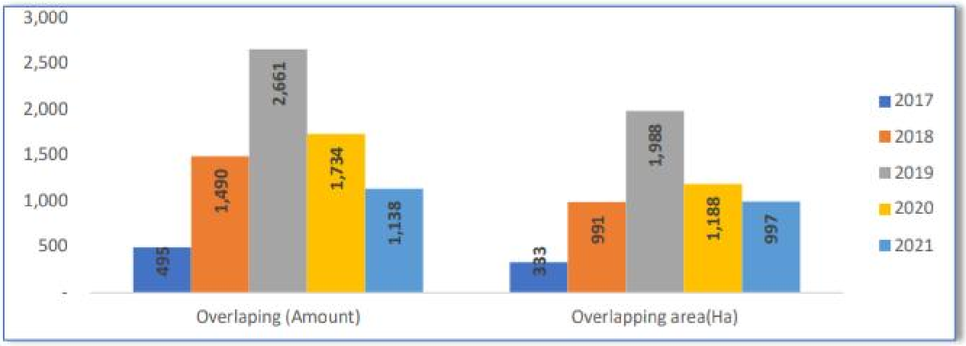

Figure 1. Overlapping of Land Records 2017-2021

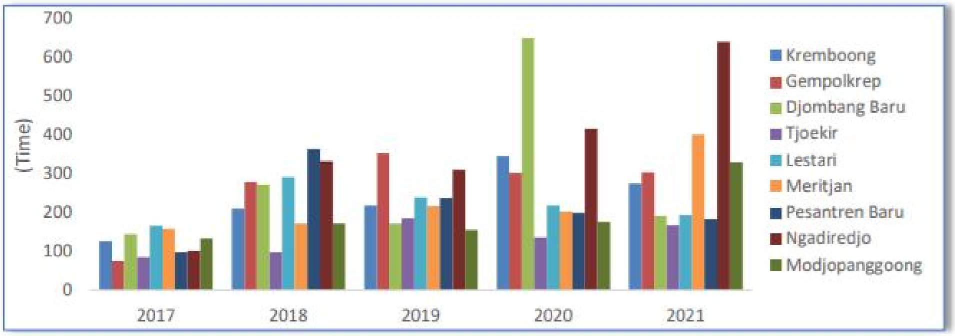

Figure 2. Overlapping of Land Records 2017-2021

According to the President Director of PTPN X (2019), Magfiroh (2019) said that entering the industrial era 4.0 one of the main principles is the connection to technology and e-farming is the starting point for plantations to become more advanced (PTPN). The existence of e-farming will certainly affect the management system or agricultural management, meaning that e-farming will affect supply chain performance. The low productivity of sugarcane is allegedly due to the cultivation process that is not up to standard, especially in terms of the timeliness of work execution. Existing work progress reporting systems cannot accurately monitor the timeliness of plantation work implementation. Holding Perkebunan Nusantara has assigned PTPN X to develop e-farming, including additional work progress features and preparation for cutting sugar cane. Management can monitor the realization of work progress more accurately. The implementation of work according to standards and at the right time is expected to significantly increase the productivity of sugarcane plants (Magfiroh, 2019).

In today's business developments, orders are getting tighter not only from competitors but also from between supply chain within the company. This requires a supply chain with good performance to survive the changing dynamics of the industry. Performance refers to the product supply chain performance measurement, which is one of the information needed by management with information about whether it is improving or decreasing. Supply chain performance measurement models are related to supply chain activities in a company, including procurement activities, production planning, customer order fulfillment, and product returns. This measurement activity can improve the determination of the current operating system policy. Several factors affect supply chain performance, including operating conditions, environmental factors, supply chain decision parameters, and internal factors. Utama et al. (2019) Information technology plays an important role in the development of the agro-industry, which helps manage the supply of agricultural products. E-farming, which was compiled as a service system to develop the Android-based agricultural sector, offers several services in the form of counseling, consulting, and marketing related to agriculture.

The E-Farming application helps farmers earn more profits if they are sold through the application. Farmers obtain information on harvest trends and selling prices to determine the calculation of selling prices.

Table 1. Research Gap E-farming Implementation on Supply Chain Performance

No	Authors	Result	Description
1	(Rum et al., 2019)	There is a significant relationship between supply chain management practices and farm performance	Significance (+)
2	(Suharto & Devie, 2013)	There is a significant and positive influence between Supply Chain Management on competitive advantage	Significance (+)
3	(Putri et al., 2019)	There is a positive influence on supply chain practices on competitive advantage and supply chain performance	Significance (+)

Based on the phenomena that have been described above and empirical studies of previous studies that are relevant to the phenomena found, Based on the background of the problems above, there are problems related to this research. The obstacles faced by the PTPN sugar industry in achieving the feasibility of a sugarcane-based industry from the on-farm aspect include limited land area and marginal land, climate change and frequent occurrence of extreme weather, limited use of agro-inputs, irrigation facilities, labor and technology, and high production costs. The high sugarcane land owned by farmers increases the uncertainty of the fulfillment of raw materials; therefore, it is necessary to take a precise and measurable inventory of the farmers' sugarcane land. Initially, land records were carried out by each sugar factory, so the potential for overlapping land records between sugar factories was very high because they were not integrated.

The low productivity of sugarcane is allegedly due to the cultivation process that is not up to standard, especially in terms of the timeliness of work execution. Existing work progress reporting systems cannot accurately monitor the timeliness of plantation work implementation. Holding Perkebunan Nusantara has assigned PTPN X to develop E-Farming, including additional work progress features and preparation for cutting sugarcane. Based on the description of the background above and the phenomenon, the authors determine the formulation of the problem in this study as how the influence of E-Farming Implementation on the Supply Chain Performance of Sugarcane Commodities at PT. Perkebunan Nusantara X?. The purpose of this study was to determine the effect of E-Farming Implementation of Sugar Cane Commodity Supply Chain Performance at PT. Perkebunan Nusantara X.

2. Literature Review & Hypothesis Development

2.1 E-farming at PTPN X

E-farming at PTPN X is an application resulting from the development of internal business processes at PTPN. The process that has been done manually and there is no integration between lines or between sugar factories is now integrated through the application. In 2020 the E-Farming program has been able to carry out land registration and monitoring the progress of garden work through the web and mobile application (android) supported by GIS and satellite technology. According to Utama et al. (2019), E-Farming is a service system in an effort to develop an Android-based agricultural sector that offers several services. Information technology plays an important role in the development of the agro-industry in realizing sustainable modern agriculture in a timely manner (Naresh et al., 2021). The utilization of technology in agriculture can be realized by using e-farming. The implementation of this e-farming application provides information services about agricultural activities from the production process to the marketing of products. Application E-farming helps farmers earn more profit by obtaining information and developing strategies for selling products (Farooq et al., 2019).

Despite being a relatively well-known concept, precision agriculture still has low adoption rates, as reported by academic surveys and professional reports Mentzer (2001). The government has announced the national priority of "making Indonesia 4.0" which is the gateway to the openness of the technological era so that Indonesia is able to increase its competitiveness as well as prepare Indonesia to enter the 4th industrial revolution (Pitaloka & Humaedi, 2020; Tirtowalujo et al., 2020). However, its implementation remains unsatisfactory. Currently, there are still farmers who are new to the introduction stage, and some are not familiar with the digitalization of agricultural technology. Compared to China and Thailand, Indonesia is still far behind. Rapid population growth and difficulty in regeneration. At the farmer level, limited land makes it seem that it is no longer possible for farmers to use conventional methods (Rachmawati, 2021).

E-Farming is an application for land registration and monitoring the progress of garden work through web and mobile applications (Android) supported by GIS and satellite technology. The implementation of E-Farming at PTPN X also supports productivity improvements on the farm side. In addition, there will be certainty of the area of sugarcane plantations and the amount of sugarcane raw materials, both TS and TR. The dimensions of e-farming were taken from research conducted by Trivelli et al. (2019) as follows:

1) Monitoring
This cluster represents one of the most important aspects of precision agriculture, as it is the basis for implementing advanced agricultural systems. It directly interacts with most other clusters and represents the IoT.

2) IoT
These clusters complement monitoring, as sensors play a central role in the IoT. This cluster describes new technologies that enable data communication between machines. The IoT and monitoring are the basis for data extraction and analysis, enabling system automation.

3) Automation
Sensor data enable the automation of processes that previously required human intervention.

4) Decision
This cluster is closely related to automation. Decision systems (especially AI and data analytics) bridge the gap between machines and humans.

Supply Chain Performance is defined as a systematic process for measuring the effectiveness and efficiency of supply chain operations (Anand & Grover, 2015). Effective supply chain performance can reduce costs, waiting times, and delivery delays and improve product quality, whereas company performance reflects how the company performs to achieve the goals, missions, and values that have been set according to mutual agreement (Gandhi et al., 2015). To identify supply chains in created applications, it is necessary to observe and evaluate supply chain performance assessments. According to Rizkya et al. (2019), Performance of activity (POA) is a performance measurement model for each activity. The modified POA dimensions in previous studies were as follows:

1) Time (Waktu)
2) Capacity (Kapasitas)
3) Productivity (Produktivitas)
4) Benefits (Manfaat)

Sugarcane plant with the Latin name Saccharum officinarum is one of the plants that can produce sugar which is cultivated in tropical to sub-tropical areas. Sugarcane plants have a plant age of up to 16 months, which in Indonesia is generally harvested at the age of approximately 12 months. Sugarcane plants have optimal growth characteristics in the planting phase before the rainy season, stem extension phase during the rainy season, and ripening phase in the dry season (Ghani, 2022).

Sugarcane cultivation standards are currently facing different environmental conditions and soil fertility; therefore, the principles and criteria for cultivation must be adjusted (Donzelli et al., 2018; Shukla et al., 2019; Tabriz et al., 2021). The optimum cultivation stages include land management, use of superior seeds, application of fertilizers as needed, plant maintenance, irrigation, pest control, Kletek, gulud, and TMA management (Ghani, 2022). Supply chain is the most important factor in increasing competitiveness since the biggest cost of a product is in the supply chain (Ikatrinasari et al., 2020). The development of supply chain performance measurement system needs to take into account the specific characteristics of the supply chain that will be measured (Hasibuan & Dzikrillah, 2018).

The framework of thought is a logical framework that places the research problem within a relevant theoretical framework.

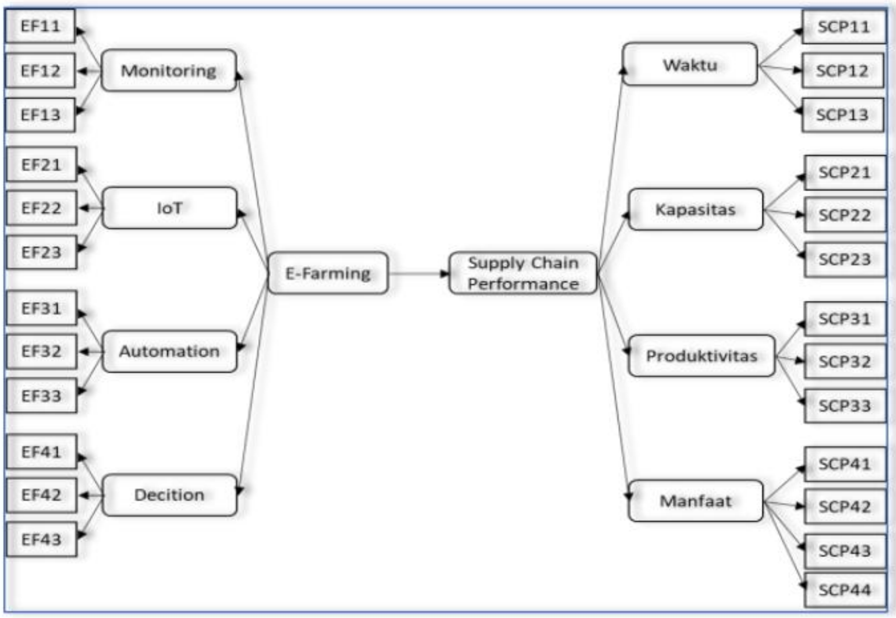

Figure 3. Conceptual Framework

2.2 Hypothesis Development

The primary hypothesis of the study is:

H_1: E-Farming Implementation has a positive and significant effect on Supply Chain Performance

3. Methodology

3.1 Research Design

The research method used was quantitative. Of the two types of quantitative methods (experimental and survey methods), this study uses a survey method through questionnaires to e-farming actors/users at PTPN X. Survey research is research conducted on large or small populations, but the data studied are a sample of the population. The population in this study was permanent employees of the Plant Division and QA Division at PT. Perkebunan Nusantara X.

3.2 Data Collection

Based on MPP (Man Power Planning) Holding Perkebunan, PTPN X data obtained as of January 2022, the permanent employees in the Plant Division was 492 employees and the QA Division permanent employees were 118 employees. The sample is part of the population to be studied or part of the number of characteristics possessed by the population (Hidayat, 2012). [15]. Sampling technique when all members of the population are used as the samples. Another term for a saturated sample is a census, where all members of the population are sampled. Therefore, the author uses a saturated sampling technique, and the sample is taken as many as 352 permanent employees of the Plant Section and the QA Section in the work unit of PT. Nusantara X Plantation.

3.3 Data Analysis

The analytical method used to test the hypothesis is the structural equation model (SEM) measured by the partial least squares (PLS) model using SmartPLS software. The PLS approach is used for predictive analysis with a weak theoretical basis, and the data do not meet the SEM assumptions based on covariance. With the PLS technique, it is assumed that all variance measures are useful for explanation.

SEM-PLS can handle problems that arise in covariance-based SEM analysis. In SEM, in addition to the characteristics of the model being estimated, the sample size should be increased under the following circumstances: (1) data deviate from multivariate normality, (2) sample-intensive estimation techniques (e.g., ADF) are used, or (3) missing data exceed 10 percent.

4. Results and Discussion

4.1 Variable E-Farming Implementation

Table 2. Variable E-Farming Implementation

Kode	N	Minimum	Maksimum	Average
EF11	352	6	10	8.28
EF12	352	4	10	8.12
EF13	352	5	10	8.60
EF21	352	3	10	8.23
EF22	352	5	10	8.24
EF23	352	3	10	8.26
EF31	352	3	10	8.26
EF32	352	4	10	7.91
EF33	352	6	10	8.23
EF41	352	5	10	8.28
EF42	352	5	10	8.24
EF43	352	1	10	8.01
		Average		8.22

Source: Data is processed from the results of the 2022 questionnaire

Based on the Table 2, the highest average value for variable E-farming Implementation was found in the Monitoring dimension for EF13 statements, namely using E-Farming provides ease of monitoring, and the lowest average value was found in the EF43 statement with a statement of whether there is an E-Farming development strategy in improving. Thus, it can be known that from each indicator on the variable E-farming Implementation, a standard deviation smaller than the mean indicates a small distribution of the data indicators or the absence of a sufficiently large gap of each lowest and highest indicator. The average score of the variable E-Farming was 8.22, which means that the average respondent tended to agree with the questions in the questionnaire.

4.1.1 Variable Supply Chain Performance

Table 3. Description of Variable Supply Chain Performance

Kode	N	Minimum	Maksimum	Average
SCP11	352	2	10	8.28
SCP12	352	2	10	8.31
SCP13	352	5	10	8.41
SCP21	352	4	10	8.30
SCP22	352	5	10	8.38
SCP23	352	2	10	8.16
SCP31	352	2	10	8.29
SCP32	352	5	10	8.32
SCP33	352	4	10	7.93
SCP41	352	2	10	8.13
SCP42	352	4	10	8.31
SCP43	352	1	10	8.16
SCP44	352	5	10	8.45
		Average		8.26

Source: Data is processed from the results of the 2022 questionnaire

Based on the Table 3, the highest average value for the Supply Chain Performance variable is found in the Dimension of Benefits for SCP44 statements, namely the use of applications that facilitate monitoring and evaluation of work and other events thshould beube presented. The lowest average value was found for SCP33, which stated that monitoring the progress of garden work in the application improved sugarcane productivity. Thus, it can be known that from each indicator on the Variable Supply Chain Performance standard, a deviation smaller than the mean indicates a small spread of the data indicator or the absence of a sufficiently large gap of each indicator's lowest and highest. The average value of the Supply Chain Performance variable is 8.26, which means that the average respondent tends to agree with the questions in the questionnaire.

4.1.2 Convergent Validity Test

Convergent Validity aims to determine the validity of each relationship between indicators and their latent constructs and variables. The convergent validity of the measurement model with reflexive indicators was assessed based on the correlation between the item or component score and the latent variable or construct score estimated by the PLS program. The following is a picture of the calculation results of the SEM PLS model, then look at the loading value of the indicators factor on each variable.

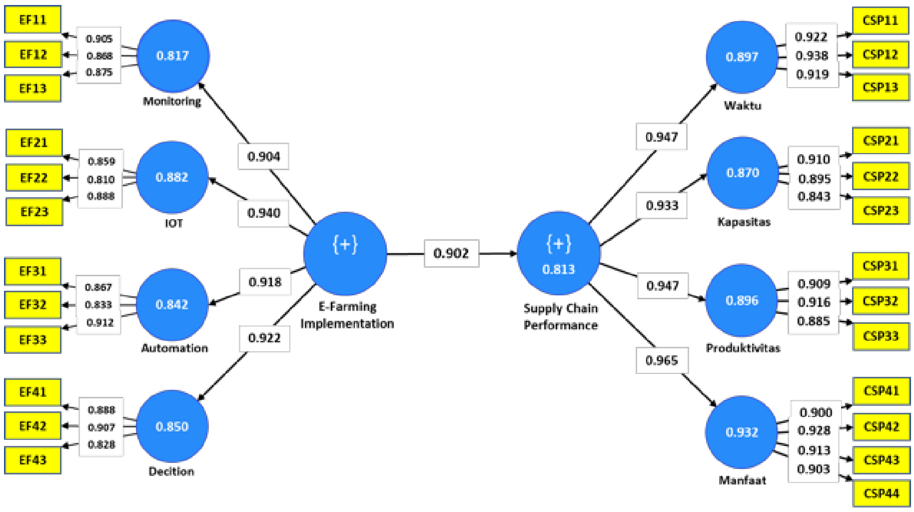

Figure 4. SEM PLS Model Calculation Results

The measurement was considered valid if the loading factor was above 0.70 and the AVE was above 0.50 for each variable (Anand & Grover, 2015). The actual result of the external charge is as follows.

Table 4. Loading Factors

Variable	Indicators	Loading Factors	Results
E-Farming Implementation (X)	EF11	0,905	Valid
	EF12	0,868	Valid
	EF13	0,875	Valid
	EF21	0,859	Valid
	EF22	0,810	Valid
	EF23	0,888	Valid
	EF31	0,867	Valid
	EF32	0,833	Valid
	EF33	0,912	Valid
	EF41	0,888	Valid
	EF42	0,907	Valid
	EF43	0,828	Valid
Suply Chain Performance (Y)	SCP11	0,922	Valid
	SCP12	0,938	Valid
	SCP13	0,919	Valid
	SCP21	0,910	Valid
	SCP22	0,895	Valid
	SCP23	0,848	Valid
	SCP31	0,909	Valid
	SCP32	0,916	Valid
	SCP33	0,885	Valid
	SCP41	0,900	Valid
	SCP42	0,928	Valid
	SCP43	0,913	Valid
	SCP44	0,904	Valid

The variables E-Farming Implementation and Supply Chain Performance have loading factor values greater than 0.70. Thus, the indicator is declared valid for measuring the variables of E-farming Implementation and Supply Chain Performance. The validity of convergence can not only be seen through the loading factor, but also known through the Average Variance Extracted (AVE). An instrument is said to meet the convergent validity test if it has an Average Variance Extracted (AVE) above 0.5. The results of the convergent validity test are presented in the participating table:

Table 5. Convergent Validity Test Results

Variable	**AVE**
E-Farming Implementation	0.642
Supply Chain Performance	0.741

Source: Data is processed from the results of the 2022 questionnaire

Based on the Table 5, it can be seen that the variables E-F arming and Supply Chain Performance resulted in an Average Variance Extracted (AVE) value greater than 0.5. Thus, the indicators measuring the E-F arming and Supply Chain Performance variables were declared reliable. The test criteria state that if the composite reliability is greater than 0.7 and Cronbach's alpha is greater than 0.6, then the construct is said to be reliable. The results of the calculation of composite reliability and Cronbach's alpha are summarized in the following table:

The calculation of composite reliability and Cronbach's alpha results can be seen in the summary presented in the following table:

Table 6. Calculation Results of Cronbach's Alpha and Composite Reliability

Variable	**Cronbach's Alpha**	**Compoasite Reliability**
E-Farming Implementation	0.949	0.955
Supply Chain Performance	0.971	0.974

Source: Data is processed from the results of the 2022 questionnaire

Based on the Table 6, it can be seen that the composite reliability value on the E-Farming implementation and Supply Chain Performance variables is greater than 0.7. Thus, based on the calculation of composite reliability, all indicators that measure the E-Farming Implementation and Supply Chain Performance variables were declared reliable. Furthermore, the Cronbach's alpha values for the E-farming Implementation and Supply Chain Performance variables were greater than 0.6. Thus, based on the Cronbach's alpha calculation, all indicators measuring the E-Farming Implementation and Supply Chain Performance variables are declared reliable.

Goodness of fit Model used to determine the magnitude of the variable ability to exogenous explains the diversity of endogenous variables, or in other words, to know the magnitude of the contribution of exogenous variables to endogenous variables. The goodness of fit model in the PLS analysis is laid out using the coefficient of determination (R-Square) and Q-Square predictive relevance (Q2). The results of the goodness-of-fit model are summarized in the following table.

Table 7. Summary Results of Goodness of Fit Model

Variable	R Square	R Square Adjusted
Supply Chain Performance	0.814	0.813

Source: Data is processed from the results of the 2022 questionnaire

The R-squared of supply chain performance is 0.814 or 81.4%. It can be noted that the diversity of Supply Chain Performance capable of being explained by E-Farming Implementation is 81.4%, or in other words, the contribution of E-Farming Implementation to Supply Chain Performance is 81.4%, while the remaining 18.6% is the contribution of other factors that are not discussed in this study. Direct influence hypothesis testing is used to test whether exogenous variables directly influence endogenous variables. The test criteria state that if the path coefficient is positive and the p-value is the level of significance (alpha = 5%), then it is stated that there is a positive and significant influence of the exogenous variable on the endogenous variable. The results of the hypothesis testing are presented in table:

Table 8. Summary of Hypothesis Testing Results

	Original	Average	STDEV	T-Statistic	P Values
EF Implementation (Automation)	0.918	0.919	0.010	92.633	0.000
EF Implementation (Decition)	0.922	0.922	0.010	95.190	0.000
EF Implementation (IOT)	0.940	0.940	0.008	120.324	0.000
EF Implementation (Monitoring)	0.904	0.904	0.013	69.017	0.000
EF Implementation (SC Performance)	0.902	0.902	0.020	45.221	0.000
SC Performance (Capacity)	0.933	0.933	0.010	89.793	0.000
SC Performance (Benefit)	0.965	0.965	0.005	190.471	0.000
SC Performance (Productivity)	0.947	0.948	0.008	114.180	0.000
SC Performance (Time)	0.947	0.948	0.009	103.601	0.000

Source: Data is processed from the results of the 2022 questionnaire

From the Table 8, it shows that all paths are positive and significantly marked with T-Statistics >1.96 and P-Values <0.05. As for hypothesis testing, then the results can be explained as follows:

Table 9. Hypothesis Testing

Hypothesis	Description	Estimate	T Test	1-Tailed P	Conclusion
H1	E-Farming Implementation has a positive influence on Supply Chain Performance	0.902	45.22	0.000	H1 Accepted (Significant)

Based on Table 9, the results can be explained as follows: H1: E-Farming Implementation has a positive and significant effect on Supply Chain Performance. This can be proven by the value of the Effect of E-Farming Implementation on Supply Chain Performance resulting in a t-test regression coefficient of 45.22 while the table-t of 1,966 for N=352 with a p values of 0.000. The resultsof the test showed that the coefficient was positive because t statistically > t of the table and the value of p value < the level of significance (alpha = 5%). This means that in this study E-Farming Implementation has a positive and significant effect on Supply Chain Performance. This study is in accordance with previous researchers

Putri et al. (2019), with the results of the study showing that a positive influence on supply chain practice on competitive advantages and supply chain performance. This research is supported by according to (Georgr et al., 2019) where management decisions influenced by supply chain structure, availability and policies have a positive effect on supply chain performance. The results of this study support previous research conducted by Munizu (2017) which stated that better information technology can encourage increasing supply chain performance, IT implementation in general is believed to be the main factor and become a necessity in optimizing supply chain performance.

5. Conclusions

Based on the phenomenon, problem formulation, hypothesis, research results, and discussion, the following conclusions can be drawn: E-Farming Implementation has a positive and significant influence on Supply Chain Performance. This means that to improve Supply Chain Performance, it is necessary to increase the role of E-Framing Implementation technology, especially if application tools can be developed to improve the effectiveness of the company's business processes.

5.1 Research Limitations

This study has several limitations. First, it focuses solely on the implementation of e-farming in PT. PTPN X, limiting the generalizability of the findings to other plantation companies or industries. Second, the research sample is restricted to 352 respondents from PTPN X, which may not fully represent the broader agricultural industry. Finally, the study primarily relies on self-reported data from the respondents, which could introduce bias in assessing the effectiveness of e-farming applications.

5.2 Suggestions and Directions for Future Research

Future research is recommended to expand the scope of study by including other plantation companies or agricultural sectors to improve generalizability. Researchers are also encouraged to incorporate additional variables such as technological readiness, innovation capability, organizational culture, and environmental uncertainty. Longitudinal studies are suggested to examine the long-term impact of e-farming implementation on supply chain performance. Furthermore, combining quantitative and qualitative approaches could provide deeper insights into the challenges and success factors in implementing digital agriculture technologies.

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Author Contributions

AF contributed to conceptualization, study design, writing of the original draft, and final approval of the manuscript. NS contributed to data collection, formal analysis, and writing—review and editing.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper. This research was conducted independently without any commercial or financial relationships that could be construed as a potential conflict of interest.

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