

Digital Transformation of Subsidized Fertilizer Distribution: Evidence From Farmer Groups in Rural Eastern Indonesia

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Abstract

This study examines the implementation and impact of TaniFlow, a web-based information system designed to improve subsidized fertilizer distribution among farmer groups in Puusangi Village, Konawe Regency, Southeast Sulawesi, Indonesia. Using a qualitative descriptive approach, data were collected through in-depth interviews, participant observation, and document analysis involving 15 informants, including farmer group administrators, farmers, extension officers, village officials, fertilizer distributors, and district agriculture staff. The findings show that TaniFlow transformed a manual, paper-based distribution system into a more efficient, accurate, transparent, and accountable digital mechanism. Its main features, including member registration, automated quota calculation, real-time distribution recording, and automated report generation, reduced administrative errors, data duplication, quota disputes, and opportunities for fertilizer misuse. The system shortened the distribution cycle from two to three weeks to only three to five days and enabled better monitoring by relevant stakeholders. Improved timeliness and accuracy of fertilizer allocation also supported better crop management, particularly for rice and maize farmers, contributing to perceived improvements in productivity and farmer welfare. The study concludes that digital transformation at the farmer group level can strengthen subsidy governance, improve distribution efficiency, and support rural agricultural development.

Keywords: digital transformation, distribution efficiency, farmer groups, subsidized fertilizer

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Introduction

Agriculture remains the backbone of Indonesia's economy, employing approximately 36.46 million workers, around 26.07% of the total national labor force, as of August 2023 (Azis & Suryana, 2023). As one of the world's most agriculturally significant nations, Indonesia's food security depends substantially on the productivity and welfare of its smallholder farming communities. Central to supporting this productivity is the government's subsidized fertilizer program, which has been operating since 1969 with the dual mandate of reducing production costs for farmers and sustaining national food output (Peraturan Menteri Pertanian Nomor 10 Tahun 2025, 2025). Despite more than five decades of implementation, this program continues to face persistent structural challenges that undermine its intended impact at the grassroots level.

The distribution of subsidized fertilizer in Indonesia remains burdened by systemic inefficiencies. According to the Ombudsman of the Republic of Indonesia 2024, approximately 16% of farmers still report experiencing delays in fertilizer distribution, primarily caused by administrative bottlenecks in the issuance of allocation decrees. Furthermore, 81% of farmers remain unaware of price violation reporting mechanisms, while 25% do not know the government-mandated maximum retail price. These figures reveal not only logistical failures but also a critical information asymmetry that disadvantages smallholder farmers throughout the subsidy chain (Ombudsman, 2025). Equally concerning, Zuhriyah et al. (2023) documented that distribution records at many farmer group levels remain paper-based, relying on handwritten notes and physical receipts, making data vulnerable to duplication errors, loss, and manipulation.

The implications of these failures extend beyond administrative inconvenience. Inefficient fertilizer distribution directly compromises agricultural productivity, as the late or inaccurate delivery of fertilizer disrupts optimal application timing across critical crop growth stages. Research consistently demonstrates that fertilizer application delays can reduce rice and maize yields by 20 to 30 percent (Rachman, 2009), while improper allocation, either insufficient or excessive, further diminishes the efficiency of nutrient uptake by crops. These productivity losses translate into reduced farmer incomes, eroding household welfare and widening rural poverty gaps. The Nilai Tukar Petani (NTP), Indonesia's primary indicator of farmer welfare, is directly sensitive to production efficiency and input access (Ombudsman, 2025).

The emergence of digital information systems offers a transformative pathway for addressing these entrenched distribution failures. Globally, agricultural digitalization has been recognized as a critical lever for improving supply chain efficiency, data transparency, and smallholder empowerment (Wolfert et al., 2017). Digital platforms enable multi-stakeholder coordination, automated record-keeping, and real-time monitoring, capabilities that directly target the administrative vulnerabilities plaguing manual distribution systems. In Indonesia's agricultural context, web-based information systems have demonstrated the potential to streamline reporting, reduce leakage, and improve targeting accuracy in fertilizer subsidy delivery (Fithriyah et al., 2024; Wulandari et al., 2023). The Ministry of Agriculture's introduction of the i-Pubers application and the national shift toward ID card-based fertilizer access signal growing institutional recognition that digitalization is no longer optional but essential for program effectiveness (Kementerian Pertanian, 2024).

Yet, despite this recognition, empirical research documenting the adoption and impact of digital information systems at the farmer group (kelompok tani) level remains scarce, particularly in

Eastern Indonesia. Most prior studies have concentrated on technical system development at the district or provincial level (Haslindah et al., 2023; Murti & Fahrurrozi, 2021), without adequately examining the sociotechnical processes through which rural farming communities adopt, adapt to, and are transformed by digital tools. Critical dimensions, such as the role of perceived usability among low-digital-literacy users, the influence of social change agents in technology diffusion, and the measurable welfare outcomes of digitally-enabled distribution, remain underexplored. Regions such as Southeast Sulawesi, characterized by geographic remoteness, infrastructure constraints, and an aging farming population, present distinct contextual challenges that are poorly represented in the existing literature.

This study addresses these gaps by investigating the implementation and impact of TaniFlow, a web-based information system deployed by farmer groups in Puusangi Village, Konawe Regency, Southeast Sulawesi. TaniFlow was introduced in early 2024 to replace manual data recording systems and to digitize the four core stages of subsidized fertilizer management at the farmer group level: member registration, automated quota calculation, real-time distribution recording, and automated reporting. The study is guided by two primary research questions: (1) How is TaniFlow implemented in managing the data and distribution of subsidized fertilizer at the farmer group level in Puusangi Village, Konawe Regency, Southeast Sulawesi?; and (2) What is the impact of TaniFlow utilization on the efficiency of fertilizer distribution and agricultural productivity among farmers in Puusangi Village?

The study draws on two established theoretical frameworks. The Technology Acceptance Model (TAM), developed by Davis (1989), provides a lens for understanding how farmer group administrators and members perceive and adopt digital tools, with particular attention to *perceived usefulness* and *perceived ease of use* as determinants of behavioral adoption. This framework is complemented by Rogers's (2003) Diffusion of Innovation Theory, which examines the social processes through which new technologies spread within communities, identifying key attributes, relative advantage, compatibility, complexity, trialability, and observability, that shape adoption rates and trajectories. Together, these frameworks enable a nuanced analysis of both individual-level technology acceptance and community-level diffusion dynamics, which are particularly relevant in rural low-literacy contexts where social trust and peer observation play significant roles in shaping technology uptake.

From a theoretical standpoint, the study also contributes to the broader literature on agricultural supply chain efficiency. Chopra and Meindl (2014) distribution efficiency framework, encompassing speed, accuracy, administrative cost, and transparency, provides an evaluative structure for assessing TaniFlow's operational impact. The study further draws on Total Factor Productivity (TFP) theory (Keith, 2015) to interpret productivity outcomes, arguing that yield improvements observed after TaniFlow implementation represent not an increase in input volumes but an enhancement of input-use efficiency: the right fertilizer, delivered at the right time, in the right dose, to the right farmer.

The significance of this study is threefold. Academically, it fills an empirical gap by generating evidence from Eastern Indonesia, a region historically underrepresented in the agricultural digitalization literature. Practically, it offers actionable insights for policymakers, agricultural extension workers, and system developers seeking to replicate or scale digital distribution systems within resource-constrained rural settings. And at the community level, it documents the lived experiences and welfare outcomes of farmers who have transitioned from opaque manual systems to digitally-enabled transparency and accountability, illuminating the human dimension of agricultural transformation that technical studies often overlook.

Methodology

This study employed a qualitative descriptive approach to examine the implementation of the TaniFlow web-based information system in subsidized fertilizer distribution among farmer groups in Puusangi Village, Konawe Regency, Southeast Sulawesi, Indonesia. This approach was considered appropriate because it enables researchers to understand social phenomena, experiences, perceptions, and contextual processes from the perspectives of participants (Creswell & Poth, 2018). The study focused on the sociotechnical process of digital adoption, including farmers' experiences, perceptions, and challenges in using TaniFlow during the 2024 agricultural season, covering fertilizer needs assessment, distribution, and harvest evaluation. The research site was selected purposively because Puusangi Village had implemented TaniFlow to address problems in manual fertilizer distribution, such as delays, data inaccuracies, and limited transparency. Informants were selected using purposive sampling based on their direct involvement in the system and distribution process, involving 15 participants consisting of farmer group administrators, farmer members, a field agricultural extension officer, village officials, fertilizer distributors, and district agriculture office staff (Hennink et al., 2020).

Data were collected through in-depth interviews, participant observation, and document analysis. Interviews were conducted to explore informants' experiences and perceptions of TaniFlow, while observation focused on system use, including member registration, quota input, distribution recording, and report generation. Document analysis involved farmer group records, fertilizer distribution reports, RDKK documents, and harvest data. The use of multiple data collection techniques strengthened the credibility of the findings through triangulation (Denzin & Lincoln, 2011). Data were analyzed using the interactive model of Miles et al. (2019), consisting of data reduction, data display, and conclusion drawing/verification. Coding was used to identify key themes related to technology adoption, distribution efficiency, transparency, and productivity outcomes. Trustworthiness was ensured through source triangulation, method triangulation, member checking, and documentation of the research process, while ethical principles were maintained through informed consent, confidentiality, and voluntary participation.

Results and Discussion

Implementation of TaniFlow in Subsidized Fertilizer Distribution Management

Prior to TaniFlow's adoption in early 2024, the farmer group in Puusangi Village managed fertilizer distribution through handwritten notebooks and basic Microsoft Excel spreadsheets. This manual system generated a cascade of operational failures that are consistent with the wider national picture documented by Zuhriyah et al. (2023) and Wulandari et al. (2023): data duplication, quota miscalculations, delayed report production, loss of physical records, and critically, the absence of any audit mechanism to deter or detect misappropriation. Between five and seven suspected misappropriation cases were recorded annually, generating intra-group conflict and eroding community trust in the distribution process.

Before TaniFlow, we recorded fertilizer distribution manually in notebooks. Recording errors happened frequently, data went missing, and making reports was very difficult. When we heard about this digital system, we were initially hesitant. But after seeing the demo, which was quite simple, we decided to try it. (Farmer Group Chair, Puusangi Village)

This testimony illustrates the dual dynamic identified in the TAM literature: initial resistance rooted in unfamiliarity, ultimately overcome by the perceived accessibility of the system (Davis, 1989). The manual system's documented failures, data loss, quota disputes, and opacity, created a clear perceived need that primed the group for adoption once a sufficiently user-friendly solution was demonstrated.

TaniFlow restructured the distribution management process through four integrated modules that collectively address the specific failure points of the prior manual system. Table 1 provides a systematic before-and-after comparison across the key operational dimensions of fertilizer distribution management.

Table 1

Comparative Analysis: Manual System vs. TaniFlow Digital System

Dimension	Before TaniFlow (Manual System)	After TaniFlow (Digital System)
Data Recording Method	Handwritten notebooks and physical receipts; prone to duplication and loss	Centralized web-based database with real-time digital entry and automated validation
Member Registration	Manual listing on paper; inconsistent formats across cycles	Standardized digital profiles including NIK, land area, crop type, and cropping season
Quota Calculation	Manual, error-prone arithmetic per member; recalculated each cycle	Automated calculation based on land area (e.g., Urea 250 kg/ha; NPK 150 kg/ha for rice)
Distribution Recording	Paper receipts collected after distribution; delayed consolidation	Real-time per-member entry at point of distribution with digital confirmation
Report Generation	Manual compilation taking several days to weeks; inconsistent formats	Automated generation of daily, weekly, and monthly reports (PDF/Excel) in minutes
Processing Time	2–3 weeks from fertilizer arrival to full member distribution	3–5 days; a 78–85% reduction in cycle time
Data Accuracy	Frequent recording errors, duplicate entries, and missing data	Near-zero errors; automated validation prevents duplicate and inconsistent entries
Stakeholder Visibility	No real-time monitoring; required repeated in-person field visits	Real-time dashboard accessible to administrators, PPL, and Dinas Pertanian
Leakage and Misuse	5–7 suspected misappropriation cases per year; no audit trail	Near-zero misuse cases; permanent digital audit trail for all transactions

Source: Author's own work, 2024

The data in Table 1 demonstrate that TaniFlow's impact was not confined to a single operational dimension but constituted a systemic transformation of distribution management. Each module addressed a specific, documented failure of the prior system: the member registration module eliminated the inconsistency and duplication endemic to paper-based lists; the automated quota calculation module removed the arithmetic errors and inter-member disputes generated by manual calculation; the real-time distribution recording module closed the lag between physical distribution and administrative documentation; and the automated reporting module compressed report generation from days or weeks to minutes.

The transition from manual to digital operations was facilitated through a structured adoption process comprising three sequential phases: socialization, intensive training, and sustained post-implementation mentoring. This sequence aligns with established best practices in technology diffusion within low-digital-literacy agricultural communities (Khaspuria et al., 2024; Klerkx et al., 2019). The socialization phase involved demonstration sessions organized by the local government that allowed farmer group administrators to observe TaniFlow's interface and core functions before committing to adoption. This trialability mechanism, identified by Rogers (2003) as a critical determinant of adoption speed, enabled prospective users to evaluate the system against their practical needs without full investment of time or trust.

The training phase comprised a two-day intensive programme covering all four modules. The Farmer Group Secretary, who became the primary day-to-day system operator, described the training experience:

We were given two days of training on how to use TaniFlow: registering members, entering fertilizer quotas, recording distribution, and generating reports. At first it was a bit confusing, but because the interface was quite user-friendly and the guidance was clear, we got used to it after a few weeks of use. (Farmer Group Secretary, Puusangi Village)

The Field Agricultural Extension Officer (PPL) assumed the role of change agent during the post-training period, a function that Rogers (2003) identifies as central to the diffusion process within social systems. The PPL provided ongoing technical assistance, validated data entries, and performed periodic system monitoring. This sustained mentoring was especially critical for managing the initial resistance among senior farmer members with limited digital experience, and for maintaining system continuity during the early months of adoption.

The adoption trajectory observed in Puusangi Village is highly consistent with the predictions of Davis's (1989) Technology Acceptance Model. Table 2 maps the four TAM constructs to the empirical evidence gathered in this study.

Table 2

TAM Analysis of TaniFlow Adoption in Puusangi Village

TAM Construct	Empirical Indicator in This Study	Informant Evidence
Perceived Usefulness (PU)	Direct operational benefits: speed, accuracy, transparency	Administrators reported immediate reduction in workload and error rates; farmers reported timely access to correct fertilizer allocation
Perceived Ease of Use (PEOU)	Interface rated as intuitive; learning curve within weeks	Group Secretary: the interface was user-friendly and guidance was clear—adaptation occurred within a few weeks of use
Attitude Toward Use	Positive disposition formed upon observing early results	Extension officer (PPL) noted reduction in quota complaints; positive attitude spread through observability within the group
Behavioural Intention to Use	Commitment to continued use; recommendation to other groups	Group Chair expressed intent to use TaniFlow each cropping season and to recommend replication to neighbouring farmer groups

Source: Author's own work, 2024

A notable finding in relation to TAM is the primacy of Perceived Usefulness over Perceived Ease of Use in driving adoption. While administrators acknowledged an initial learning curve, the immediacy and clarity of practical benefits, reduced workload, elimination of quota disputes, faster report generation, outweighed usability concerns. This pattern echoes findings by Venkatesh et al. (2016) in their extended UTAUT2 model, which identifies performance expectancy (analogous to PU) as consistently the strongest predictor of technology adoption intention across diverse user populations, including those with limited prior technology exposure. The role of the PPL as a facilitating condition, in TAM terms, an external variable that enhances both PU and PEOU perceptions, is also theoretically significant. Institutional support and training quality are well-established moderators of TAM adoption pathways in agricultural technology contexts (Mwangi & Kariuki, 2015), and the Puusangi findings corroborate this relationship.

Diffusion of Innovation Theory provides a complementary community-level lens for understanding how TaniFlow spread through the social system of the farmer group (Rogers, 2003). Table 3 evaluates TaniFlow against Rogers' five innovation attributes.

Table 3

Diffusion of Innovation Analysis of TaniFlow Implementation

Attribute	Assessment	Evidence from Puusangi Village
Relative Advantage	HIGH clear superiority over manual system	Distribution cycle reduced by 78–85%; near-zero recording errors; elimination of quota disputes that had generated persistent intra-group conflict
Compatibility	HIGH aligned with existing operational workflows	TaniFlow mirrors the logical sequence of manual distribution tasks; cultural and workflow fit facilitated adoption without requiring major behavioural restructuring
Complexity	LOW accessible to non-technical users	Two-day training sufficient for primary operators; interface simplicity acknowledged by administrators despite limited prior digital experience
Trialability	HIGH tested across one full growing season before full commitment	Trial period allowed administrators to compare system outputs with manual records, building confidence incrementally before fully abandoning paper-based systems
Observability	HIGH results visible to all group members	Farmers observed real-time quota displays, eliminating informational disputes; visible outcomes accelerated acceptance among initially sceptical members

Source: Author's own work, 2024

A particularly important finding within the diffusion framework is the role of Observability in accelerating acceptance among initially hesitant farmer members. Because quota information was now displayed transparently through the system, all members could directly verify their individual allocations, a feature that not only reduced disputes but functioned as a live demonstration of the system's value for every member of the group. This aligns with Klerkx et al. (2019) observation that in agricultural communities, peer observation of tangible outcomes is often more persuasive than formal extension messaging in driving technology uptake. The PPL's role as a change agent is also consistent with Rogers (2003) identification of change agents as critical accelerators of diffusion in social systems characterized by high uncertainty and low prior technology exposure. By providing continuous technical support and building

interpersonal trust with administrators, the PPL effectively lowered the perceived complexity of TaniFlow and reinforced its relative advantage over the prior system.

Impact of TaniFlow on Distribution Efficiency and Agricultural Productivity

The most immediately apparent efficiency gain from TaniFlow implementation was a dramatic reduction in distribution cycle time. Prior to adoption, the process from fertilizer arrival at the kiosk to complete member distribution took two to three weeks, a delay attributable to the time required for manual member verification, quota calculation, physical receipt collection, and report compilation. Following TaniFlow implementation, this cycle was compressed to three to five days, representing a reduction of 78 to 85 percent.

Before TaniFlow, the distribution process could take 2–3 weeks from when the fertilizer arrived at the kiosk until all members had received their allocation. This was because we had to record everything manually, calculate quotas one by one, and arrange pick-up schedules. Now, the process takes only 3–5 days. The system calculates quotas automatically, pick-up schedules are coordinated through the system, and recording is much faster. (Farmer Group Chair, Puusangi Village)

From a farmer's perspective, this speed improvement had direct consequences for crop management:

Previously, fertilizer often arrived late, so I was late in fertilizing my rice. As a result, plant growth was not optimal and yields declined. Now with TaniFlow, we know when fertilizer will arrive, can plan our fertilization properly, and the fertilizer reaches us on time according to the plant growth stage. (Farmer Member, Puusangi Village)

TaniFlow's automated quota calculation engine eliminated the manual arithmetic errors that had previously generated both administrative inefficiency and inter-member conflict. Quotas are computed directly from each member's registered land area data, applying government-mandated application rates for each crop type (Urea: 250 kg/ha; NPK: 150 kg/ha for rice). This automation ensured that every member received a precisely calculated entitlement, regardless of the computational capacity of the operator. Individual farmer members confirmed the practical impact of improved accuracy: “I never get the wrong allocation anymore. Before, it often came out smaller than it should have been” (Farmer Member, Puusangi Village).

Transparency was identified by informants across all stakeholder categories as the most transformative dimension of TaniFlow's impact. The system provides real-time dashboard access for farmer group administrators, the PPL, and the Dinas Pertanian Kabupaten Konawe, enabling remote monitoring of quota status, distribution progress, and remaining stock without requiring physical field visits.

TaniFlow gives us full visibility over fertilizer distribution at the farmer group level—from stock levels, to who has collected their allocation, to any distribution anomalies. This is far more effective than manual monitoring, which required repeated field visits. (Staff, Dinas Pertanian Kabupaten Konawe)

The PPL observed that intra-group conflict over quota allocation, previously a recurring source of tension, was effectively eliminated: “There used to be many complaints about quotas, but

after the system was used, grievances almost disappeared entirely because everything is clearly recorded” (Field Agricultural Extension Officer (PPL), Puusangi Village).

The digital audit trail embedded in TaniFlow proved highly effective in deterring and detecting fertilizer misappropriation. Each distribution transaction is time-stamped and linked to a specific member's identity, creating an immutable record that distributors, administrators, and government monitors can cross-reference at any time. The result was a near-complete elimination of the 5–7 suspected misuse cases that had been reported annually under the manual system:

Before TaniFlow, there were occasionally people trying to purchase subsidized fertilizer using someone else's identity or fictitious data. Now, with strict digital verification and real-time recording, it is very difficult to commit such fraud. Every transaction is recorded with digital evidence and can be traced. (Fertilizer Distributor, Puusangi Village)

This finding is consistent with Sari et al. (2024) argument that digital documentation systems reduce the informational opacity that enables opportunistic behaviour in subsidy distribution chains. The audit trail functions as both a deterrent, through the certainty of detection and an accountability mechanism through the availability of evidence for post-hoc verification.

Table 4 synthesizes the four efficiency dimensions documented above against Chopra and Meindl (2014) analytical framework and connects each to the relevant theoretical literature.

Table 4

TaniFlow Performance Against the Supply Chain Efficiency Framework

Efficiency Dimension	Pre-TaniFlow Baseline	Post-TaniFlow Outcome	Theoretical Link
Speed	2–3 weeks per distribution cycle	3–5 days per cycle (78–85% reduction)	Supply chain velocity improvement (Chopra & Meindl, 2014): reduced cycle time enables timely fertilizer application at optimal crop growth stages
Accuracy	Frequent manual recording errors; quota miscalculations common	Near-zero recording errors; automated per-hectare quota calculation	Technical efficiency gains (Farrell, 1957): automated systems minimize waste from over/under-allocation
Transparency	No real-time visibility; monitoring required repeated field visits	Real-time multi-stakeholder dashboard; all quota and distribution data accessible	Information asymmetry reduction (Sari et al., 2024): transparency deters opportunistic behaviour and builds institutional trust
Leakage Minimization	5–7 suspected misuse cases per year; no audit capability	Near-zero misuse; permanent digital audit trail	Accountability mechanism theory (Zuhriyah et al., 2023): digital trails function as inherent deterrents to misappropriation

Source: Author's own work, 2024

The cumulative efficiency gains across all four dimensions represent what Chopra and Meindl (2014) term a fundamental improvement in supply chain responsiveness: the system can now deliver the right product, to the right person, at the right time, with complete information

visibility for all stakeholders. This multi-dimensional improvement is particularly significant because prior research has demonstrated that gains in any single efficiency dimension, speed alone, or accuracy alone, are insufficient to prevent leakage and ensure program effectiveness; it is the combination that produces systemic change (Jamil et al., 2023).

Agricultural Productivity Outcomes

The most consequential downstream outcome of TaniFlow's efficiency gains was a perceived improvement in agricultural productivity among farmer group members. For rice cultivators, who represent the majority of Puusangi Village's farming population, informants consistently reported experiencing noticeably better harvests following TaniFlow implementation, attributing this change to improved timeliness and accuracy of fertilizer delivery. Because this study employs a qualitative design, any yield figures cited below reflect informants' own recollections and self-assessments as gathered through in-depth interviews and cross-validated against available farmer group harvest records; they are not derived from controlled agronomic measurement and should be interpreted as indicative rather than statistically precise. Maize farmers similarly described perceived improvements in crop performance, specifically attributing these changes to the elimination of fertilizer delays during critical vegetative and reproductive growth stages. Consistent with the qualitative nature of this study, the following account represents the informant's subjective experience and observation rather than measured agronomic data.

Table 5 summarizes the productivity outcomes by commodity and links them to the specific mechanisms through which TaniFlow's efficiency gains translated into yield improvements.

Table 5

Informant-Reported Perceptions of Agricultural Productivity Change by Commodity and Theoretical Mechanistic Attribution

Commodity	Recalled Yield (Pre-TaniFlow)	Perceived Change (Post-TaniFlow)	Attribution and Mechanism
Rice (Padi)	Informants recalled approximately ~4.5 tonnes/hectare (self-reported; not independently verified)	Perceived improvement to approx. 5.5–6.0 tonnes/hectare (informant self-report, triangulated with kelompok tani harvest records; not independently measured)	Timely fertilizer delivery enabled application at tillering and panicle initiation stages; accurate Urea (250 kg/ha) and NPK (150 kg/ha) dosage optimized nitrogen uptake
Maize (Jagung)	Below-optimal; inconsistent cob fill	Healthier plants; larger, denser cobs	Elimination of delays during vegetative and reproductive growth stages; accurate quota prevented under-dosing that previously stunted root development and grain fill

Source: Author's own work, 2024

The productivity gains documented in Table 5 are theoretically significant because they represent an increase in Total Factor Productivity rather than a simple expansion of input volume. Farmers did not receive more fertilizer after TaniFlow implementation; they received

the same quantity or in some cases a more precisely calculated and thus more appropriate quantity, but delivered at the optimal point in the crop growth cycle. This distinction is central to TFP theory: Keith (2015) defines TFP gains as improvements in output per unit of combined inputs, arising not from input additions but from enhanced efficiency of input utilization.

Based on informants' accounts and the available contextual evidence, the mechanism connecting TaniFlow adoption to perceived TFP improvement plausibly operates through three channels. First, the elimination of distribution delays enabled fertilizer to be applied closer to the critical nutrient-responsive windows of crop development, particularly tillering and panicle initiation for rice, and the vegetative stage for maize when nutrient uptake efficiency is highest. Second, the accuracy of automated quota calculation aligned dosage more closely with agronomic recommendations (Urea 250 kg/ha; NPK 150 kg/ha for rice), reducing the risk of both the yield-suppressing effects of under-fertilization and the efficiency losses of over-application. Third, the elimination of emergency purchases of non-subsidized fertilizer, a common adaptive response to subsidy delays under the manual system, reduced effective input costs per farmer, improving economic productivity even in cycles where physical yields showed modest change. These mechanisms are inferred from qualitative evidence and should be confirmed through quantitative longitudinal study.

This finding suggests that the efficiency gains of digital supply chain management may produce perceived productivity improvements in ways theoretically consistent with TFP gains without any change in the physical composition of inputs provided. While the qualitative nature of this study precludes causal attribution, the consistency of informant accounts across multiple stakeholder groups lends credibility to this interpretation. Future quantitative research comparing TaniFlow and non-TaniFlow farmer groups within the same agroecological zone would be necessary to confirm these inferences and estimate the magnitude of TFP gains with statistical precision. Notwithstanding this limitation, the finding has important implications for policy: investment in distribution system digitalization may generate productivity-related returns that complement, and in some contexts rival, investment in new agricultural technologies.

The productivity and cost-reduction gains documented above translated into measurable improvements in farmer household welfare, a finding that connects TaniFlow's technical impact to the broader social welfare objectives of Indonesia's subsidized fertilizer program. The PPL, who is positioned to observe welfare changes across the farming community, provided the most comprehensive account of these downstream effects:

Since TaniFlow was implemented and fertilizer distribution improved, I can see that farmers in Puusangi Village are better off. They are able to send their children to higher levels of education, renovate their homes, and set aside savings for the future. This shows that the fertilizer subsidy program, when distributed efficiently, truly impacts the improvement of farmer welfare. (Field Agricultural Extension Officer (PPL), Puusangi Village)

These welfare gains are consistent with the predictions of Lestari et al. (2024), who argue that efficient distribution of agricultural subsidies generates compound welfare benefits: higher yields increase gross income, while reduced dependency on non-subsidized inputs decreases production costs, together expanding net household income in ways that have tangible effects on education, housing, and savings capacity. The finding also affirms Rachman's (2009) foundational argument that the welfare impact of Indonesia's fertilizer subsidy program is

directly contingent on the efficiency of its distribution, a relationship that TaniFlow appears to have significantly strengthened in the Puusangi context.

Conclusion

This study concludes that the implementation of TaniFlow as a web-based information system has improved the management of subsidized fertilizer distribution among farmer groups in Puusangi Village, Konawe Regency, Southeast Sulawesi, by transforming the previous manual and paper-based system into a more efficient, accurate, transparent, and accountable digital mechanism. Through member registration, automated quota calculation, real-time distribution recording, and automated report generation, TaniFlow reduced administrative errors, minimized data duplication, shortened the distribution cycle from two to three weeks to only three to five days, reduced quota disputes and misuse, and strengthened farmer trust in the distribution process. The findings imply that digital transformation at the farmer group level can support not only administrative efficiency but also agricultural productivity and farmer welfare by ensuring that subsidized fertilizer reaches the right farmers, in the right amount, and at the right time for critical crop growth stages. However, this study is limited by its qualitative design, its focus on one village context, and its reliance on informants' experiences rather than controlled agronomic measurement. Therefore, future studies are recommended to use quantitative or mixed-method approaches to measure the long-term impact of TaniFlow on crop yields, production costs, household income, and farmer welfare, as well as to compare digital and non-digital fertilizer distribution systems in different rural areas.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

The author declares that Grammarly, an AI-assisted writing software, was used in proofreading and refining the English language used in the manuscript. The usage was limited to correcting grammatical and spelling errors, improving punctuation, and refining sentence clarity. The author further declares that, apart from Grammarly, no other AI or AI-assisted technologies were used to generate content in writing the manuscript. The ideas, research design, procedures, findings, analyses, and discussion are originally written and derived from the careful and systematic conduct of the research.

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