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Analyzing Farmers' Interpersonal Communication Networks in the Utilization of Two-Wheel Tractors in Panyabungan, Mandailing Natal Regency

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Abstrak

Modernisasi pertanian dalam dekade terakhir ditandai dengan percepatan mekanisasi, digitalisasi, dan pemanfaatan teknologi cerdas untuk meningkatkan produktivitas dan keberlanjutan. Di negara berkembang, adopsi mekanisasi tidak hanya ditentukan oleh aspek teknis, tetapi juga dipengaruhi oleh dinamika sosial dan kualitas komunikasi antarpetani. Traktor roda dua, meskipun sederhana, terbukti strategis bagi petani kecil karena terjangkau dan sesuai dengan keterbatasan lahan. Namun, rendahnya literasi teknis dan akses modal membuat penyebaran informasi melalui jaringan komunikasi menjadi faktor kunci dalam mempercepat adopsi. Penelitian ini dilaksanakan di Kecamatan Panyabungan, Kabupaten Mandailing Natal, dengan melibatkan 103 petani dari lima kelompok tani. Analisis dilakukan melalui Structural Equation Modeling (SEM-PLS) dan Social Network Analysis (SNA). Hasil SEM-PLS menunjukkan bahwa komunikasi interpersonal berpengaruh signifikan terhadap intensitas penggunaan traktor roda dua ($\beta = 0{,}421$; $p < 0{,}01$). Temuan SNA memperlihatkan perbedaan peran aktor dalam jaringan: MK (Ketua Kelompok Satahi) memiliki nilai outdegree tertinggi (0,255) sebagai penyebar utama informasi, MB (anggota Satahi) menempati indegree tertinggi (0,69) sebagai rujukan informasi, sementara GM (anggota Sahata) menunjukkan betweenness tertinggi (8,82) sebagai penghubung utama antaranggota. Dari sisi closeness, MK (Satahi, 2,01) dan GM (Sahata, 2,02) menempati posisi terdepan dalam menjangkau anggota lain secara cepat. Hasil ini menegaskan bahwa adopsi mekanisasi sederhana tidak dapat dilepaskan dari dimensi sosial. Secara teoretis, penelitian ini memperluas literatur mekanisasi dengan pendekatan jejaring sosial, sementara secara praktis merekomendasikan strategi penyuluhan berbasis jejaring yang melibatkan opinion leader dan kelompok rentan, sehingga mekanisasi tidak hanya meningkatkan efisiensi produksi, tetapi juga memperkuat kohesi sosial dan keberlanjutan pertanian pedesaan.

Kata kunci: Difusi inovasi, Komunikasi interpersonal petani, Mekanisasi pertanian, *Social network analysis*, Traktor roda dua

Abstract

Agricultural transformation in the past decade has been driven by rapid mechanization, digitalization, and the use of smart technologies to enhance productivity, cost efficiency, and sustainability. In developing countries, however, mechanization is not merely a technical matter but also a social process shaped by farmers' communication networks. The two-wheel tractor, although simple, is a strategic innovation for smallholders due to its affordability and suitability for limited land. Yet, adoption remains constrained by low technical literacy, limited capital, and inadequate after-sales services, making interpersonal communication among farmers essential for knowledge sharing and technology diffusion. This study was conducted in Panyabungan District, Mandailing Natal Regency, North Sumatra, involving 103 farmers from five farmer groups. The research employed Structural Equation Modeling (SEM-PLS) to test causal relationships and Social Network Analysis (SNA) to map communication structures. SEM-PLS results confirm that interpersonal communication significantly influences the intensity of two-wheel tractor utilization ($\beta = 0.421$; $p < 0.01$). SNA further reveals distinct actor roles: MK (head of Satahi group) recorded the highest outdegree (0.255) as the primary information disseminator; MB (Satahi member) had the highest indegree (0.69) as the most trusted reference; GM (Sahata member) achieved the highest betweenness (8.82), acting as a critical information broker; while MK (Satahi, 2.01) and GM (Sahata, 2.02) also demonstrated the highest closeness values, enabling faster information reach across the network. These findings highlight that mechanization adoption is deeply embedded in social structures. Theoretically, the study enriches mechanization literature by integrating social network perspectives. Practically, it provides evidence for network-based extension strategies that empower opinion leaders, women, and youth, ensuring more inclusive, efficient, and sustainable diffusion of agricultural innovations in rural communities.

Keywords: Agricultural mechanization, Innovation diffusion, Interpersonal communication, Social network analysis, Two-wheel tractor

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INTRODUCTION

Recent decades have witnessed profound transformations in global agricultural systems, characterized by the acceleration of mechanization, digitalization, and the application of smart technologies to enhance productivity, cost efficiency, and sustainability in farming practices. For developing countries, the adoption of agricultural mechanization is not merely a technical matter but also a social process involving collective learning, knowledge exchange, and the legitimization of practices at the community level. The two-wheel tractor (hand tractor), despite its simplicity, plays a crucial role in rice cultivation modernization due to its compatibility with the characteristics of small-scale farming on limited landholdings. Its effective utilization, however, largely depends on how quickly farmers access information regarding costs, benefits, and usage strategies factors that are deeply embedded in the quality of interpersonal communication networks (Colussi *et al*., 2024; Zhang *et al*., 2024).

In the Indonesian context, agricultural development policies emphasize small- and medium-scale mechanization, which is highly relevant for smallholders as the backbone of national food security. Hand tractors are considered strategically important because they are relatively affordable, versatile, and reduce dependency on increasingly scarce manual labor. Nevertheless, numerous studies have highlighted the low adoption rates of agricultural machinery due to limited technical literacy, capital constraints, and inadequate after-sales services. Farmer-to-farmer communication networks therefore become the primary channels for sharing knowledge on machine maintenance, operational costs, and collective strategies such as sharing or renting equipment. This positions interpersonal communication as a determinant factor, equally important as economic or technical considerations in the adoption of hand tractors (Herdiansyah *et al*., 2023; Badan Pusat Statistik Kabupaten Mandailing Natal, 2024).

Social network theory provides a compelling framework to understand these dynamics, emphasizing that community-level relational structures shape the speed and direction of innovation diffusion. Dense networks accelerate the flow of information, while actors with high centrality often act as opinion leaders. Conversely, overly homogenous networks may hinder the inflow of novel information. Evidence from various agricultural sectors suggests that such communication patterns influence not only the adoption of digital innovations but also conventional mechanization, including hand tractors. Mapping these farmer networks is thus critical to identify bridging actors, gatekeepers of information, and

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the local pathways through which technical knowledge circulates (Matous *et al*., 2024; Hidayat *et al*., 2024).

At the local level, Panyabungan District in Mandailing Natal Regency, North Sumatra, is recognized as a major agricultural and horticultural hub underpinning the regional economy. Data from *Mandailing Natal Regency in Figures 2024* and the *2023 Agricultural Census* show the dominance of smallholder farming with limited landholdings, underscoring the relevance of hand tractors in this area. Yet, most existing studies focus on aspects of land cultivation and production costs, with little attention paid to the social dimension of farmer communication networks. Understanding these dynamics is essential to explain adoption disparities across regions despite comparable levels of equipment availability (Badan Pusat Statistik Kabupaten Mandailing Natal, 2024).

Beyond technical efficiency, farmer communication also intersects with issues of inclusivity and sustainability. Recent research highlights how women and younger generations are often excluded from decision-making regarding mechanization, even though they contribute substantially to agricultural activities. Social network analysis (SNA) can reveal the extent to which these marginalized groups gain access to information and opportunities to participate in hand tractor utilization. From a sustainability perspective, increasing mechanization also entails socio-environmental implications: land intensification may affect soil quality, while shifts from traditional labor-sharing systems to rental arrangements could alter village-level social cohesion. Thus, this research is not only technically relevant but also contributes to advancing inclusive and sustainable agricultural development (Food and Agriculture Organization of the United Nations, 2023; Herdiansyah *et al*., 2023).

Methodologically, social network analysis (SNA) offers a robust analytical framework to address these issues by mapping key actors, levels of connectivity, and the flow of information within farmer networks. Although widely applied to digital technology adoption and environmentally friendly practices, studies employing SNA to examine two-wheel tractor usage in Indonesia remain scarce. This gap opens opportunities for research that enriches both the academic literature and local policymaking (Hidayat *et al*., 2024; Matous *et al*., 2024).

Based on this background, the objectives of this study are to map the structure of interpersonal communication networks among farmers regarding the use of hand tractors in Panyabungan District, Mandailing Natal Regency. Identify key actors and dominant

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information pathways influencing decisions on adoption, rental, and maintenance. Analyze the relationships between network attributes such as degree centrality, betweenness, and density and the intensity of hand tractor utilization.

Through these aims, the study seeks to make a dual contribution: theoretically, by advancing the literature on socially embedded mechanization, and practically, by providing insights for extension agents, local governments, and farmer groups in designing more effective, inclusive, and sustainable technology diffusion strategies (Colussi *et al*., 2024; Badan Pusat Statistik Kabupaten Mandailing Natal, 2024).

RESEARCH AND METODOLOGY

The study was conducted in Pidoli Village, Panyabungan District, Mandailing Natal Regency, North Sumatra Province. The location was selected purposively based on three considerations: (1) the majority of residents are engaged in farming, (2) the average size of cultivated land is relatively larger compared to neighboring villages, and (3) farmers have widely adopted two-wheel tractors as their primary tool for land preparation. Fieldwork took place between December 2021 and January 2022.

This study employed a quantitative explanatory design. The quantitative approach emphasizes the collection of numerical data for statistical analysis, while the explanatory dimension was chosen to not only describe the phenomenon but also to test causal relationships between variables and explain both antecedents and outcomes. Two complementary analytical methods were applied: Structural Equation Modeling (SEM-PLS) using SmartPLS software to examine causal relationships among latent variables. Social Network Analysis (SNA) using UCINET-NetDraw to map farmers' communication structures, identify key actors, and measure network indicators such as outdegree centrality, indegree centrality, closeness centrality, and betweenness centrality. The integration of SEM-PLS and SNA provided a comprehensive perspective by combining variable-level causal testing with network-level communication mapping.

The population comprised all farmers in Mandailing Natal Regency who had adopted two-wheel tractors. Out of 17 districts, 14 were identified as active users of this technology. A *stratified random sampling* technique was applied in several stages: identifying districts with the highest number of hand tractor users, selecting Panyabungan District as the study site, choosing Pidoli Village purposively, based on land size and number of tractor users, from 25 farmer groups in the village, five groups were randomly selected as research respondents. The final sample consisted of 103 farmers, distributed as

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follows: Satahi (21), Sahata (21), Sepakat (16), Willem Iskander (30), and Biara Dagang (15).

Two main data sources were utilized primary data that obtained through field observations, in-depth interviews with farmers and extension agents, and structured questionnaires completed by respondents. Secondary data, drawn from institutional records (BPS Mandailing Natal, BP3K Mandailing Natal), official reports, and other relevant documentation related to agricultural mechanization.

Multiple techniques were employed to ensure comprehensive data collection. Direct observation, involving systematic recording of farmers' behavior and activities in using hand tractors. Structured and semi-structured interviews, conducted with farmers, tractor owners, farmer group leaders, and extension officers to capture deeper insights. Questionnaires, designed with measurable scales to obtain quantitative data on farmer characteristics, farm practices, and communication intensity. Documentation review, including archival records, official reports, and field photographs supporting the analysis.

Research instruments were rigorously tested to ensure quality consisted of convergent validity was assessed using outer loading values (>0.60), discriminant validity was evaluated through Average Variance Extracted (AVE), with thresholds of >0.50, reliability was tested using Cronbach's Alpha and Composite Reliability, with minimum acceptable values of 0.70. Results confirmed that all constructs met the validity and reliability requirements, making them suitable for further analysis.

Data analysis proceeded in two stages. Measurement model (outer model) evaluation, to assess indicator reliability, convergent validity, discriminant validity, and construct consistency. Structural model (inner model) evaluation, to test relationships among latent variables through R-square values, path significance, and predictive relevance (Q-square).

In parallel, Social Network Analysis (SNA) was applied to compute centrality measures within farmer communication networks. Visualization was carried out using UCINET-NetDraw to generate sociograms, enabling a clear depiction of farmer linkages and identification of key actors within the network.

RESULTS AND DISCUSSION

General Overview of the Research Area

Pidoli Dolok and Pidoli Lombang Villages, located in Panyabungan District of Mandailing Natal Regency, are characterized by their strong agrarian profile. The

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geographical condition, consisting of flatlands supported by technical irrigation systems, makes the area highly suitable for lowland rice cultivation. Land-use data reveal that more than 80% of the area is devoted to agriculture, while non-agricultural sectors account for only a minor share. Farming is the dominant livelihood, with most residents engaged either as landowners or tenant farmers.

These findings reinforce the rationale for selecting Pidoli as a representative location to investigate farmer communication patterns in adopting agricultural technology, particularly the two-wheel tractor. Such observations are consistent with the Food and Agriculture Organization of the United Nations (2023), which highlights that agrarian-based regions are more responsive to the adoption of simple mechanization tools due to their immediate need for efficiency in land preparation.

Table 1. Land use in Pidoli Village (2025)

Land Use Type	Area (Ha)	Percentage (%)
Settlements	40	2.17
Irrigated rice	250	13.56
Rainfed rice	50	2.90
Others	1,504	81.56

Updated: 2025

Farmers' Characteristics

The analysis indicates that most farmers are within the productive age group (41–55 years), while a smaller proportion fall into the highly productive category (25–40 years). This suggests that the farmers still possess sufficient physical capacity and farming experience to adopt and practice agricultural innovations.

Table 2. Farmers' characteristics in Pidoli Village (2025)

Variable	Category	Number	Percentage (%)
Age	25–40 (Highly Productive)	18	17.5
Age	41–55 (Productive)	47	45.6
Age	>55 (Less Productive)	38	36.9
Education	Low	32	31.1
Education	Secondary	64	62.1
Education	Higher	7	6.8
Farming Experience	<10 years	30	29.1
Farming Experience	11–20 years	45	43.7
Farming Experience	>20 years	28	27.2
Cosmopolitan Level	Low	34	33.0
Cosmopolitan Level	Medium	6	5.8
Cosmopolitan Level	High	63	61.2

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The majority of farmers in Pidoli Village are in their productive years and have attained secondary-level education. This demographic profile supports the earlier proposition that interpersonal communication networks play a pivotal role in accelerating the diffusion of agricultural innovations. Younger and better-educated farmers are more capable of understanding technical information and tend to adopt two-wheel tractor technology more rapidly. Furthermore, a high level of cosmopolitanism enhances the spread of innovation, as farmers actively seek knowledge beyond their local context and disseminate it through farmer groups.

These findings align with Matous *et al*. (2024), who emphasized the significance of social networks in technology diffusion, and Zhang *et al*. (2024), who highlighted the role of education and interpersonal communication in accelerating mechanization adoption. Therefore, it can be concluded that the combination of productive age, secondary education, and high cosmopolitan levels creates a favorable social foundation for agricultural innovation in Pidoli Village. These factors not only accelerate the diffusion of two-wheel tractor adoption but also strengthen the capacity of farmer groups to serve as agents of change in promoting sustainable agricultural development.

This finding underscores the importance of human capital and social dynamics in shaping the trajectory of mechanization in smallholder farming systems. While technological availability remains a prerequisite, its effective utilization is highly contingent on farmers' demographic characteristics and their access to communication networks. Productive-age farmers with adequate education demonstrate greater openness to innovation, while cosmopolitan individuals play a bridging role by linking local knowledge with external sources of information. Such conditions enhance the flow of technical know-how across farmer groups, thereby reducing information asymmetry and enabling more equitable access to agricultural technologies.

Moreover, these results highlight the role of farmer organizations not only as recipients of innovation but also as institutional actors capable of facilitating collective decision-making, resource sharing, and knowledge dissemination. The strengthening of farmer groups in Pidoli illustrates how localized social structures can be mobilized to accelerate mechanization while maintaining inclusivity and sustainability. This aligns with the broader literature emphasizing that agricultural innovation is a socially embedded process, where trust, reciprocity, and collaborative learning are as critical as technical efficiency.

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From a policy perspective, the evidence suggests that government and extension agencies should adopt strategies that integrate technical training with social-network strengthening initiatives. Programs designed to empower younger farmers, enhance rural education, and expand access to external information sources can significantly amplify the impact of mechanization policies. Equally important, acknowledging and leveraging the role of cosmopolitan farmers as opinion leaders may accelerate diffusion and improve adoption outcomes. By combining technical support with social empowerment, interventions can move beyond narrow efficiency gains toward fostering a resilient and sustainable agricultural transformation.

Interpersonal Communication Networks in Pidoli Village, Panyabungan District, Mandailing Natal Regency

The analysis of interpersonal communication networks plays a critical role in understanding how agricultural information flows among members of farmer groups. Each actor in the network assumes a distinct role: *opinion leaders* act as primary references, *bridges* connect otherwise separate groups, *hubs* coordinate interactions, *gatekeepers* filter information, and *isolates* remain relatively passive (Eriyanto, 2014). Through this approach, it becomes possible to map which farmers occupy strategic positions in disseminating information on the use of two-wheel tractors.

Centrality serves as a key indicator for identifying such strategic roles. Degree centrality reflects the extent of an actor's connections, whether in terms of disseminating (outdegree) or receiving information (indegree). Closeness centrality measures how quickly an actor can access information from the network as a whole, while betweenness centrality highlights actors serving as intermediaries who connect otherwise unlinked individuals (Bonacich, 1984). Taken together, these metrics provide a comprehensive picture of who drives innovation diffusion within the farmer network.

The results from Pidoli Village show that each farmer group has key actors who play dominant roles in information dissemination. Farmers with high outdegree values serve as the primary disseminators of information on two-wheel tractor use, while those with high indegree values are trusted sources from whom others seek knowledge. Furthermore, closeness and betweenness centrality reveal the importance of certain farmers in bridging both intra- and inter-group communication, preventing information bottlenecks and ensuring that knowledge circulates across the network.

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These findings align with Matous *et al*. (2024), who reported that the social networks of cocoa farmers in Indonesia exhibit a hub-and-spoke structure that accelerates the homogenization of agricultural practices. Similarly, Nababan (2021) found that farmers with high betweenness centrality act as crucial connectors in agricultural cooperatives in North Sumatra. Colussi *et al*. (2024) also emphasize that interpersonal communication is a decisive factor in mechanization adoption in Brazil and the United States.

Consequently, interpersonal communication networks should be understood not merely as channels of information but as social structures that shape the speed and breadth of innovation adoption. Identifying central actors within Pidoli's farmer networks provides empirical evidence that the success of two-wheel tractor diffusion is strongly determined by those who occupy strategic positions in the group.

This perspective highlights that innovation is not diffused uniformly across farming communities but is mediated by the relational architecture of the network itself. Farmers who serve as central actors whether as disseminators of knowledge, trusted references, or intermediaries hold the capacity to accelerate or constrain the adoption process. Their influence extends beyond individual decision-making to collective behavioral change, thereby reinforcing the argument that mechanization adoption is as much a social phenomenon as it is a technical one.

Moreover, recognizing communication networks as embedded social structures offers important practical implications. Extension strategies and agricultural policies that rely solely on technical training or equipment distribution may fall short if they fail to consider the dynamics of local communication. Targeting opinion leaders and highly connected farmers can significantly enhance the reach and credibility of innovation campaigns. In this way, interventions can leverage existing trust networks to achieve more efficient, equitable, and sustainable outcomes.

In the context of Pidoli, strengthening farmer groups by empowering central actors while also integrating peripheral members is essential to avoid information gaps. Encouraging inclusivity ensures that innovation does not remain concentrated among a small subset of influential farmers but rather spreads across the entire community. This balanced approach aligns with broader development goals, where agricultural modernization is pursued not only for productivity gains but also for strengthening social cohesion and resilience in rural areas.

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Degree Centrality

Network analysis further demonstrates that not all farmers play equivalent roles in information exchange. Some individuals function as central nodes capable of accelerating innovation diffusion, while others act primarily as information receivers. This asymmetry can be visualized through degree centrality, which measures how many ties an actor maintains within the network either as an information sender (*outdegree*) or receiver (*indegree*). Mapping these values allows researchers to identify the main drivers of technology adoption at the group level.

Table 3. Outdegree and Indegree Centrality of Interpersonal Communication Networks (updated: 2025)

Centrality Type	Farmer Group	Actor	Outdegree/Indegree Value	Position
Outdegree Centrality	Satahi	MK	0.255	Group Leader
		AH	0.131	Member
		MB	0.083	Member
	Sahata	IF	0.076	Group Leader
		RS	0.074	Member
		MI	0.069	Member
	Sepakat	KH	0.076	Group Leader
		AS	0.074	Member
		MB	0.055	Member
	Willem Iskander	NS	0.207	Group Leader
		MB	0.200	Member
		SW	0.166	Member
	Biara Dagang	PL	0.076	Member
		KH	0.069	Member
		PD	0.055	Group Leader
Indegree Centrality	Satahi	MB	0.690	Member
		SA	0.620	Member
		MK	0.550	Group Leader
	Sahata	SP	0.690	Member
		SD	0.620	Member
		MI	0.550	Group Leader
	Sepakat	KH	0.113	Group Leader
		HN	0.620	Member
		LM	0.550	Member
	Willem Iskander	NS	0.620	Group Leader
		MH	0.550	Member
		EN	0.550	Member

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Centrality Type	Farmer Group	Actor	Outdegree/Indegree Value	Position
	Biara Dagang	PN	0.620	Group Leader
		AP	0.550	Member
		AS	0.550	Member

Closeness Centrality

Closeness centrality measures how quickly an actor can reach other members within a communication network. The higher the closeness score, the greater the ability of an individual to connect directly or indirectly with others. In the context of farmer groups, actors with high closeness centrality serve as *bridges* who accelerate the flow of information by minimizing the number of intermediaries required for communication. Such actors become critical figures in strengthening social integration while simultaneously facilitating the rapid adoption of agricultural innovations (Eriyanto, 2014).

The results from Pidoli Village highlight that several actors occupy strategic positions as connectors. As shown in Table 4, actor MK from the Satahi group (2.01) and actor GM from the Sahata group (2.02) recorded the highest closeness scores, indicating their ability to quickly access and transmit information across members. These individuals act as key facilitators of communication cohesion. Conversely, actors with low closeness scores, such as PN from the Biara Dagang group (0.69), are positioned at the margins of the network and remain weakly connected. This pattern suggests that the distribution of information within groups is uneven and highly dependent on a limited set of central actors.

These findings are consistent with Zhang *et al*. (2024), who demonstrated that high-closeness actors in rice-farming communities in China function as bridges for accelerating the adoption of water-saving technologies. Similarly, Matous *et al*. (2024) reported that farmers with extensive network access were instrumental in spreading cocoa management innovations in Indonesia. Colussi *et al*. (2024) further emphasize that the effectiveness of mechanization diffusion in Brazil is strongly influenced by farmers who occupy bridging positions within farmer group networks.

Thus, closeness centrality not only reflects the degree of proximity among actors but also captures the strategic capacity of individuals to reinforce network cohesion. The identification of high-closeness actors in Pidoli Village demonstrates that the successful diffusion of two-wheel tractor adoption is heavily dependent on their role as primary connectors among farmers.

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This finding highlights the dual function of high-closeness actors: on one hand, they accelerate the circulation of innovation-related knowledge within farmer groups, and on the other, they contribute to maintaining social cohesion by linking otherwise distant members of the network. Such actors reduce communication fragmentation, ensuring that innovation messages do not remain confined to elite subgroups but reach the wider farming community. This mechanism is particularly important in rural contexts where formal extension services are limited, and farmer-to-farmer interactions remain the dominant mode of knowledge exchange.

Furthermore, the prominence of closeness centrality underscores that agricultural innovation cannot be explained solely by access to resources or government programs. Rather, it is embedded within the relational fabric of rural communities. When actors positioned at the center of communication structures actively participate in disseminating information, the rate and scale of adoption increase substantially. Conversely, when these actors are absent or disengaged, innovation diffusion slows, and disparities in adoption emerge.

In line with evidence from Zhang *et al*. (2024), Matous *et al*. (2024), and Colussi *et al*. (2024), the Pidoli case reinforces that identifying and empowering bridging actors is essential for designing effective agricultural development strategies. Policymakers and extension agencies could leverage these individuals as community-based facilitators, ensuring that information flows are both inclusive and continuous. Importantly, strategies should not only focus on strengthening central actors but also create mechanisms to integrate peripheral farmers, thereby reducing the risk of innovation inequality.

In conclusion, closeness centrality provides more than a technical measurement of relational distance; it offers a lens to understand the social dynamics that govern agricultural modernization. By positioning high-closeness actors as facilitators of communication, Pidoli's farmer networks illustrate how socially embedded structures determine the effectiveness, inclusivity, and sustainability of mechanization adoption. Moreover, these insights emphasize that fostering innovation in rural communities requires more than distributing technology; it demands strengthening the relational infrastructure that enables equitable knowledge flows.

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Table 4. Closeness centrality of farmers' interpersonal communication network (Updated: 2025)

Centrality Type	Farmer Group	Actor	Closeness Value	Status
Closeness Centrality	Satahi	MK	2.01	Group Leader
		EL	1.80	Member
	Sahata	GM	2.02	Member
		IP	1.94	Member
	Sepakat	KH	1.96	Group Leader
		EH	1.92	Member
	Willem Iskander	NS	1.97	Group Leader
		BD	1.94	Member
	Biara Dagang	AK	1.95	Member
		PN	0.69	Group Leader

Betwenenes Centrality

Betweenness centrality measures the extent to which an actor functions as a connector within a communication network. Actors with high betweenness values act as brokers or gatekeepers, individuals who control the flow of information by determining whether a message is transmitted, modified, or withheld before reaching other members (Eriyanto, 2014). In this sense, betweenness confers structural power to actors, as it allows them to influence the communication pathways and interaction patterns among farmers.

Findings from Pidoli Village indicate that several actors occupy strategic positions as primary connectors. As presented in Table 5, in the Sahata group, actor GM recorded the highest betweenness score (8.82), while in the Willem Iskander group, actor NS held a similarly dominant role with a score of 8.72. In contrast, actors with lower scores, such as MI from the Biara Dagang group (1.69), play a more limited role in facilitating interactions. This distribution demonstrates that only a small subset of farmers truly controls the communication channels within their groups, while the majority remain dependent on them for access to information.

The presence of high-betweenness actors is vital for accelerating innovation adoption, since information regarding the use of two-wheel tractors does not spread evenly but often travels through pathways controlled by opinion leaders. Their position also reflects the hierarchical structure of farmer groups, where access to information is not solely determined by the number of connections (degree centrality) but also by control over strategic communication links.

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These results are consistent with Nababan (2021), who found that farmers with high betweenness in Pidoli played a key role in disseminating information related to cooperative access and agricultural technologies. Recent studies by Matous *et al*. (2024) further support this observation, showing that bridging actors in Indonesian cocoa networks accelerated the diffusion of sustainable farming innovations through informal communication channels. Similarly, Zhang *et al*. (2024) emphasized that in Chinese rice-farming networks, brokers were more effective in promoting eco-friendly technology adoption than internally popular actors with limited external influence.

Therefore, betweenness centrality not only reflects an individual's position in the communication structure but also demonstrates their capacity to regulate the distribution of information. In the case of Pidoli, identifying actors who serve as brokers is a critical step in designing effective extension strategies. By engaging these central connectors as key partners, innovation campaigns can ensure that information regarding two-wheel tractor adoption spreads more rapidly and inclusively across all members of the farmer groups.

These findings also reveal the vulnerability of communication structures that rely heavily on a few central brokers. While high-betweenness actors such as GM and NS accelerate information diffusion, they also create a dependency that may lead to bottlenecks if these individuals withdraw or limit their engagement. This suggests that although betweenness centrality is crucial for ensuring efficiency in communication, it also introduces risks of unequal access when information is overly concentrated in specific actors.

From a practical standpoint, this highlights the importance of designing extension programs that diversify communication pathways. Strengthening horizontal ties among farmers and encouraging collective leadership can reduce the overreliance on a few key brokers. By doing so, farmer networks become more resilient and less vulnerable to disruptions, while maintaining the speed and inclusivity of innovation diffusion.

Table 5. Betweenness Centrality of Farmers' Interpersonal Communication Networks

Centrality Type	Farmer Group	Actor	Betweenness Score	Status
Betweenness Centrality	Satahi	MK	4.55	Group Leader
		RB	2.01	Member
	Sahata	GM	8.82	Member
		IF	1.71	Group Leader
	Sepakat	KH	7.27	Group Leader
		MR	1.51	Member

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Centrality Type	Farmer Group	Actor	Betweenness Score	Status
	Willem Iskander	NS	8.72	Group Leader
		SW	5.79	Member
	Biara Dagang	KH	3.27	Member
		MI	1.69	Member

CONCLUSIONS

Based on the findings of this study, it can be concluded that interpersonal communication networks play a strategic role in accelerating the adoption of two-wheel tractors in Pidoli Village, Panyabungan District, Mandailing Natal Regency. The analysis of degree centrality, closeness centrality, and betweenness centrality demonstrates that farmers do not occupy equal positions within the network. Some act as primary disseminators of information, others as connectors between members, and still others as gatekeepers who regulate the flow of knowledge. These differentiated roles collectively shape the communication structure that determines the effectiveness of innovation diffusion at the local level. The demographic profile of farmers dominated by individuals in their productive age, with secondary-level education and relatively high levels of cosmopolitanism further strengthens the adoption process. These social factors reinforce the argument presented in the introduction that mechanization depends not only on technical and economic aspects but also on the quality of communication networks. As such, the diffusion of simple agricultural innovations, such as two-wheel tractors, can be significantly accelerated when key actors occupying central positions in the network are actively engaged. The results also show that betweenness centrality plays a critical role in ensuring that information does not remain concentrated within a single node but flows across the entire farmer group. This highlights that the success of mechanization adoption is strongly shaped by community social structures and communication patterns. From a practical perspective, the study provides valuable insights for extension workers and policymakers in designing more effective strategies for agricultural technology dissemination. A network-based extension approach can be implemented by leveraging key actors particularly opinion leaders as agents of innovation diffusion. Furthermore, inclusivity must be prioritized, ensuring that women and younger farmers are not marginalized from information access and participation in mechanization practices. With well-designed strategies, agricultural mechanization can not only enhance production

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efficiency but also strengthen social cohesion and contribute to the broader goal of sustainable agricultural development.

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