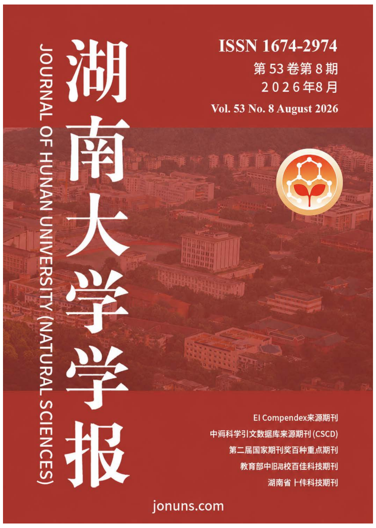

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Communication Network Structures, Innovation Diffusion, and Agricultural Governance: Evidence from Indonesian Farmer Groups

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Abstract: Agricultural systems in developing countries depend on complex interactions among farmers, agricultural extension agents, market actors, and institutions, making communication networks important for innovation diffusion, coordination, food security, and economic resilience. Conventional surveys, however, often fail to capture the relational structures underlying these processes. This study developed and applied a sociometric survey framework integrated with Social Network Analysis (SNA) to examine collaborative communication networks within agricultural systems. Using an exploratory research design, data were collected from 241 maize farmers belonging to two farmer groups located in the northern and southern areas of Lamongan Regency, East Java, Indonesia. Communication networks across nine sustainable agricultural technology (SAT) domains were examined using network density, degree centrality, closeness centrality, and betweenness centrality. The results revealed distinct communication patterns between the two groups. The southern group had denser communication networks for innovation generation and development, whereas the northern group had denser networks for innovation use and harvest-related activities. This mismatch suggests that intensive communication during innovation development does not necessarily correspond to equally developed networks for subsequent adoption and application. Centralized network configurations may facilitate rapid information exchange but can also increase dependence on a limited number of key actors. More distributed configurations may promote broader participation and reduce vulnerability to the loss of individual network actors. These findings demonstrate how the integration of sociometric surveys and SNA can identify structural strengths and communication bottlenecks within farmer groups. The resulting evidence may inform agricultural governance and the design of network-based interventions intended to support innovation diffusion, food security, and economic resilience.

Keywords: social network analysis; sociometric survey; innovation diffusion; agricultural governance; farmer groups; sustainable agricultural technology.

传播网络结构、创新扩散与农业治理：来自印度尼西亚农民群体的证据

摘要： 发展中国家的农业系统依赖农户、农业推广人员、市场主体和相关机构之间的复杂互动，因此，传播网络对于创新扩散、协作协调、粮食安全和经济韧性具有重要意义。然而，传统调查方法往往无法揭示这些过程背后的关系结构。本研究构建并应用了一个与社会网络分析（Social Network Analysis，SNA）相结合的社会计量调查框架，以考察农业系统中的协作传播网络。研究采用探索性研究设计，以印度尼西亚东爪哇省拉蒙岸县北部和南部地区两个农民组织的241名玉米种植户为研究对象收集数据。研究运用网络密度、度中心性、接近中心性和中介中心性等指标，分析了九个可持续农业技术（Sustainable Agricultural Technology，SAT）领域的传播网络。研究结果显示，两个农民组织呈现出不同的传播模式。南部农民组织在创新产生与开发方面具有更为密集的传播网络，而北部农民组织在创新应用和收获相关活动方面的传播网络密度更高。这种不匹配表明，创新开发阶段的密集沟通并不必然意味着后续采纳与应用阶段也会形成同等发达的网络。集中型网络结构可能有助于信息的快速传递，但也可能加剧对少数关键行动者的依赖。分布更为均衡的网络结构则可能促进更广泛的参与，并降低因个别网络行动者流失而产生的脆弱性。研究结果表明，将社会计量调查与社会网络分析相结合，有助于识别农民组织内部的结构性优势和传播瓶颈。相关研究证据可为农业治理以及旨在促进创新扩散、保障粮食安全和增强经济韧性的网络干预措施提供参考。

关键词： 社会网络分析；社会计量调查；创新扩散；农业治理；农民组织；可持续农业技术。

1. Introduction

Agricultural systems in developing countries are increasingly characterized by complex and multi-layered governance arrangements involving diverse actors such as farmers, agricultural extension workers, traders, and formal institutions. In these systems, communication is not merely a supporting function but a central mechanism shaping coordination, innovation diffusion, and production outcomes [1]–[3]. In Indonesia, where small-scale farming dominates agricultural production, these dynamics are particularly pronounced, as farmers operate within dense and interdependent social structures that influence decision-making processes and access to resources then determine the ends of farming and or food security.

Empirical evidence suggests that agricultural innovation and performance are not solely determined by individual characteristics but are fundamentally embedded in communication networks that facilitate coordination and knowledge exchange [1], [4]. General survey approaches often ignore relational structures risk producing analytically incomplete, partial, and potentially misleading explanations of agricultural outcomes, including the policy, etc., [5] in examining the social phenomena and problem hitherto.

From a theoretical perspective, this methodological gap contrasts with established frameworks that emphasize the centrality of social relationships. Diffusion of Innovation Theory [6], [7] conceptualizes innovation adoption as a communication-driven process influenced by social networks and opinion leaders. Similarly, Social Network Theory highlights that actors are embedded in relational structures, where network properties such as centrality, density, and brokerage shape access to information and opportunities [8]. Likewise, Collaborative Governance theory emphasizes that effective coordination in complex systems relies on interaction patterns that foster trust, shared understanding, and collective decision-making [9], [10]. Despite these theoretical advances, empirical survey-based research has been slow to incorporate relational data, resulting in a persistent mismatch between relational theory and individualistic methodologies.

The related previous research take focus on how collaborative communication significant for mutual understanding regarding resilience supply chain and crucial information among the stakeholders [11]. However, the collaborative communication potentials to decrease economic resilience if there is not mutual understanding, discordance of value, goal, and culture[12]. This research strives to fill the gap to find and explain about the collaborative communication in social system, particularly agricultural systems by capturing interaction patterns of farming actors regarding the contextual information [13], [14].

This study integrates sociometric survey data with Social Network Analysis (SNA) to generate quantitative measures of network structure, to enhances the analytical capacity by linking relational configurations to governance outcomes such as innovation diffusion and coordination effectiveness. Also it provides systematic assessment of how varying communication patterns affect agricultural social-stage and performance. Besides, it shows the relation and the click or group and the actors role in social context level by level. Additionally, the group dynamic be traced initially through and based on the result of the Social Network Analysis to support several purposes according to the basis and goal sphere.

2. Literature Review and Research Question Formulation

2.1 Communication Networks in Agricultural Systems

Communication is a fundamental mechanism that enables agricultural innovation systems to operate, enabling knowledge exchange, coordination, and collective problem-solving among heterogeneous actors. As emphasized by Leeuwis agricultural development is inherently communicative, involving repeated interactions between farmers, extension agents, institutions, and markets [2]. Beyond the linear model of knowledge transfer, contemporary perspectives conceptualize innovation as a relational and systemic process, where outcomes emerge from structured interactions within networks [1], [15].

From a network perspective, communication is not simply the transmission of information but also a structural property embedded in social relationships. The configuration of these relationships determines access to resources, learning opportunities, and adaptive capacity. Empirical studies in agricultural innovation systems indicate that communication networks significantly influence technology adoption, resilience, and governance effectiveness [16].

2.2 Social Network Analysis and Governance

Social Network Analysis (SNA) provides a rigorous analytical framework for examining how relational structures shape governance outcomes. Unlike traditional attribute-based approaches, SNA focuses on the patterns of relationships between actors, enabling the quantification of relational dynamics through metrics such as density, centrality, and betweenness [8].

In the context of governance, networks represent coordination mechanisms that complement or replace hierarchical and market-based structures. Bodin and Crona argue that network configuration significantly influences the capacity for collective action, trust formation, and institutional performance [10]. Dense and cohesive networks tend to support cooperation and norm enforcement, while bridging structures facilitate knowledge integration among fragmented groups.

Importantly, governance effectiveness is determined not only by the presence of actors but also by how they are connected, reinforcing the need for relational measurement approaches capable of empirically capturing these structures. This means, that social network survey and analysis can be effectively utilized to portray the social ties, the condition of social relationship, quality of relationship in a social context. It is usually neglected and averted in traditional surveys, although there are still gaps left by social network survey design; for instance, such surveys do not fully account for or present data on naturally occurring social conditions, nor do they capture social dynamics within whole of picture.

2.3 Diffusion of Innovation and Network Structure

The theoretical foundation of innovation diffusion is rooted in the Diffusion of Innovations theory [6], which states that the spread of innovations depends on communication channels, time, and social systems. Within this framework, network structure plays a crucial role in shaping diffusion dynamics.

Highly connected actors (central nodes) serve as information hubs, accelerating the diffusion process, while network topology determines the speed and inclusiveness of adoption. Centralized networks can increase efficiency but risk creating barriers and dependencies, while decentralized networks foster inclusiveness and resilience [17].

Recent empirical studies in agricultural systems confirm that network structure significantly influences innovation adoption, particularly in smallholder contexts where informal communication prevails [4]. Knowledge sharing and inter-agency collaboration are critical drivers for sustainable food system[18]

2.4 Research Question Formulation

This study conceptualizes a relational data-generating mechanism, capturing the communication ties of network structure. By transforming survey responses into a proximity matrix, this study operationalizes social interactions as a measurable construct aligned with Social Network Theory [8]. These structures represented by density, centrality, and instrumentality serve as mechanisms linking communication processes to governance outcomes, particularly in agricultural systems characterized by dispersed actors and informal institutions.

Network density reflects the proportion of actual ties relative to all possible ties, capturing the overall level of cohesion within a network. High-density networks facilitate: Faster information exchange; Stronger mutual awareness; Increased trust and social cohesion. From a collaborative governance perspective, dense networks support collective action and coordination efficiency, as actors are more connected and able to align decisions [10]. However, excessive density can also lead to redundancy and reduced exposure to new information, suggesting a potential trade-off between cohesion and innovation.

RQ1: How do differences in communication network structures (centralized vs. distributed) influence the diffusion and adoption of sustainable agricultural technologies among farmer group?

Degree centrality measures the number of direct connections an actor has, indicating their level of activity and influence within the network. Actors with high degree centrality are better able to: Access diverse information sources; Diffuse innovations efficiently; Influence peer adoption behavior. In line with Diffusion of Innovation theory, central actors act as primary diffusion agents, accelerating the spread of agricultural technologies and practices [6]. Empirical evidence suggests that farmers with higher degree centrality are more likely to adopt innovations earlier and influence the decisions of others[17] (Valente, 1996).

RQ2: How do centrality patterns (degree, closeness centrality, and betweenness) shape actor roles, information flow, and network resilience in agricultural communication systems?

Betweenness centrality captures an actor's role as a broker in connecting previously disconnected groups. These actors occupy a brokerage position, which allows them to: Bridge structural gaps; Facilitate information flows between groups; Integrate diverse knowledge sources; Obstfeld, Borgatti and Davis (2014) highlight that brokerage positions dynamic and crucial in bridging many things intra and inter-organizational networks. Brokerage provides strategic advantages, especially in systems where information is unevenly distributed[19]. In the agricultural context, brokers often connect farmers with external institutions such as extension services, NGOs, and markets, thereby enhancing system-level coordination and learning.

Network centralization reflects the extent to which relationships are concentrated around a few dominant actors. While centralized networks can increase efficiency and rapid diffusion, they also pose risks: Over-dependence on key actors; Vulnerability to node removal; Reduced and potentially risk system resilience. Borgatti et al., emphasize that highly centralized networks may perform well in stable environments but are less adaptive under conditions of uncertainty[8]. Therefore, centralization presents a dual effect, balancing efficiency and resilience in governance systems. It also significantly brings about to participative of various member initiative. As well it prevents higher and rapid new innovation outside the central point and actors.

RQ3: To what extent does network density affect collaboration, coordination efficiency, and production stability across different stages of sustainable agricultural practices?

3. Methods/Materials

This study employed an explanatory sociometric design using quantitative survey data to examine the structural properties of communication networks and their implications for information exchange and innovation diffusion in agricultural systems. The research was conducted among two maize farmer groups in Lamongan, East Java, Indonesia, representing the southern and northern regions of this major food-producing are. The target population comprised 532 active members: Sumber Rahayu (N=282) and Sidodadi Banyubang Solokuro (N=250). Data were collected from 241 respondents (45.36% of the population), including 142 respondents (50.35% of active members) from Sumber Rahayu and 99 (39.6% of 250 active members) from Sidodadi Banyubang Solokuro, enabling comparative network analysis across geographically distinct but socioeconomically similar farming communities. Data collection was conducted between July and December 2025. Respondents were active farmers regularly engaged in communication, information exchange, and interaction within their perspective groups based on their experience and knowledge.

The instrument operationalized communication as a multidimensional construct through a domain-specific sociometric survey covering nine Sustainable Agricultural Technology (SAT) domains: innovation, innovation use, innovation development, seeds, fertilizers and pesticides, machinery, harvesting, distribution, and land management. Respondents nominated actors with whom the exchanged information in each domain, generating relational data that were converted into adjacency matrices for network analysis. Snowball sampling was employed based on both social network theory and field realities, beginning with farmer group leaders and key community figures: Sumber

Rahayu (N=282), representing the southern area, and Sidodadi Banyubang Solokuro (N=250), representing the northern area. Respondents were selected as actors actively involved in communication networks related to farming practices. They were asked to identify communication partners across the nine SAT domains. Although extension agents and traders of farming commodity were not included as participants, respondents reported their interactions with these actors regarding SAT-related activities.

The network boundary is defined on the basis of formal membership of each farmers' group. Consequently, the main nodes in the analysis are those members of farmers' groups who meet the inclusion criteria and participated in the survey. Actors who were nominated but did not participate in the survey are treated as non-respondent nodes, in accordance with the network construction rules established prior to the analysis. The participants are who every day practice of farming as the active members who registered and existed in the farming group data base, this study achieved near-complete network coverage.

Nominations are limited to a maximum of three actors. Each communication link is coded as a directed relationship, as a nomination from one actor to another indicates the existence of an information link between the actors, without automatically assuming that every actor nominates every other actor. Relationships are constructed as binary (0/1), with a value of 1 indicating the presence of a nomination and a value of 0 indicating the absence of a nomination. The frequency or intensity of communication is not used as a relationship weight, as the instrument is designed to identify the existence and structure of communication relationships between actors.

This study uses Social Network Analysis (SNA) with Ucinet version 6.814 to measure network structure and actor positions. Four core metrics are used: Density, which captures the overall level of network cohesion and connectivity; Degree centrality, which indicates actor prominence and interaction intensity; Closeness centrality, which reflects the efficiency and reach of communication; and Betweenness centrality, which identifies the role of intermediaries and control over information channels. This design provides a robust, theory-based framework for explaining how communication structures influence agricultural governance, knowledge diffusion, and collective action outcomes.

4. Results

4.1. Overview and Variations

Generally, Dataset 1 (Farmer Group Sumber Rahayu) exhibits a moderately centralized communication network in which a limited number of actors occupy dominant positions as information sources, recipients, and intermediaries. This structure facilitates efficient information transmission but increases dependency on central actors, potentially constraining network resilience and limiting peripheral members' participation in innovation diffusion. In contrast, Dataset 2 (Farmer Group of Sidodadi, Banyubang Solokuro) demonstrates a more decentralized and interconnected network, where communication and brokerage functions are distributed across multiple actors. This configuration enhances network resilience, broadens participation, and supports more stable innovation diffusion. Overall, the South Area reflects a **leader-centered diffusion model**, characterized by reliance on influential actors, whereas the North Area exhibits a **network-centered diffusion model**, with denser and more decentralized communication patterns that are more conducive to widespread innovation adoption (see table 2) and brief description of the groups as shown in table 1 as follows:

Table 1 Farming Groups Characteristics: Sumber Rahay & Sidodadi Banyubang 2025

Characteristic	Sumber Rahayu	Sidodadi Banyubang Solokuro
Location	South Lamongan	North Lamongan
Number of respondents	142 (50.35%) of 282 Active members	99 (39.6%) of 250 active members
Main commodity	Maize	Maize
Organizational type	Farmer group	Farmer group
Communication structure	More centralized	More distributed
Dominant actors	Actor 5, 6	Actor 5, 6, 7
Main network characteristic	Reliance on key actors	Shared communication roles

These two groups seem contrasting networks—one with bottlenecks and operational fragmentation, the other with smoother communication and wider engagement—allows an assessment of how network structure affects **innovation diffusion, adoption behaviour, and overall production stability,** the details as displaying in table 2. And general result of it as mentioned in sub 4.1 above.

Table 2 Nine Domains of Communication Innovation Diffusion Network Structure - Sumber Rahayu & Sidodadi

Aspect	Density (Data 1/ South Area)	Density (Data 2/ North Area)	Out Degree (Data 1/ South Area)	Out Degree (Data 2/ North Area)	In Degree (Data 1/ South Area)	In Degree (Data 2/ North Area)	Out Closeness Centrality (Data 1/ South Area)	Out Closeness Centrality (Data 2/ North Area)	In Closeness Centrality (Data 1/ South Area)	In Closeness Centrality (Data 2/ North Area)	Betweenness (Data 1/ South Area)	Betweenness (Data 2/ North Area)
Innovation	0.118	0.111	0.674–0.404	0.776–0.776	0.972–0.787	0.776–0.745	0.536–0.468	0.653–0.653	0.922–0.788	0.616–0.641	3153–2427	1254–1189
Innovation usage	0.087	0.117	0.631–0.355	0.776–0.765	0.965–0.766	0.724–0.714	0.434–0.387	0.667–0.658	0.928–0.783	0.613–0.616	5359–1157	1134–1096
Innovation improvement	0.136	0.094	0.652–0.411	0.551–0.418	1.000–0.993	0.765–0.765	0.504–0.452	0.402–0.363	1.000–0.993	0.624–0.641	6698–1550	1621–618
High-Quality Seeds	0.103	0.126	0.993–0.986	0.765–0.755	0.542–0.542	0.776–0.765	0.993–0.986	0.645–0.641	0.442–0.442	0.667–0.662	2871–2190	1014–983
Fertilizers and Pesticides	0.079	0.123	0.475–0.355	0.765–0.755	0.461–0.411	0.776–0.776	0.597–0.566	0.636–0.628	0.522–0.496	0.681–0.681	3298–2798	1066–1047
Agricultural Tools and Machinery	0.030	0.124	0.567–0.376	0.765–0.765	0.468–0.426	0.765–0.765	0.356–0.330	0.636–0.636	0.357–0.352	0.636–0.636	2902–1736	995–995
Harvest	0.029	0.121	0.461–0.426	0.724–0.673	0.482–0.411	0.776–0.776	0.329–0.326	0.649–0.598	0.359–0.345	0.653–0.653	2703–1640	982–980
Distribution of Harvested Products	0.030	0.129	0.447–0.390	0.776–0.776	0.433–0.383	0.745–0.745	0.309–0.303	0.681–0.681	0.308–0.301	0.616–0.616	2720–1972	1014–1014
Land Management and Utilization	0.030	0.115	0.433–0.305	0.653–0.613	0.546–0.288	0.653–0.570	0.310–0.298	0.653–0.613	0.327–0.298	0.613–0.570	4000–1276	1339–866

4.2. Key SAT Communication Components

The analysis of two datasets of this research as displayed in above table, from the Sumber Rahayu and Sidodadi Banyubang maize-farming groups provides detailed insights into communication network structures and actor roles across sustainable agricultural technology (SAT) components. The evaluation focuses on **network density, degree centrality, closeness centrality, and betweenness centrality**, which collectively reveal patterns of information flow, influence, and coordination capacity [8]. SAT components analysis as follow:

4.2.1. Innovation

According to the data that farmers group of Sumber Rahayu (South Lamongan)/Dataset 1 and Sidodadi Banyubang (North Lamongan)/Dataset 2 is slightly different. In Innovation, South Lamongan farmer is higher (0.118) than North Lamongan farmer (0.111). Out-degree centrality score of both groups show the dissimilar point, Sumber Rahayu's is higher (0.674) than Sidodadi's (0.404), indicating that actors initiated fewer interactions, while in-degree remained stable (0.776), indicating key actors were still recognized as sources of knowledge. Centralization scores also designate the dissimilarity Sumber Rahayu's (0.972) is higher than Sidodadi's (0.776), reflecting a more distributed influence structure. Likewise, the Closeness values of Sumber Rahayu's is higher than Sidodadi's (0.776 and 0.745; 0.536 and 0.468), indicating structural accessibility or potential efficiency of reaching other actors, although subgroup cohesion increased slightly (0.616 and 0.641). Betweenness centrality as well designated the similar result, that Sumber Rahayu's higher than Sidodadi's (3.153 and 2.427; 1.254 and 1.189), indicating fewer intermediaries bridging the network. Overall, Dataset 1 (Sumber Rahayu group) shows a relatively denser and more centralized communication structure, with greater direct interaction initiation and stronger concentration of network position among key actors. While, Dataset 2 (Sidodadi group) is comparatively less centralized, suggesting a more distributed pattern of actor positioning.

4.2.2 Use of Innovation

Between Dataset 1 and Dataset 2, network density scores are different (0.087 and 0.117), indicating greater overall collaboration. Out-degree scores are 0.631 and 0.355, indicating fewer actors initiating interactions, while in-degree remained high (0.776 and 0.765), reflecting continued recognition of key knowledge sources. Centralization decreased (0.965 and 0.766), indicating more evenly distributed influence. Closeness values are slightly diverse (0.724 and 0.714; 0.434 and 0.387), indicating slightly slower information flow. Betweenness centrality points are sharply diverse (5.359 and 1.157; 1.134 and 1.096), indicating fewer intermediaries connecting network areas. Overall, Dataset 2 shows a denser but less mediated communication structure, with reduced proactive engagement and slower cross-network knowledge exchange.

4.2.3. Innovation Development

Network density was low in both datasets (0.136: Dataset 1 and 0.094: Dataset 2), indicating sparse communication structures, although the innovation Development network was denser in Dataset 1 (Sumber Rahayu, South Area). Out-degree (0.652 vs. 0.411) and in-degree (0.551 vs. 0.418) were also higher in Dataset 1, reflecting greater interaction and recognition of knowledge sources. Despite similarly high centralization (1.000 and 0.993) closeness centrality was lower in Dataset 2 (0.452 and 0.363) than in Dataset 1 (0.504 and 0.402), suggesting slower information diffusion. Betweenness centrality differed substantially between datasets, indicating variation in intermediary roles, while subgroup cohesion was comparable (0.624 and 0.641). Overall, Dataset 2 (Sidodadi, North Area) revealed a sparser and more centralized network, potentially constraining coordinated innovation[20].

4.2.4. High-Quality Seeds

Between Dataset 1 and Dataset 2, network density scores are different 0.103 and 0.126, indicating slightly stronger connectivity. Out-degree and in-degree remained high but still both scores are dissimilar slightly (0.993 and 0.986; 0.765 and 0.755), indicating key actors remained central but slightly less proactive. Subgroup proximity and cohesion changed minimally (0.776→0.765; 0.667→0.662; 0.645→0.641), while betweenness also dissimilar extremely enough (2.871 and 2.190; 1.014 and 983), reducing the role of intermediaries. Overall, Dataset 2 reflects a more connected but less mediated network, with stable local collaboration but slightly slower cross-network coordination[21]. Thus, seed information spreads effectively in both areas, but South diffusion is driven by highly influential senders.

4.2.5. Fertilizers and Pesticides

Between Dataset 1 and Dataset 2, network density points are 0.079 and 0.123, indicating stronger overall connectivity. Out-degree and in-degree still different slightly (0.475 and 0.355; 0.765 and 0.755), indicating fewer proactive actors but continued recognition of key knowledge sources. Subgroup closeness and cohesion changed minimally (0.776 and 0.776; 0.597 and 0.566; 0.636 and 0.628), while betweenness points are moderate (3.298 and 2.798; 1.066 and 1.047), reducing the role of intermediaries. Overall, Dataset 2 reflects a denser but less mediated network, with stable key actors but slightly slower intergroup coordination.

4.2.6. Agricultural Tools and Machinery

Between Dataset 1 and 2, network density values are from 0.030 and 0.124, indicating statistically significant connectivity. Out-degree still different (0.567 and 0.376) while in-degree remained stable (0.765), indicating fewer actors initiating interactions but key actors remaining central. Subgroup closeness and cohesion were largely stable (0.765 and 0.765; 0.636 and 0.636), while betweenness still dissimilar points (2.902 and 1.736; 995 and 995), reducing the role of intermediaries. Overall, Dataset 2 reflects a denser but less mediated communication structure, stable central actors but slower intergroup knowledge flows [8].

4.2.7. Harvest

Between Dataset 1 and Dataset 2, network density scores are 0.029 and 0.121, indicating stronger connectivity. Out-degree and in-degree slightly different (0.461 and 0.426; 0.724 and 0.673), while subgroup closeness and cohesion are moderate (0.776 and 0.776; 0.649 and 0.598). Betweenness remained dissimilar (2.703 and 1.640; 982 and 980), reducing the role of intermediaries. Overall, Dataset 2 reflects a denser but less mediated communication network, with central actors remaining key but knowledge flows between groups being slightly slower [2].

4.2.8. Distribution of Harvested Products

Between Dataset 1 and Dataset 2, network density points are (0.030 and 0.129), indicating stronger connectivity. Out-degree are (0.447 and 0.390) while in-degree remained stable (0.776), indicating fewer proactive actors but the presence of central knowledge holders. Subgroup closeness and cohesion remained largely stable (0.745 and 0.745; 0.681 and 0.681), while betweenness are (2.720 and 1.972; 1.014 and 1.014), reducing intermediaries. Overall, Dataset 2 reflects a denser but less mediated communication network, with central actors remaining key but knowledge flows between groups being slightly slower [22].

4.2.9. Land Management and Utilization

Between Dataset 1 and Dataset 2, network density values are (0.030 and 0.115), showing stronger connectivity. Out-degree and in-degree are (0.433 and 0.305; 0.653 and 0.613), indicating fewer proactive actors and slightly reduced recognition of key knowledge holders. Closeness and subgroup cohesion are (0.653 and 0.570; 0.613 and 0.570), while betweenness fell sharply (4.000→1.276; 1.339→866), reducing intermediaries. Overall, Dataset 2 reflects a denser but less intermediated communication network, with central actors still key but slower cross-group knowledge flow (Wu & Pretty, 2004; Bodin & Crona, 2009).

4.3 Network Analysis

4.3.1. Differences in Innovation Diffusion Potential

Network density reflects the proportion of actual relationships among all possible connections and directly influences the diffusion of innovations. Higher density facilitates rapid and broad exchange through multiple channels, while lower density concentrates influence among key actors, creating barriers and limiting coordination. In Sumber Rahayu (Dataset 1), density peaks in innovation development (0.136) but is low in innovation adoption (0.087) and operational activities (0.029–0.103), enabling the circulation of ideas among key actors but slowing farm-level adoption and coordination of inputs, machinery, harvesting, and land management. This fragmentation reduces efficiency and can undermine food security.

In contrast, Sidodadi Banyubang Solokuro that locates on the north of Lamongan (Dataset 2) exhibits moderate and balanced density across innovations and operations (0.094–0.129), supporting broader participation, smoother coordination, faster adoption, and more stable production outcomes. These patterns suggest that dense, evenly connected networks enhance innovation diffusion, collaboration, and resilience, while centralized, uneven networks risk slowing adoption and uneven system performance.

4.3.2. Influence Structures Across Networks

Degree centrality, which reflects the direct relationship between actors in sending or receiving information, shapes influence within the network. In Sumber Rahayu (Dataset 1)/South Lamongan, Actor 5 dominates in the areas of seeds, pesticides, machinery, land management, and harvesting, creating a top-down hierarchical system that allows for rapid coordination but makes innovation adoption dependent on a single individual, increasing vulnerability.

In contrast, Sidodadi Banyubang Solokuro (Dataset 2)/North Lamongan exhibits more evenly distributed degree centrality among Actors 5, 6, and 7, establishing shared leadership with multiple communication channels. This increases inclusiveness, access to innovation, and network resilience, although collective decision-making may be slower. Overall, centralized networks prioritize speed at the expense of fragility, while distributed influence promotes equity and resilience.

4.3.3. Speed of Information Circulation

Proximity centrality, which indicates how quickly actors can send or receive information, shapes communication efficiency and adaptability. In Sumber Rahayu (South Lamongan), high proximity is concentrated among a few actors (2, 3, 5), enabling rapid information flow but creating dependency and vulnerability if these actors are absent. In contrast, Sidodadi Banyubang Solokuro (North Lamongan) exhibits more distributed proximity among Actors 5, 6, and 7, enabling multiple pathways, broader access, and greater resilience. Centralized networks prioritize speed but risk fragility, while distributed networks balance timely communication with inclusiveness and stability.

4.3.4. Network Control and Vulnerability

Betweenness centrality measures an actor's role as a bridge in network communication, indicating control and potential vulnerability. In Sumber Rahayu (South Lamongan), Actor 2 dominates as the primary broker, with Actors 5 and 3 as secondary bridges, enabling efficient but fragile information flow. In contrast, Sidodadi Banyubang Solokuro (North Lamongan) distributes the brokerage role among Actors 5, 6, and 7, creating multiple communication pathways that increase resilience. A centralized network supports rapid diffusion but is vulnerable to disruption, while distributed brokerage strengthens stability and ongoing coordination.

SAT Domain Insights

Across all domains, Dataset 2 consistently demonstrates: Better connectivity; More balanced communication; Stronger coordination capacity. These findings highlight the importance of network structure in shaping agricultural performance.

Actor Roles in Collaborative Communication and Governance

Actors were classified using centrality measures to identify information hubs, intermediaries, and peripheral members. Degree centrality indicates key information sources, while betweenness centrality identifies actors bridging subgroups. Linking these roles to collaboration in production, input provision, and marketing reveals the governance structures that support collective action and technology adoption[1]. Both datasets indicate a predominantly centralized communication network, particularly in Sumber Rahayu (South Lamongan), where actors 5 and 6 consistently occupied strategic positions with high degree, closeness centrality, and betweenness centrality. This pattern suggests a strong reliance on key actors for innovation diffusion, technical coordination, and crop distribution. While such centralization can facilitate efficient decision-making and information dissemination, it may also increase network vulnerability if central actors become inactive.

In contrast, the Sidodadi Banyubang Solokuro (North Lamongan) network exhibits a more collective and distributed network pattern, with the involvement of more dominant actors in each aspect. The relatively even distribution of centrality reflects stronger collaborative capacity, particularly in innovation development and post-harvest stages. This pattern demonstrates greater network resilience because it does not rely on one or two key actors, instead coordination can be more complex. Thus, these differences in network structure indicate that the effectiveness of sustainable agricultural communication is potentially influenced by the configuration of centrality and the distribution of actor roles within farmer groups. This in line with previous research regarding the food sustainable and collaborative communication in social context[18].

4.4. Discussion

The findings extend beyond identifying differences in communication structures between farmer groups and highlight the methodological contribution of a survey-based sociometric approach for examining agricultural governance networks. By systematically collecting relational data through structured questionnaires, the study moves survey research beyond conventional attribute-oriented analysis toward a network-based perspective that captures the social construction or architecture of communication. The approach enables the visualization and measurement of person-to-person, intra-group, and inter-group relationships, thereby providing a more comprehensive understanding of how social structures shape collective action, information exchange, and decision-making processes. In this sense, communication networks serve not merely as channels for information transmission but as social infrastructure through which governance, coordination, and knowledge sharing are organized.

The collaboration as the significant term shows us through this research that effective of innovation diffusion is highly related to network structure. And the findings also show us that the innovation and innovation improvement will diffused and adopted depend on several factors whether tangible or intangible [24], personal, organizational, and social context[25], including the learning process of the innovation[26].

The combination of survey-generated relational data with quantitative network metrics (e.g., degree, closeness, and betweenness centrality) provides a powerful analytical lens for understanding communication systems. The data shown us about structural explanations of governance processes, such as how information flows, where bottlenecks emerge, and which actors function as key intermediaries. The contrast between the centralized structure in Dataset 1 and the distributed structure in Dataset 2 illustrates how hidden organizational dynamics that exist in social context of diffusion of innovation and its adoption. Additionally, the result elucidated social interaction as the socio-metric or social map in society or group(s) or intergroup. This is essential for getting into the inter-actors' things or social or system research. It confirms that network structure determines the effectiveness of innovation diffusion.

Otherwise, it explained that the collaborative communication is happening in Indonesia to reach the food security toward economic resilience as national goal (interdependent local area/geographical and social systems). Without collaborative, the innovation diffusion and its adaptation as the crucial factors of security food before the economic resilience is difficult to be reached by Indonesia. There are society with spirit to do innovation and improve the innovation and other society (area) take a role as the innovation user toward security and resilience of systems.

The research captured communication ties across multiple agricultural functions, from innovation development to market distribution. This scalability means the approach can be applied not only to farmer groups but also to broader governance contexts, including multi-stakeholder platforms, policy networks, and institutional collaborations. By standardizing how relational data are collected and analyzed, the framework supports comparability across cases, regions, and sectors, which is essential for cumulative knowledge building in governance and communication research.

The actor roles are fundamental in determining both network performance and resilience. While the structure function to improve coordination efficiency, it introduces system vulnerability that displayed by Dataset 1 (Sumber Rahayu). Conversely, Sidodadi (Dataset 2) exhibits a more balanced distribution of centrality across multiple actors which promotes shared influence, inclusiveness, and adaptive capacity. Based on this comparison we got that collaboration through social networks as the determining factors for food security toward economic resilience.

More broadly, the findings suggest that sustainable agricultural development depends not only on expanding technological access but also on strengthening the communication structures that support knowledge exchange and collective learning. Networks characterized by balanced connectivity, distributed participation, and effective brokerage are likely to enhance information accessibility, reduce dependency on single actors, and improve the capacity of farming communities to respond to technological, economic, and environmental challenges. Accordingly, communication networks should be recognized as strategic governance assets that facilitate innovation diffusion, strengthen social capital, and support long-term agricultural resilience. And it potentially to support or bring about food security which is potentially supporting and buzzing economic resilience.

Overall, the research emphasize that the effectiveness of agricultural innovation systems depends not only on technological availability but also on the structural properties of communication networks that govern knowledge exchange and collective action.

5. Conclusion

This study demonstrates that the effectiveness of agricultural innovation systems depends not only on the availability of technology but also on the structure of communication networks through which knowledge is exchanged, coordinated, and adopted. By integrating sociometric survey data with Social Network Analysis (SNA), this study provides a relational approach to examining agricultural governance and innovation diffusion. The South Area follows a leader-centered diffusion model, where innovations dissemination depends on a few influential actors. In contrast, the North Area reveals a network-centered diffusion model with denser, more decentralized communication, supporting broader and more efficient adoption. In conclusion: **First**, the findings show meaningful differences in network structure between Sumber Rahayu (South Lamongan) and Sidodadi Banyubang (North Lamongan). Sidodadi generally reveals higher network density and lower network centralization, indicating stronger connectivity and less concentrated distribution of structural positions. Sumber Rahayu, exhibits greater concentration around key actors in several SAT domains. **Second**, the findings demonstrate that different SNA metrics represent different structural properties. Degree centrality identifies actors with many direct communication ties; in-degree and out-degree distinguish receiving from intiating communication; closeness centrality reflects structural accessibility through short network paths; betweennes centrality identifies potential brokerage and bridging positions; and network centralization indicates the extent to which centrality is concentrated at the network level. Third, network density is an important structural conditions for collaborative communication. Higher density provides more potential communication pathways, while lower density may increase dependence on particular actors or subgroups. However, density alone does not determine communication effectiveness, it should be interpreted together with centralization, degree, closeness, and betweenness. Finally, strengthening agricultural communication systems requires more than increasing the number of communication ties. A resilient agricultural communication therefore characterized not simply by high centrality or high density, but by an appropriate balance among connectivity, accessibility, distributed participation, and brokerage redundancy.

Methodologically, the study highlights the importance of explicitly reporting the operational definition and normalization status of SNA metrics. Clear differentiation between raw and normalized scores, actor-level centrality and network-level centralization, and directional degree measure will contribute the validity and reproducibility of SNA-based agricultural communication research. It indicates collaborative communication networks constitute an important governance mechanism for supporting sustainable technology diffusion, collective action, food security, and economic resilience.

Declarations

Author Contributions

Conceptualization: Mohamad Ghozali Moenawar, and Muchammad Nasucha.;
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Software UCI-Net6 version 6.814: Mohamad Ghozali Moenawar;
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All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

Data available on request. The data presented in this study are available on request.

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Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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